Economic Impact of Fires in Buildings

by

Dominic C. Esposito

A thesis submitted to the faculty of Graduate Studies and Research in partial
fulfillment of the requirements of the degree of

Master of Applied Science

Department of Civil and Environmental Engineering
Carleton University
Ottawa, Ontario

© Dominic C. Esposito, 2004

Library and
Archives Canada

Bibliothèque et
Archives Canada

Published Heritage
Branch

Direction du
Patrimoine de l'édition

395 Wellington Street
Ottawa ON K1A 0N4
Canada

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence

ISBN: 0-612-97994-6

Our file Notre référence

ISBN: 0-612-97994-6

NOTICE:

The author has granted a non-exclusive license allowing Library and Archives Canada to reproduce, publish, archive, preserve, conserve, communicate to the public by telecommunication or on the Internet, loan, distribute and sell theses worldwide, for commercial or non-commercial purposes, in microform, paper, electronic and/or any other formats.

The author retains copyright ownership and moral rights in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

AVIS:

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque et Archives Canada de reproduire, publier, archiver, sauvegarder, conserver, transmettre au public par télécommunication ou par l'Internet, prêter, distribuer et vendre des thèses partout dans le monde, à des fins commerciales ou autres, sur support microforme, papier, électronique et/ou autres formats.

L'auteur conserve la propriété du droit d'auteur et des droits moraux qui protègent cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

In compliance with the Canadian Privacy Act some supporting forms may have been removed from this thesis.

Conformément à la loi canadienne sur la protection de la vie privée, quelques formulaires secondaires ont été enlevés de cette thèse.

While these forms may be included in the document page count, their removal does not represent any loss of content from the thesis.

Bien que ces formulaires aient inclus dans la pagination, il n'y aura aucun contenu manquant.

Canada

ABSTRACT

With a move towards performance based building codes, building designs are evaluated not only on the basis of whether or not they provide acceptable levels of safety but also on whether they are cost-effective. Cost-effectiveness can be determined by considering the cost of fire protection and the expected damages resulting from fires during the life of the building. In addition to the resulting damages that fires may cause, the impact that they may have on business production may also be significant. To help identify cost-effective fire safety designs, this thesis describes a computer model which assesses the economic impact of fires in buildings. This model calculates the cost of both direct and indirect damages to building construction, fire protection systems and contents that result from fire. This economic computer model is part of the fire hazard and fire risk analysis computer model being developed at Carleton University.

ACKNOWLEDGEMENTS

Financial support for the Industrial Research Chair in Fire Safety Engineering was provided by Forintek Canada Corporation and the Natural Sciences and Engineering Council of Canada (NSERC).

First and foremost I would like to thank Dr. Hadjisophocleous who not only allowed me to participate in the fire safety engineering program at Carleton University but was always available to discuss my project or answer the many questions that I had.

I would like to thank the following people who took time out of their busy schedules to either meet with me to discuss my project or to provide me with relevant information:

- Dr. Thomas Barry
- Mr. Peter Daley (Daley Ferraro Associates)
- Mr. William Kuffner (Leber-Rubes Inc.)
- Dr. Zhuman Fu
- Dr. Jim Mehaffey

Thank you to the following people who I had preliminary meetings with to discuss my project:

- Mr. Ian Chambers (The Dominion of Canada - General Insurance Company)
- Mr. George Fawcett (Leber-Rubes Inc.)
- Mr. Rob Fletcher (The Dominion of Canada - General Insurance Company)

Thank you to my fellow classmates who worked with me on overlapping areas of my project and provided feedback to me:

- Mr. Steven Craft
- Mr. Derek Gruchy
- Mr. Chandra Juneja
- Mr. Ehab Zalok

I would like to thank my parents, sister and Randy for always being there for me.

Last but not least, I would like to thank Carly who taught me that there is more to life than work.

TABLE OF CONTENTS

1.0	INTRODUCTION AND OBJECTIVES	1
2.0	LITERATURE REVIEW	3
2.1	Cost of fire	3
2.2	Probability of having a fire	7
2.3	Preventative action.....	8
2.4	Losses.....	10
2.4.1	Indirect losses.....	11
2.4.2	Direct fire losses	14
2.4.2.1	Extent of damage	14
2.4.2.2	Building damage	15
2.4.2.3	Fire and temperature damage.....	17
2.4.2.4	Non-thermal damage.....	21
2.4.2.5	Water damage	27
2.5	The behaviour of a building's materials in fire.....	29
2.5.1	Wood.....	30
2.5.2	Steel.....	31
2.5.3	Glass.....	32
2.5.4	Stones.....	33
2.5.5	Bricks	34
2.5.6	Gypsum	35
2.5.7	Concrete	35
2.6	Insurance	36
2.7	Fire protection systems	37
2.7.1	Passive fire protection.....	45
2.7.2	Active fire protection	46
2.7.2.1	Fire Extinguishers	46
2.7.2.2	Sprinklers	47
2.7.2.2.1	The Effect of having sprinklers.....	49
2.7.2.2.2	The Operation of sprinklers	52
2.7.2.2.3	The Reliability and effectiveness of sprinklers.....	54
2.7.2.2.4	Accidental sprinkler activation	56
2.7.2.2.5	Cost of sprinklers	57
2.7.2.2.6	Water damage caused by sprinklers.....	59
2.7.3	Alarm systems.....	61
2.7.4	Detectors	63
2.7.5	Fire hose/standpipe	64
2.8	Literature correlations.....	65
2.8.1	Probability of structural failure.....	65
2.8.2	Indirect losses.....	66
2.8.3	Corrosion rate.....	67

2.8.4	Water requirements.....	67
2.8.5	Optimal economical level of safety	71
2.8.6	Property damage	73
2.8.7	Monetary Loss Expectation	75
2.8.8	Cost index factor	77
2.9	Summary	79
3.0	DESCRIPTION OF THE ECONOMIC COMPUTER MODEL	81
3.1	Components of the economic computer model	85
3.1.1	Building components details.....	85
3.1.2	Background to fire protection systems	87
3.1.2.1	Description of active fire protection systems.....	87
3.1.2.2	Description of passive fire protection systems	91
3.1.2.3	Description of emergency systems	93
3.1.3	Building contents	93
3.1.4	Downtime.....	96
3.1.5	Damages.....	96
4.0	INPUT DATA FOR THE ECONOMIC COMPUTER MODEL.....	99
4.1	Building components inputs	99
4.2	Active fire protection systems and emergency systems inputs.....	100
4.3	Passive fire protection inputs.....	104
4.4	Building contents inputs	105
4.5	General data inputs	106
5.0	METHODOLOGY	109
5.1	Cost of the building.....	109
5.1.1	Initial costs of building construction.....	110
5.1.2	Initial cost of additional fire protection in compartments.....	114
5.1.3	Initial cost of contents	117
5.1.4	Initial cost of fire protection systems.....	118
5.2	Cost of damages.....	120
5.2.1	Cost of damages to a compartment's assemblies, doors and windows.	122
5.2.2	Cost of damages to building components	133
5.2.3	Cost of damages to contents	137
5.2.3.1	The probability of individual damages	138
5.2.3.2	The probability of total damages to contents	141
5.2.3.3	Values for compartment conditions	142
5.2.3.4	Total cost of damages to contents	146
5.2.4	Cost of damages to fire protection systems	147
5.3	Cost of downtime.....	150
5.4	Other calculations	153
5.4.1	Approximate damage to the contents as a percentage of the total damages to the contents	153

5.4.2	Approximate damage to the entire building as a percentage of the total damages	157
5.4.3	Ratio of damages to building cost.....	161
5.4.4	Rush construction and reduction of downtime	161
5.5	Damages and downtime due to fire spread	162
6.0	PREDICTIONS OF THE ECONOMIC COMPUTER MODEL	166
6.1	Case study description	166
6.2	Compartment conditions	184
6.3	Case study predictions	190
6.4	Fire cost expectation description	203
6.5	Fire cost expectation results.....	207
6.6	Effect of calibration factors	216
7.0	CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS FOR FUTURE WORK.....	222
7.1	Conclusions.....	222
7.2	Limitations of the economic computer model	224
7.3	Recommendations for future work	226
8.0	REFERENCES.....	228
APPENDIX A: OUTLINE OF ECONOMIC MODEL.....		237
APPENDIX B: INPUT ESTIMATES.....		249
1.0	INPUT ESTIMATES INTRODUCTION.....	250
2.0	GENERAL INPUT DATA.....	251
3.0	BUILDING COMPONENTS.....	253
3.1	Costing for building components.....	254
4.0	FIRE PROTECTION AND EMERGENCY SYSTEMS	259
5.0	BASIC BUILDING CONSTRUCTION AND ADDITIONAL PASSIVE FIRE PROTECTION	266
5.1	Costs.....	266
5.2	Interior walls	267
5.3	Exterior walls	269

5.4	Floors/ceilings.....	274
5.5	Doors.....	276
5.6	Windows	280
5.7	Downtime for building construction and downtime factors	281
6.0	CONTENTS.....	282
7.0	THRESHOLDS VALUES.....	287
8.0	PROBABILITY OF FIRE SPREAD	294

APPENDIX C: INPUT FILES FOR CASE STUDY	297
--	-----

APPENDIX D: COMPARISON DATA.....	318
----------------------------------	-----

1.0	INTRODUCTION.....	319
2.0	ONTARIO FIRE MARSHALL'S DATA ANALYSIS.....	320
3.0	OTHER COMPARISON DATA	335

GLOSSARY.....	346
---------------	-----

LIST OF TABLES

Table 1: General percentage approximations of fire costs internationally (Wilmot, 1986).	4
Table 2: Annual fire costs in Canada (Lie, 1972a).	5
Table 3: Cost of fires in the United States (Meade, 1991).	7
Table 4: Downtime levels (Barry, 2002).	12
Table 5: Building damage levels (Barry, 2002).	16
Table 6: Five categories of building damage (Cole, 1993).	17
Table 7: A description of the different radiation damage levels (Netherlands Arbeidsinspectie, 1992).	18
Table 8: Temperature damage to different types of core materials (Barry, 2002).	19
Table 9: Materials and their melting points (Ashby and Jones, 1996).	21
Table 10: Corrosion damage caused by chloride ions to telecommunication central offices (Tewarson, 2003).	23
Table 11: Smoke damage thresholds to electronic equipment* (Barry, 2002).	26
Table 12: Smoke density and the damages to electronic equipment (Barry, 2002). ..	26
Table 13: Types of water damage (Water Damage, 2004).	27
Table 14: Hand line sizes and acquired flows (Clark, 2000).	28
Table 15: Typical construction materials, their ignition temperatures and their critical heat fluxes (Quintiere, 1997).	29
Table 16: Wood ignition type including ignition temperature range (Wood Engineering Handbook, 1990).	31
Table 17: Upper and lower temperature limits for the breakage of glass (Hadjisophocleous and Bénichou, 1999).	33

Table 18: The strength of different types of stone at high temperatures (Chakrabarti et al., 1996).	34
Table 19: Fire protection systems relationship with aid in extinguishing fires and the notification of the fire department.	37
Table 20: Effectiveness of different fire protection measures (Bennetts and Thomas, 2002).	38
Table 21: The cost of fire protection systems as a percentage of the total building cost for various occupancies.....	39
Table 22: The cost of fire protection as a percentage of the total building cost (Schaenman et al., 1994).....	41
Table 23: Cost of fire protection for a two floor 42,000 ft ² (3,902 m ²) shop (Silcock, 1967).	42
Table 24: Cost of fire protection for three typical reinforced concrete slab type office blocks with staircases at each end (Silcock, 1967).	43
Table 25: Maintenance costs of some fire protection equipment (Schaenman et al., 1994).	44
Table 26: Types of fire extinguishers (Blair, 1983).....	47
Table 27: Sprinkler behaviour and the percentage of fires that cause heat damage to a building's structure in industrial and commercial sprinklered buildings in the United Kingdom (Melinek, 1993).....	50
Table 28: Percentage decrease in losses per fire when sprinklers are present versus not present (for 1989 to 1998) (Canadian Wood Council, 2002).	51
Table 29: Types of sprinklers, including maximum ceiling temperature and range of operation (Hasofer et al., 1997).	53
Table 30: Temperature class and temperature ratings (Clark, 2000).....	53
Table 31: Reliability of sprinkler systems (Dowling et al., 1993) and (Miller, 1974).	55
Table 32: Effectiveness of sprinkler systems from 1970-1972 Factory Mutual Research Corporation data (Miller, 1974).	55

Table 33: Reasons for sprinkler activation in the absence of fire (Plant Engineering, 2001).	57
Table 34: Examples of different types of alarm systems (DLE Engineering, 1998)..	62
Table 35: Constants c and b for indirect losses correlation (Ramachandran, 1998)...	66
Table 36: Description of building components.....	86
Table 37: Description of active fire protection systems.	89
Table 38: Typical contents in different content categories.....	95
Table 39: Description of various inputs for building components and fire protection systems components.....	102
Table 40: Temperature, smoke and water threshold units.	103
Table 41: Description of the different general data inputs.	107
Table 42: Example of fire spread probability matrix.....	163
Table 43: Description of the compartments in the CTTC Building.....	172
Table 44: Details of the different fire scenarios analyzed.	175
Table 45: The scenarios run for the CTTC building using the economic computer model.....	176
Table 46: Probabilities of fire spread for different scenarios.	179
Table 47: Predictions of the economic computer model for scenarios (3/4) and (7/8).	190
Table 48: Predictions of the economic computer model by compartment for scenario 3/4.	193
Table 49: Predictions of the economic computer model by compartment for scenario 7/8.	195
Table 50: The predicted cost of the total damage for all scenarios in CTTC building (variation A)......	208

Table 51: The scenarios run for the CTTC building (variation B) using the economic computer model along with the predicted cost of the total damage.	209
Table 52: The scenarios run for the CTTC building (variation C) using the economic computer model along with the predicted cost of the total damage.	210
Table 53: The scenarios run for the CTTC building (variation D) using the economic computer model along with the predicted cost of the total damage.	211
Table 54: Capital costs, annual costs and expected fire loss per year for different scenarios.....	212
Table 55: Present worth of annual costs and expected fire losses with fire cost expectation and relative fire cost expectation for different scenarios using an interest rate of 7% and an inflation rate of 3%.	214
Table 56: Present worth of annual costs and expected fire losses with fire cost expectation and relative fire cost expectation for different scenarios.....	215
Table 57: Effect of rush construction factors and reduction of downtime factors on damages from fire.	216
Table 58: Effect of building construction calibration factor on damages from fire.	217
Table 59: Effect of building component calibration factor on damages from fire. ..	218
Table 60: Effect on predictions using different extinguishment calibration factors for scenario 7/8.	219
Table 61: Results by compartment using different extinguishment calibration factors for scenario 7/8.	220
Table B1: Recommended values for the general input data.	252
Table B2: The cost adjustment factors for the cost of building components.....	254
Table B3: Estimates for the costs of building components for the Ottawa, Ontario area.*	255
Table B4: The adjustment factors for the cost of active fire protection systems, passive fire protection systems and emergency systems.	261
Table B5: Estimates for the costs of active, passive and emergency fire protection systems for the Ottawa, Ontario area.	262

Table B6: Fire Resistance Ratings for different types of building construction (Egan, 1978).	267
Table B7: The cost adjustment factors for interior walls.....	268
Table B8: Estimates for the costs of interior walls for the Ottawa, Ontario area.* ..	269
Table B9: The cost adjustment factors for exterior walls.	270
Table B10: Estimates for the costs of exterior walls for the Ottawa, Ontario area.*	270
Table B11: Types of brick walls and corresponding Fire Resistance Ratings (Egan, 1978).	273
Table B12: The cost adjustment factors for floors/ceilings.	275
Table B13: Estimates for the costs of floor/ceilings for the Ottawa, Ontario area.*	275
Table B14: Types of doors and corresponding Fire Resistance Ratings (1 ¾ inch thick) (Egan, 1978).	277
Table B15: The cost adjustment factors for doors/windows and door frames.	278
Table B16: Estimates for the costs of door and frames for the Ottawa, Ontario area.*	279
Table B17: Estimates for the costs of windows for the Ottawa, Ontario area.*	280
Table B18: The cost adjustment factors for finishes of a compartment.	284
Table B19: The sensitivity of contents to temperature, smoke and water (Daley, 2004).	285
Table B20: Concentration of smoke and possibility of damages.	288
Table B21: Threshold values with respect to temperature, smoke and water.	293
Table D1: Average, median, high and low direct damage costs for structure fires in Ontario from 1995-2002.*	321
Table D2: Average, median, high and low direct damage costs in residential building fires in relation to floor area in Ontario from 1995-2002.*	322

Table D3: Average, median, high and low direct damage costs in residential building fires in relation to fire spread in Ontario from 1995-2002.*	323
Table D4: Average, median, high and low direct damage costs in residential building fires in relation to smoke spread in Ontario from 1995-2002.*	324
Table D5: Average, median, high and low direct damage costs in residential building fires in relation to building construction era in Ontario from 1995-2002.*	325
Table D6: Average, median, high and low direct damage costs in residential building fires in relation to floor construction in Ontario from 1995-2002.*	325
Table D7: Average, median, high and low direct damage costs in residential building fires in relation to interior construction in Ontario from 1995-2002.*	326
Table D8: Average, median, high and low direct damage costs in residential building fires in relation to ceiling construction in Ontario from 1995-2002.*	327
Table D9: Average, median, high and low direct damage costs in residential building fires in relation to roof construction in Ontario from 1995-2002.*	328
Table D10: Average, median, high and low direct damage costs in other structure fires in relation to floor area in Ontario from 1995-2002.*	328
Table D11: Average, median, high and low direct damage costs in other structure fires in relation to fire spread in Ontario from 1995-2002.*	329
Table D12: Average, median, high and low direct damage costs in other structure fires in relation to smoke spread in Ontario from 1995-2002.*	330
Table D13: Average, median, high and low direct damage costs in other structure fires in relation to building construction era in Ontario from 1995-2002.*	331
Table D14: Average, median, high and low direct damage costs in other structure fires in relation to floor construction in Ontario from 1995-2002.*	331
Table D15: Average, median, high and low direct damage costs in other structure fires in relation to interior construction in Ontario from 1995-2002.*	332
Table D16: Average, median, high and low direct damage costs in other structure fires in relation to ceiling construction in Ontario from 1995-2002.*	333
Table D17: Average, median, high and low direct damage costs in other structure fires in relation to roof construction in Ontario from 1995-2002.*	334

Table D18: Average losses for fires with and without sprinklers as determined by Factory Mutual Research Corporation (Dowling et al., 1993).	336
Table D19: Average losses per fire from NFPA data for the years 1980-1990 (Dowling et al., 1993).	337
Table D20: Average losses in commercial buildings in the USA between the years 1989-1998 (Canadian Wood Council, 2002).	338
Table D21: Extent of flame damage from USA retail fires between the years 1983- 1993 (Thomas, 1997).	339
Table D22: Flame damage with and without sprinklers from USA retail fires between the years 1983-1993 (Thomas, 1997).	340
Table D23: Smoke damage with and without sprinklers from USA retail fires between the years 1983-1993 (Thomas, 1997).	341
Table D24: Flame damage and the time it takes the fire department to arrive from USA retail fires between the years 1983-1993 (Thomas, 1997).	342
Table D25: Type of construction and losses from NFPA data from 1980-1998 (Ahrens, 2003).	343
Table D26: Extent of flame damage and losses from NFPA data from 1980-1998 (Ahrens, 2003).	344
Table D27: Extent of smoke damage and losses from NFPA data from 1980-1998 (Ahrens, 2003).	345

LIST OF FIGURES

Figure 1: The relationship between the fire hazard and fire risk analysis computer model and the economic computer model.	83
Figure 2: Input and output files for the economic computer model.	84
Figure 3: Tree diagram of the active fire protection systems in the economic computer model.....	88
Figure 4: Tree diagram of passive fire protection components.	92
Figure 5: Tree diagram of emergency systems.	93
Figure 6: Relationship between the smoke computer model and the economic computer model.	98
Figure 7: Tree diagram of available cost options.....	104
Figure 8: Standard and real fire temperature-time curves.	126
Figure 9: Probability of damage versus threshold limits.	138
Figure 10: Venn diagram representing the relationship between probabilities of damages.....	142
Figure 11: Floor plan of the first floor of the CTTC building.	168
Figure 12: Floor plan of the second floor of the CTTC building.....	169
Figure 13: Floor plan of the third floor of the CTTC building.	170
Figure 14: Floor plan of the fourth floor of the CTTC building.....	171
Figure 15: Upper layer temperature-time curves obtained from the smoke computer model for the compartment of fire origin for scenarios 3/4 and 7/8.....	185
Figure 16: Soot concentration-time curves obtained from the smoke computer model for the compartment of fire origin for scenarios 3/4 and 7/8.....	186
Figure 17: Heat release rate-time curves obtained from the smoke computer model for the compartment of fire origin for scenarios 3/4 and 7/8.....	189

Figure 18: Screen output for the total damages per compartment for scenario 3/4..	198
Figure 19: Screen output for the damages to contents and the damages to building construction and fire protection systems per compartment for scenario 3/4.	199
Figure 20: Screen output for the total amount of downtime per compartment for scenario 3/4.	200
Figure 21: Screen output for the total damages per compartment for scenario 7/8..	201
Figure 22: Screen output for the damages to contents and the damages to building construction and fire protection systems per compartment for scenario 7/8.	202
Figure 23: Screen output for the total amount of downtime per compartment for scenario 7/8.	203
Figure A1: Input and output files for the economic computer model.....	238
Figure B1: An illustration of a floor plan consisting of five compartments where the third compartment is the compartment of fire origin.....	295

NOMENCLATURE

$A(0)$	Initial floor area ignited
A	Annuity amount
A	Area
A	Exposed area of burning material
A	Fire area
A_B	Total floor area of the building
$Adjusted \int$	Adjusted integral of the standard fire curve adjusted for a baseline temperature
A_F	Floor area of compartment
AFL	Expected annual fire loss
A_{QT}	Area under heat release rate-time curve
$A(t)$	Damaged floor area in t minutes from ignition
b	Constant
b	y intercept
$BasicC$	Basic ceiling assembly
$BasicD$	Basic door
$BasicF$	Basic floor assembly
$BasicW$	Basic wall assembly
$BasicWi$	Basic window
BBC	Basic building construction
BC	Building component

<i>BF</i>	Building per unit floor area not including fire protection
<i>Building</i>	Building construction
<i>c</i>	Constant
<i>c</i>	Specific heat
<i>C</i>	Building construction factor
<i>C</i>	Cost
<i>CA</i>	Capital
<i>CC</i>	Contents
<i>CDB</i>	Damage to building components
<i>Ceiling</i>	Ceiling assembly
<i>CF</i>	Contingency fees
<i>CG</i>	Contents in content category
<i>CI_L</i>	Loss cost index
<i>C_J</i>	Concentration of the corrosive compounds
<i>CO</i>	Carbon monoxide
<i>CO₂</i>	Carbon dioxide
<i>Comp</i>	Compartment
<i>Contents</i>	Contents of the building
<i>C_p</i>	Specific heat capacity of water
<i>CP</i>	Initial cost of component with the highest FRR or fire rating
<i>CT</i>	Commission and testing fees

<i>D</i>	Damage
<i>DamageFS</i>	Cost of damage, estimate of damage or the amount of downtime if there is a fire in the compartment
<i>DamageSS</i>	Cost of damage, estimate of damage or the amount of downtime taking into account only smoke spread
<i>Days</i>	Number of days that it will take to repair or replace a component
<i>DB</i>	Damage to building component
<i>DC</i>	Damage to component
<i>DCC</i>	Damage to building component
<i>DCT</i>	Total damages to all of the contents
<i>DD</i>	Downtime per day
<i>DEast</i>	Damage to a compartment's East wall
<i>Dep</i>	Depth
<i>DFP</i>	Damage to fire protection system as a result of the temperature, smoke and water conditions
<i>DL</i>	Direct losses
<i>DNorth</i>	Damage to a compartment's North wall
<i>DO</i>	Design and other fees
<i>Doors</i>	Doors
<i>DP</i>	Damage to the component with the highest FRR or fire rating
<i>DS</i>	Damage to contents in content category as a result of smoke conditions
<i>DSouth</i>	Damage to a compartment's South wall

D_T	Downtime
DT	Damage to contents in content category as a result of temperature conditions
DTC	Damage to contents in content category as a result of the temperature, smoke and water conditions
$D_T(Total)$	Total amount of downtime
DW	Damage to contents in content category as a result of water conditions
$DWest$	Damage to a compartment's West wall
E	East
E	Expected damage to property
EAC	Estimate of the damage to all of the contents in the building as a percentage of the total damage to the contents in the building
EC	Estimate of the cost of damage to contents
$EC(\%)$	Estimate of the damage to the contents as a percentage of the total damage to the contents
EFP	Estimate of the damage to the fire protection system component
ETD	Estimate of the damage as a percentage of the total damage to the building, its fire protection systems and its contents
f	Inflation rate as a fraction
f_A	Area adjustment factor
f_B	Building component calibration factor
f_C	Building construction calibration factor
FCE	Fire cost expectation
FD	Damage caused by flames

f_{DT}	Factor used to adjust downtime period
f_{Ex}	Extinguishment calibration factor
$Floor$	Floor assembly
F_{Loss}	Expected annual fire loss for all scenarios analyzed
FP	Fire protection system(s)
FPC	Additional passive fire protection in compartment
$FPDC$	Damages to fire protection system
FPF	Fire protection measures per unit floor area of the building
f_R	Retrofit factor
f_{RC}	Rush construction factor
f_{RD}	Reduction of downtime factor
$Freq_{AF}$	Frequency of having a fire
FS	Fire spread
h	Constant Δx
H	Heat absorbed
H	Height
hc	Hydrocarbons
H_v	Heat of vaporization of water
i	Interest rate as a fraction
i_f	Market interest rate
IL	Indirect losses

k	Growth factor
k	Thermal conductivity
L	Lower threshold
L_c	Labour cost
m	Ratio of the sum of loss of contents and indirect losses to the building
m	Slope of a straight line
$\dot{m}''$	Mass loss rate
$\dot{m}_{air}$	Mass flow rate of air
Max	Maximum
MLE	Monetary loss expectation
n	Number
N	Design life of the building
N	Mean number of large fires per unit floor area of the building per unit time
N	North
N_c	Number of compartments in the building
N_D	Number of doors
NFF	Needed fire flow
N_L	Number of compartments lost by fire
N_w	Number of windows
O	Occupancy factor

p_0	Probability that structure becomes damaged due to the absence or failure of active fire protection systems
p_1	Probability that structure becomes damaged due to the inability of the active fire protection systems to control the fire
p_2	Probability that the active fire protection systems fail when a fire occurs
p_3	Probability that the structure becomes damaged due to the failure of passive fire protection
P	Communication paths within buildings factor
P	Probability
$(P/A, i_f, N)$	Present worth of annual costs and losses based on the continuous compounding of the market interest rate
$(P/A, r, N)$	Continuous uniform series present worth factor using the nominal interest rate
PD	Property damage
p_f	Probability of failure of a structural element
$P(\text{FireIn})$	Probability that during the year, a compartment experiences a fire
p_m	Mean rate of occurrence of large fires
ppm	Parts per million
p_{sf}	Conditional probability of structural failure given a large fire
p_y	Probability of a fire occurring in a building per year
$\dot{Q}$	Heat release rate of the fire
$\dot{Q}_A$	Adjusted heat release rate

Q_o	Input heat release rate
Q_s	Heat release rate assuming sprinklers are 100% effective
Q_w	Theoretical energy absorption rate of water
r	Nominal annual interest rate as a fraction
r	Number
R	Fire resistance of the structural element
RCD	Damages using rush construction
R_{corr}	Corrosion rate
RDC	Reduction in downtime cost
R_{DC}	Ratio of total damages to total building cost
$Real$	Real fire curve
S_0	Mean fire severity
S_1	Corresponding cost of the fire damage related to given probabilities
S_2	Corresponding cost of the fire damage related to given probabilities
S_3	Corresponding cost of the fire damage related to given probabilities
S_4	Corresponding cost of the fire damage related to given probabilities
s	Soot
S	South
S	Stoichiometric mass air to fuel ratio

<i>Scenario</i>	Scenario
<i>SD</i>	Smoke damage
<i>S_{eff}</i>	Effectiveness of sprinklers
<i>Standard</i>	Standard fire curve
<i>T₀</i>	Ambient temperature
<i>t</i>	Time
<i>T</i>	Temperature
<i>t_a</i>	Time from ignition to when fire department arrives
<i>t_b</i>	Time from when the fire department arrives to when the fire is under control
<i>TCD</i>	Total damage to contents in the entire building
<i>TD</i>	Temperature damage
<i>t_D</i>	Planned service life of the building
<i>TDB</i>	Total damage to building components
<i>TDC</i>	Total damage to additional passive fire protection and basic building construction
<i>TDFP</i>	Total damage to the building's fire protection systems (not including additional passive fire protection)
<i>TFPC</i>	Total additional passive fire protection in the building
<i>TFS</i>	Total cost of damage, estimate of damage or amount of downtime taking into account smoke spread and fire spread
<i>t_h</i>	Time
<i>t_i</i>	Time from ignition to when sprinklers activate
<i>Total</i>	Total

t_s	Time from when sprinklers activate to when fire is extinguished
U	Upper threshold
V	Volume of air in the building
w	Constant
W	Amount of water needed to extinguish a fire
$\dot{W}$	Flow rate of water required to extinguish a fire
$\dot{W}$	Rate of application of water needed to extinguish fire
W	West
W	Width
$Water$	Water
$\dot{W}_{average}$	Average flow rate of water required to extinguish a fire
WD	Water damage
WE	East wall assembly
$Windows$	Windows
$\dot{W}_{maximum}$	Maximum flow rate of water required to extinguish a fire
$\dot{W}_{minimum}$	Minimum flow rate of water required to extinguish a fire
WN	North wall assembly
WS	South wall assembly
WW	West wall assembly
x	Independent variable

X	Adjacent exposed buildings factor
y	Dependant variable
Y	Annual
Y	Adjusted yield
Y, ∞	Yield in well ventilated conditions

Greek letters

α	Mean number of failures per unit time
β	Capital value of the sprinklers as a ratio of the capital value of the building
β_a	Fire growth parameter
β_b	Fire growth parameter
β_i	Fire growth parameter
β_s	Fire growth parameter
χ	Efficiency of water being applied
ΔT	Change in temperature
Δx	Change in the x variable
ϕ	Calibration factor
Φ	Equivalence ratio
γ	Indirect loss as a ratio of the capital value of the building
η_{ab}	Efficiency that the water absorbs energy from the fire
φ	Repair cost as a ratio of the capital value of the building

λ	Cost of passive fire protection as a ratio of the capital value of the building
μ	Constant
θ	Calibration factor
ρ	Density

1.0 INTRODUCTION AND OBJECTIVES

Each year in Canada billions of dollars are spent on fire damage loss and fire protection systems. The purpose of fire protection systems is to ensure the safety of the building occupants and to reduce the damages to the building and its contents. With a movement towards performance based building codes, the design of a building is evaluated not only on safety of its occupants but also on cost-effectiveness. Cost-effectiveness can be determined by considering the cost of fire protection and the expected damages resulting from fires during the life of the building. Therefore, knowledge of how fire can damage a building and its contents becomes essential when deciding what fire protection measures should be incorporated into a building. Since a building owner would like to protect his/her investment and insurance companies would rather not pay out large settlements, it is advantageous to all parties to increase the amount of fire protection to a building. Presently a number of computer based models exist, which include FiRECAM (Yung et al., 2002), FIERASystem (Bénichou et al., 2002), CESARE (Thomas, 2003) and Alarm (Weber and Lippiatt, 1994) which are capable of calculating the damages due to fire but are not publicly available. This thesis attempts to describe a functional fire protection model which determines the economic impact of fires in buildings.

Statement of objectives:

1. To develop a computer model capable of calculating the cost of a building's construction, its contents and fire protection systems.
2. To develop a computer model capable of calculating the cost of fire damage to a building's construction, its contents and fire protection systems, as well as the cost due to downtime and business interruption.
3. Integrate this computer model with fire development and smoke movement models.
4. To conduct a comparison of the economic impact between different fire protection designs.

The following thesis is divided into six chapters: a literature review, a description of the economic computer model, input data for the economic computer model, methodology used in the development of the economic computer model, predictions of the economic computer model and conclusions, limitations and future considerations of the economic computer model.

2.0 LITERATURE REVIEW

This chapter is a discussion of the available literature on the economic impact of fires in buildings. Most of the relevant data collected on this subject is given for the United States and therefore it must be noted that although the United States has similar building methods and similar conditions as those found in Canada, the United States has a larger population, different terminology and different methods of data collection which can make it difficult to compare data (Richardson, 2001). Since Canadian data are at times limited, comparisons using US data will be made. In regards to the economic impact of fire, only generalized data relating to cost and damages will be presented. The following information will give a better understanding of the background and assumptions made in the economic computer model.

2.1 Cost of fire

The following section describes the national cost of fire which includes such factors as the cost of life safety measures, the cost of damages, prevention costs, and environmental damages (Hurley, 2000).

When discussing the cost of fire, both losses and expenses are considered. The most costly loss components are loss of life, damage to property, inability to use the property for its intended use, and loss due to human injury (Lie, 1972a). The main

expenses in the cost of fire are the cost of suppression, prevention, protection, insurance and research and development (Lie, 1972a).

Table 1 illustrates a general percentage approximation of fire costs when divided into five categories, namely, direct losses, indirect losses, firefighting, insurance, and building protection. Direct losses may include damages to the structure and the contents of a building due to fire whereas indirect losses may stem from the shutdown of business which may result in lawsuits leading to negative effects on company image and/or the decline of future sales (Hixenbaugh, 1996). Indirect losses can also include: businesses interruption, loss of market share, temporary housing, legal fees, etc.

Table 1: General percentage approximations of fire costs internationally (Wilmot, 1986).

Category	Percentage (%)
Direct losses	30
Indirect losses	10
Firefighting	15
Insurance	15
Building protection	30

Table 2 describes the breakdown of the annual fire cost in Canada. Included are the damage to the building and contents, the cost of care to people who are injured in a fire, fire protection systems in buildings, and the development and updating of fire codes and standards. What is not included are the indirect fire costs such as business interruption, loss of market share, etc.

Table 2: Annual fire costs in Canada (Lie, 1972a).

Costs	Percentage of total costs (%)
Property damages	30.3
Injury costs	0.3
Suppression costs	34.3
Prevention and protection costs	14.8
Insurance fees	20.2
Research and development costs	0.1

Most countries spend 1% of their gross domestic product (GDP) (see Glossary) on fire which includes: direct damage, indirect damage, human loss, protection of buildings, cost of fire departments and cost of fire insurance (Woodward, 1989). In the United States, direct fire losses in 1994 accounted for 0.2% of its GDP while 2% of the US's GDP includes the total cost of fire (direct losses, indirect losses, fire protection, insurance and the cost of fire departments) (Hurley, 2000). Even though

fires comprise a significant fraction of the GDP they are not considered a political issue (Wilmot, 1986). With respect to the gross national product (GNP) (see Glossary) it is estimated that the fire cost in many countries is approximately 1% of the GNP, however, it has been shown that large fires account for approximately 50% of the total losses from fire but represent only 0.5% of all fires (Lie, 1972a). The contribution to the cost of fire in the United States is shown in Table 3.

A good concise reference for the total fire costs in Canada can be found in Schaenman et al. (1994). This report analyses the direct dollar losses for fires (\$1.7 B/year), the cost of fire services (\$2.2 B/year), the cost of fire protection in structures (\$3.3 B/year), the cost of built-in fire safety (into equipment, vehicles, goods and operations) (\$2.3 B/year), insurance overhead (\$0.4 B/year), indirect losses from fire (\$0.3 B/year), the cost deaths and injures (\$0.1 B/year) and miscellaneous costs (\$0.1 B/year). It is clear from the literature that the cost of fire is high and therefore warrants further research to more accurately assess its cost.

Table 3: Cost of fires in the United States (Meade, 1991).

Component	Percentage of total (%) fire cost
Direct and indirect losses	
• Residential property	3.5
• Industrial property	3.6
• Other property	0.6
• Residential interruption	0.7
• Business interruption	7.3
• Product liability	3.0
Insurance	
• Product liability	0.1
• Net fire insurance	4.9
Fire service	
• Professional	8.3
• Volunteer (paid)	26.0
Proactive measures	
• Fire protection built into structures	17.9
• Fire protection built into equipment	15.6
• Standards activity	0.2
• Retardants/testing	2.2
• Fire maintenance	5.6
• Disaster recovery	0.5

2.2 Probability of having a fire

The probability of fire generally increases with an increase in building size (Lie, 1972a) and the number of years a building is in use (Lie, 1979). It has been suggested by Lie (1979) that the probability of having a fire is proportional to the building's floor area. In addition, the contents of the building will affect this probability; for example, if a building contains hazardous materials the probability of fire will be

higher (Lie, 1972a). The probability of having a large fire depends on the following factors: floor area, life of the building, occupancy and fire protection systems (Lie, 1972a).

The average probability of having a “serious” fire (not defined by Charters) in a building is approximately 1×10^{-2} per year (Charters, 1998). Baldwin (1974) estimates that the probability of having a fire is 1.2×10^{-1} per year for entertainment assemblies, and 8.4×10^{-3} per year for commercial offices. Lie (1972a) offers low, medium and high risk probabilities of 0.5×10^{-7} , 2×10^{-7} and 10×10^{-7} per m^2 per year, respectively. Gaskin and Yung (1993) estimated the frequency of fires in Canadian office buildings to be 7.68×10^{-6} per m^2 of floor area per year. This is the value used for risk analysis calculations in this work. It should be noted that although rough probability estimates are available, the definition of what constitutes a “serious” fire or fire is not readily discussed. Taken together, this data suggests that the likelihood of fire occurring during the lifespan of a building is probable and therefore preventative precautions should be taken. In the United States in 1996, the fire departments responded to a structure fire every 55 seconds (Karter, 1997).

2.3 Preventative action

In order to limit the damage that a fire might cause, planning becomes necessary. The primary objective of fire safety in buildings is to ensure that the occupants can make a

safe exit if a fire occurs (Charters, 1998). Safety is always the priority in planning for possible fires, however, property protection is also important when an invested interest is present. To reduce fire losses the following precautionary measures can be taken: add more active and passive fire protection measures, control the amount of combustibles in a compartment and design the building so that the fire will remain in a compartment (Lie, 1972a). Other measures that should be taken before the fire department arrives are: prevention, detection, automatic extinguishment and restraints against fire spread (Cote, 1986). Using fire safety management will help balance the cost of fire protection while providing the benefits of added fire protection. Risk assessments and cost-benefit analysis can ensure that the addition of fire protection systems makes economic sense (Charters, 1998).

Fire is the main cause of destruction to a company's computer system followed by natural disasters and computer sabotage (Klopp, 1990). If a company's data centre is affected by fire, floods or explosions, the company usually does not recover from the loss (Klopp, 1990). Most companies should implement a disaster recovery plan that will ensure that the companies have backups in case of disaster such as the occurrence of fire. For example, when a fire damages a company's computer system where lost data are a result, if a good recovery system is present, businesses can resume their normal operations within 24 hours to one week depending on the amount of prevention planning that is employed (Korzeniowski, 1990).

Another way to reduce damage from fire is to train employees on how to deal with the occurrence of a fire (Dittman, 1988). Many of these fire preventive elements are not readily estimated, however, others such as the cost of adding sprinklers can be more readily determined.

2.4 Losses

Losses due to fire in newer buildings may be higher than in older buildings because newer buildings generally cost more and have higher restoration costs. (Lie, 1972a) However, newer buildings generally have more fire protection systems than older buildings which may reduce their losses. Losses may increase if a fire occurs in a large building since the cost of contents will be presumably higher. Not only do larger buildings cost more but the increase in surface area alone may impact the probability of a fire occurring (Lie, 1972a). Therefore, for larger buildings the expected losses from fire will increase, making added fire protection for these buildings a good decision (Lie, 1979).

There are three categories of fire losses which are described as follows: damage to the structure of the building (direct loss), damage to the contents of the building (direct loss), and indirect losses (Dowling et al., 1993). Wilmot (1986) estimates that indirect fire losses and direct fire losses are approximately 10% and 30% of the total national fire cost, respectively. Wilmot also assumes that approximately 50% of

these indirect losses affect the national economy since the result may be the loss of a business competitor. In Canada in 1965, the direct fire losses as a percentage of the GNP was 0.28% (Lie, 1972a). It should be noted that direct fire losses are comparable to the fire losses 20 or 30 years ago if inflation is taken into account (Woodward, 1989).

When fire loss estimates are made by firefighters they generally have a margin of error of approximately 25% (Schaenman et al., 1994). In Canada there is no common template for the collection of fire damage data. Insurance companies have adjusters experienced in the estimation of damages, but because many fires go unreported to insurance companies it becomes difficult to compare the estimates made by firefighters and those made by insurance companies (Schaenman et al., 1994).

2.4.1 Indirect losses

Indirect fire losses can be between three to four times greater than direct fire losses (Meade, 1991). Many have estimated that the impact of downtime (the time that it takes for a business to return to normal operating conditions; indirect damage) can be as great as two to six times the cost of direct damage (Meade, 1991). Table 4 shows levels of downtime categories as proposed by Barry (2002).

Table 4: Downtime levels (Barry, 2002).

Level	Production Downtime Range (Days)	Average Production Downtime (Days)	Definition	Probability (Events/year)
Slight	0-1	0.5	<ul style="list-style-type: none"> • Minor damage to equipment • Cleaning is needed, but not repairs 	0.33
Light	1-10	5	<ul style="list-style-type: none"> • Localized damage of equipment with minimal downtime occurring 	0.10
Moderate	10-30	20	<ul style="list-style-type: none"> • Localized damage of equipment with moderate downtime occurring 	0.01
Heavy	30-90	60	<ul style="list-style-type: none"> • Damage will require repair and replacement 	1×10^{-3}
Major	90-270	180	<ul style="list-style-type: none"> • Damage is throughout building • Many repairs • Replacement of equipment 	5×10^{-3}
Critical	270-365	318	<ul style="list-style-type: none"> • Most of the building will experience downtime 	1×10^{-4}
Total or Maximum	365-730	Max	<ul style="list-style-type: none"> • Maximum downtime expected 	1×10^{-6}

Downtime estimations can differ due to factors such as different types of businesses, and different contents and/or equipment and their sensitivity to temperature, smoke and water. Indirect losses will be large in comparison to direct losses (Fry, 1964), however, Schaenman et al., (1994) suggests the opposite by stating that indirect losses make up 7% to 15% of direct losses.

Many companies do not recover from fire losses (Hixenbaugh, 1996). Dittman (1988) estimates that 40% of businesses that are insured do not recover from a fire. One type of indirect loss may occur when, to fulfill a customer demand, companies must give confidential information to their competitors which may have a negative impact on their future sales (Hixenbaugh, 1996). Indirect losses may result when a fire occurs at a location which links one business to another (Woodward, 1989). In this case all of the businesses in the chain will be indirectly affected by fire. Another example of indirect losses may occur when the agents used to extinguish a fire cause damage. For example, buildings that store toxic and flammable liquids have the potential for the water used to extinguish the fire to contaminate the ground through water runoff (Meade, 1991).

There is a large discrepancy in the relative costs of direct and indirect losses. Direct losses are easily defined but the estimation of indirect losses is not readily done.

2.4.2 Direct fire losses

In this section direct fire losses will be examined with respect to extent of damage, building damage, fire and temperature damage, non-thermal damage and water damage.

2.4.2.1 Extent of damage

Damage from the occurrence of a fire depends on factors which include: time it takes the fire department to arrive at the scene of a fire, building materials used in the building construction, the type of combustibles in a compartment and the active and passive fire protection systems available (Bengtson and Laufke, 1979/1980).

The extent of damage is highly dependent on the time that it takes the fire department to arrive at the scene of a fire (Fontana et al., 1999). For example if flashover (see Glossary) has occurred, the fire is much harder to extinguish and therefore, for the damage to be limited, the fire should ideally be extinguished before flashover occurs. Also, depending on when the growth of fire is controlled only then can the conditions of the damage be estimated as proportional to the floor area (Bengtson and Laufke, 1979/1980).

In a survey done in Holland of low-rise industrial buildings, it was shown that 30% of fire damages were related to structural damage while 50% were related to content

damage (Dowling et al., 1993). It is estimated that if a building collapses, the amount of damage is 100% to 150% of the original building costs (Baldwin, 1974).

2.4.2.2 Building damage

Damage to the building is inevitable in fires. Buildings made of combustible material have the disadvantage of having the fire spread to larger areas than non-combustible type buildings, however, it was shown in Switzerland that buildings which have a modern timber frame (combustible type building) with compartmentation (see Glossary) and active fire protection systems do not suffer large fire losses (Fontana et al., 1999).

Table 5 shows building damage levels as recommended by Barry (2002) and Table 6 describes five categories of types of building damage as described by Cole (1993).

Table 5: Building damage levels (Barry, 2002).

Level of damage	Damage factor range (%)	Definition
Slight	0-1	No repairs are required
Light	1-10	Some damage has occurred but large repairs are not needed
Moderate	10-30	More damage that in light category requiring some repairs
Heavy	30-60	Lots of damage requiring large repairs
Major	60-100	Damage has occurred throughout the building requiring extensive repairs or demolition of the building
Destroyed	100	Building cannot be repaired

Table 6: Five categories of building damage (Cole, 1993).

Type of damage	Definition
Threatened undamaged	No damage to the building but may be 100 ft (30.5 m) from flame damage to other buildings or vegetation
Minimal damage	Damage is less than 10% of the value of the building, no large repairs needed
Minor damage	Repairs to the building will not be more than 10% of the value of the building
Major damage	Damage is great but building can be repaired
Destroyed	Damage is so great that the entire building must be rebuilt

2.4.2.3 Fire and temperature damage

In a fire, the contents and structure of a building can be greatly damaged from the effects of heat and temperature. With regard to damages due to radiation (heat), there are two damage levels shown in Table 7.

Table 8 describes some of the effects of temperature on common core materials typically found in a compartment.

Table 7: A description of the different radiation damage levels (Netherlands Arbeidsinspectie, 1992).

Radiation damage level ^A	Description
Level 1	<ul style="list-style-type: none">• Ignition of surfaces and breakages• Failure of structural elements
Level 2	<ul style="list-style-type: none">• Serious discoloration of materials• Peeling off of paints• Some deformation of structural elements

^A – Radiation is greater in level 1 than in level 2.

To assess the damages due to temperature, the melting point of common materials are given in Table 9. At 70°C synthetic materials can be observed to degrade whereas at 100°C, thermoplastic materials are observed to change colour and deteriorate (Netherlands Arbeidsinspectie, 1992). It can be assumed that if a part of a building's contents reaches their melting point that the damage to the contents will be 100%. It should be noted that the damage can be 100% even before the contents reach their melting point, and therefore the evaluation of content damage should be done on an individual basis.

Table 8: Temperature damage to different types of core materials (Barry, 2002).

Type of material	Type of product	Type of damage	Temperature (°C)
Aluminium and alloys	Fixtures, casings, brackets, small mechanical parts	Softens	400
		Melts	600
		Drop formation	650
Brass	Locks, taps, door handles, clasps	Melts (particularly at edges)	900 to 1,000
		Drop formation	950 to 1,050
Bronze	Windows, fittings, door bells, ornamentation	Edges rounded	900
		Drop formation	900 to 1,000
Cast iron	Radiators, pipes	Melts	1,100 to 1,200
		Drop formation	1,150 to 1,250
Cellulose	Wood, paper, cotton	Darkens	200 to 300
Copper	Wiring, cables, ornaments	Melts	100 to 1,100
Glass	Glazing, bottles	Softens, sharp edges rounded	500 to 600
		Flows easily, viscous	800
Lead	Plumbing Sanitary installations, toys	Melts, sharp edges rounded	300 to 350
		Drop formation	
Paint	-	Deteriorates	100
		Destroyed	250
Polyethylene	Bags, films, bottles, buckets, pipes	Shrivels	120
		Softens and melts	120 to 140

Table 8 continued...

Type of material	Type of product	Type of damage	Temperature (°C)
Polymethyl methacrylate	Handles, covers, skylights, "glazing"	Softens Bubbles	130 to 200 250
Polystyrene	Thin wall food containers, foam, light shades, handles, curtain hooks, radio casings	Collapses Softens Melts and flows	120 120 to 140 150 to 180
Polyvinyl chloride	Cables, pipes, ducts, linings, profiles, handles, knobs, houseware, toys, bottles	Degrades Fumes Browns Chars	100 150 200 400 to 500
Silver	Jewelry, spoons, cutlery, etc.	Melts Drop formation	900 950
Solder	Plumbing joints	Melts	250
Wood	-	Ignites ^A	240
Zinc	Sanitary installations, gutter, down pipes	Drop formation Melts	400 420

^A – Barry provides a very low ignition temperature for wood. This is most likely a damage threshold than an ignition threshold.

Table 9: Materials and their melting points (Ashby and Jones, 1996).

Material	Temperature (°C)
Diamond, graphite	3,727
Tungsten alloys	3,227-3,410
Tantalum alloys	2,677-2,996
Silicon carbide, SiC	2,837
Magnesia	2,800
Alumina, Al ₂ O ₃	2,050
Iron	1,536
Stainless steels	1,327-1,417
Silicon	1,410
Copper alloys	847-1,083
Gold	1,063
Silver	961
Aluminium alloys	477-650
Magnesium alloys	457-650
Lead alloys	177-328
Tin alloys	127-236

2.4.2.4 Non-thermal damage

In many fires, the damage caused by smoke and other gases can be significant (Watts, 2001). Non-thermal damages occur from smoke containing corrosive gases which linger in the contents of a building after a fire. Even small amounts of smoke can cause a severe amount of damage. Owners of any building that house paper materials or artwork should be particularly concerned since these contents can cause extensive non-thermal damage (Watts, 2001).

With respect to life safety, approximately 70% of deaths in fire are a result of the inhalation of smoke and other toxic gases (Hixenbaugh, 1996). Using statistics from the United States from the years 1981 to 1984, Hall (1989) states that 23.8% of deaths in residential fires are due to smoke inhalation, 6.0% are due to burns, while 66.1% of deaths are from both burns and smoke inhalation. Dowling et al. (1993) states that 95% of deaths in fires are from both smoke inhalation and burns. This data suggests that smoke can have a significant affect on life safety.

The smoke produced in a fire may contain a multitude of compounds which can be damaging to the contents of a building. These compounds may include: carbon monoxide, hydrogen chloride, hydrogen cyanide, carbon and metals (Bradford, 1990). Table 10 shows the corrosion damage caused by chloride ions per cm² of surface area to telecommunications central offices.

Non-thermal damage can be minimized if a prompt cleanup is implemented after the fire is extinguished (Bradford, 1990). The faster the cleanup occurs, the more likely that non-thermal damage will be limited. Chemical strips are a means by which restoring companies can determine which electronic equipment is worth cleaning, however, the only effective way to determine whether equipment has been damaged is to manually test it (Security Magazine, 2000).

Table 10: Corrosion damage caused by chloride ions to telecommunication central offices (Tewarson, 2003).

Chloride ions ($\mu\text{g} / \text{cm}^2$)	Description of damage, cleaning and/or restoration
≤ 2	<ul style="list-style-type: none"> No damage, no cleaning or restoration needed
< 30	<ul style="list-style-type: none"> Equipment easily restored by cleaning with small impact on long term functioning
30 to 90	<ul style="list-style-type: none"> Equipment easily restored by cleaning, if no major corrosion has occurred and fire cleanup has been initiated promptly after the fire has occurred
> 90	<ul style="list-style-type: none"> Cleaning cost is near replacement cost

Non-thermal damage is a major issue in the telecommunications and microelectronic sectors since they house smoke sensitive equipment. In a microelectronic plant, extensive damage can occur even before the fire is detected (Bolemen, 1989). A small fire in a microelectronics wafer fabrication plant can affect the entire fabrication process and potentially cost millions of dollars in business interruption (Bolemen, 1989). It is estimated that the damage to a Class 1 (see Glossary) wafer fabrication plant due to the products of combustion can be in the order of \$1 billion from direct and indirect damages (Bolemen, 1989).

If a small fire occurs in a Class 1 wafer fabrication plant, the level of cleanliness maintained by this unit will be abolished. For example, when polypropylene burns,

the smoke will cause the Class 1 wafer fabrication plant to become entirely damaged after only a few minutes (Sherin, 1989). Flame retardant plastics will burn at a slower rate and produce less smoke than in the past, however, their physical properties may be compromised (Wigotsky, 1987).

Most damages from fire in telecommunications central offices occur because of smoke damage (Tewarson, 2003). Fires in the telecommunications industry that involve cables produce toxic and corrosive gases which can put sensitive electrical equipment at risk (Alvares and Fernandez-Pello, 2000). It has been shown by Tewarson (2003) that if the cable vapour concentration (see Glossary) is below 3 g/m³ that restoration of electrical equipment is possible. Damage will occur when the cable vapour concentration reaches 6 g/m³ (Tewarson, 2003). Soot particles (see Glossary), for example, are very effective in absorbing compounds that can be toxic or corrosive and also carry electrical charges, depending on their temperature, that can damage electronic equipment (Tewarson, 2003). Many industries use computer controlled and robot-operated production lines that are very sensitive to fire, smoke and water damage (Woodward, 1989). The loss of such production lines can cause great cost due to business interruption (Woodward, 1989).

Smoke can be harmful to many types of contents within a building (Hixenbaugh, 1996). For example, when a plastic that is made of polyvinyl chloride is in a fire, it releases chlorides such as hydrogen chloride, which when mixed with smoke and

moisture forms a corrosive gas, hydrochloric acid, which can damage electrical equipment (Security Magazine, 2000) by corroding electrical contacts (Alvares and Fernandez-Pello, 2000). If computers are on, the fans that cool them can suck in soot which can damage the computer. The restoration of electrical equipment can be between 20% and 40% of the replacement cost, which includes the cost of the equipment and excludes the cost of labour (Security Magazine, 2000). For businesses involving food products, non-thermal damages can have a large effect. If the taste of the food is affected, the food cannot be sold and must be thrown away (Bradford, 1990).

The following lists reasons why electrical equipment may not be functional (Tewarson, 2003):

- Corrosion of the metal surfaces
- An increase in resistance at the contact points
- Increase of current leakages
- Interference of soot particles in the motion of moving parts
- Increased electrical shorts

Damage thresholds for electronic equipment can be found in Table 11. Table 12 shows the effect of smoke density and HCl concentration on electronic equipment.

Table 11: Smoke damage thresholds to electronic equipment* (Barry, 2002).

Combustion product	Damage threshold (ppm)
Hydrochloric acid (HCl)	100
Hydrogen fluoride (HF)	1,000
Nitrogen dioxide (NO ₂)	1,000
Sulphur dioxide (SO ₂)	>1,000

* – Electronic equipment was exposed to different products of combustion for 22 hours at a relative humidity of 75%.

Table 12: Smoke density and the damages to electronic equipment (Barry, 2002).

Smoke Density (kg/m ³)	HCl concentration (ppm)	Possibility of damages
0.02	-	• Can cause shorting of equipment
0.04	100	• Some damage to equipment, equipment can be restored
0.06	220	• Equipment will be severely damaged

2.4.2.5 Water damage

Water damage is a major concern in fires. The damage that water causes is primarily to contents and is negligible to the structure of the building. The damage caused by the water used by sprinklers and the water that the fire departments use to extinguish the fire can cause major cleanup costs.

Water damage is a major issue if a fire occurs in a semi-conductor facility (Sherin, 1989). The damage to computers and business interruption will be limited if the computers are dried soon after exposure to water (Mauzerall, 1990). There are two major categories of water damage shown in Table 13.

Table 13: Types of water damage (Water Damage, 2004).

Type of water damage	Description
Primary	<ul style="list-style-type: none">• Visible to the human eye• Can include a colour change, swelling and/or shrinkage
Secondary	<ul style="list-style-type: none">• Moisture travels to locations where moisture should not be

The amount of water that a fire department will use during the extinguishing process is usually the greatest contributor of water damage. The water flow used by firefighters is difficult to determine since there are many different types of nozzles with different set flows and pressures (Clark, 2000). Firefighters also use different types of hoses which can provide different flow rates (Clark, 2000). A 1 ¾ in (44 mm) to 2 ½ in (75 mm) fire hose stream can have a discharge of 946 L/min to 1,893 L/min (Dieken, 2000) while smaller hoses can discharge 114 L/min (Clark, 2000). Table 14 provides the hand line (see Glossary) size and the flow that can be acquired using that hand line.

Table 14: Hand line sizes and acquired flows (Clark, 2000).

Hand line size (in)	Hand line size (mm)	Range of flow (L/min)
¾-1	19-25	114
1 ½, 1 ¾, 2	38, 44, 50	378 to over 946
2 ½	64	625-1,230

Master stream devices are also used in large fires. These master stream devices which include the wagon pipe, deluge sets and ladder pipes, can deliver a flow over 1,325 L/min (Clark, 2000), however, it should be noted that flow through is affected by many factors such as friction and pressure in the line.

From the above mentioned data it can be concluded that with respect to the contents of a compartment, water damage can be expensive and is an area of research that needs addressing.

2.5 The behaviour of a building's materials in fire

In this section, the behaviour of building materials such as, wood, steel, glass, stone, brick, gypsum, and concrete will be discussed. These building materials are generally what most buildings in Canada are made of. Table 15 shows the different ignition temperatures of compartment construction materials and their critical heat fluxes.

Table 15: Typical construction materials, their ignition temperatures and their critical heat fluxes (Quintiere, 1997).

Material	$k\rho c$ (kW/m ² K) ² s	Ignition temperature (°C)	Critical heat flux (kW/m ²)
Plywood, plain (6.35 mm)	0.46	390	16
Hardboard (6.35 mm)	1.87	298	10
Particleboard (12.7 mm)	0.93	412	18
Carpet (wool, untreated)	0.25	435	20
Carpet (wool, treated)	0.24	455	22
Carpet (nylon/wool blend)	0.68	412	18
Carpet (acrylic)	0.42	300	10
Gypsum board (12.7 mm)	0.45	565	35
Gypsum board, wall paper	0.57	412	18
Asphalt shingle	0.70	378	15
Fiberglass shingle	0.50	445	21

Values are also provided for $k\rho c$ (where k is the thermal conductivity, ρ is the density and c is the specific heat) since the ignition temperatures and critical heat fluxes in Table 15 are for those specific materials with a given $k\rho c$ value.

2.5.1 Wood

It is difficult to use generalized data on how wood behaves in a fire since there are many types of wood used and their properties will vary depending on type and moisture content. The fire resistance of a wooden member may depend on factors such as type of wood, size, and rate of charring (Bénichou and Sultan, 2000). As wood heats up, some of its moisture evaporates and some of its moisture goes deeper into the wood which may cause the wood to lose some of its strength and rigidity (Bénichou and Sultan, 2000).

Wood undergoes a slow dehydration process at temperatures between 100°C and 250°C which eventually leads to the charring of the wood (Wood Engineering Handbook, 1990). It is generally assumed that wood loses its moisture at 100°C (Pettersson, 1986) however some researchers have suggested that wood loses its moisture between 100°C and 160°C (Bénichou and Sultan, 2000). Wood can spontaneously ignite when exposed to a heat flux of 28 kW/m² (Hadjisophocleous and Bénichou, 1999). The maximum temperature at which wood can be exposed to for a long period of time without igniting is usually taken to be 77°C or 100°C (Wood

Engineering Handbook, 1990). Wood exposed to temperatures of 66°C for long periods of time will be permanently weakened (Merritt, 1983). Table 16 shows the ignition type and the temperature range of wood.

Table 16: Wood ignition type including ignition temperature range (Wood Engineering Handbook, 1990).

Ignition type	Temperature range
Radiant heating of cellulosic solids nonpiloted transient ignition	300°C to 410°C
Persistent flaming ignition	>320°C
Convective heating of wood nonpiloted ignition	270°C to 470°C

2.5.2 Steel

Both the temperature and the duration of a fire are important factors that affect the strength of a building's structural members (Bennetts and Thomas, 2002). It has been shown that the fire resistance of a single member is less than the fire resistance of the building's structure as a whole (Bennetts and Thomas, 2002). The load of a building can also have an affect on the performance of steel in a fire (Netherlands Arbeidsinspectie, 1992).

Although steel is not a combustible material, the strength of steel will decrease very quickly when exposed to high temperatures (Netherlands Arbeidsinspectie, 1992). Prestressed steels lose up to 30% of their strength when heated to 500°C and then cooled and lose 50% of their strength when heated to 600°C (Buchanan, 2002). It has been suggested that steel can fail between temperatures of 400°C and 600°C (Netherlands Arbeidsinspectie, 1992) or between temperatures of 480°C and 540°C (Barry, 2002).

In fully developed fires, unprotected steel may be damaged more readily than protected steel (Buchanan, 2002). However, steel construction can be used without protection in certain instances such as when combustibles are positioned in a fashion which only allows for small fires to occur, when the quantity of combustibles are limited, when compartments are large compared to the amount of combustibles that are present, when a compartment's fire load density is small, or when active fire protection measures are present (Bennetts and Thomas, 2002).

2.5.3 Glass

Typically glass will soften and melt between the temperatures of 600°C and 800°C (Buchanan, 2002). However, it has been shown that glass can crack due to temperature gradients within the glass itself or when the frame encasing the glass expands (Buchanan, 2002). Barry (2002) states that values for the breakage of inner

glass may vary from 100°C to 300°C. Hadjisophocleous and Bénichou (1999) describe lower and upper temperature limits for glass breakage shown in Table 17.

Table 17: Upper and lower temperature limits for the breakage of glass (Hadjisophocleous and Bénichou, 1999).

Type of glass	Lower limit (°C)	Upper limit (°C)
Ordinary glass	100	175
Tempered glass	270	350

2.5.4 Stones

Some buildings contain natural stonework which behaves well in fires. Table 18 shows the effect of temperature on buildings with natural stonework. Visible effects of fire are colour changes which become apparent at lower temperatures between 200°C and 300°C (Chakrabarti et al., 1996). This colour change is also observed when stones are subjected to higher temperatures (Chakrabarti et al., 1996). Discolouration, cracking and spalling (see Glossary) of the stones are the most commonly observed damages (Chakrabarti et al., 1996). When calcination (see Glossary) of calcium carbonate in the stone occurs, this will result in a reduction in the stone's strength (Chakrabarti et al., 1996). These damages are usually around

openings such as windows and doors but can also affect the structural integrity of the building (Chakrabarti et al., 1996).

Table 18: The strength of different types of stone at high temperatures (Chakrabarti et al., 1996).

Type of stone	Strength
Limestone	<ul style="list-style-type: none">• Unchanged in small fires• Calcination of the calcium carbonate occurs at 600°C and continues rapidly over 800°C
Sandstone	<ul style="list-style-type: none">• Heating to 573°C will cause the stone to be weakened
Granite	<ul style="list-style-type: none">• Heating to 573°C will cause the stone to be weakened, to crack or to shatter• Heating from 20°C to 250°C is reversible for small fires at a rate of 1°C a minute
Marble	<ul style="list-style-type: none">• Heating to 200°C results in a 50% reduction in flexural strength

2.5.5 Bricks

Ceramic clay bricks can withstand temperatures as high as 1,000°C without suffering any damage. Although the bricks will not be damaged, the mortar holding the bricks together can be damaged at temperatures much lower than 1,000°C (Buchanan, 2002).

2.5.6 Gypsum

The strength and stiffness of gypsum is zero when temperatures are between 100°C and 120°C (Bénichou and Sultan, 2000). In a fire, typical gypsum board will dehydrate at a rate of 0.5 mm per minute (Buchanan, 2002).

2.5.7 Concrete

Concrete behaves well in fires because when exposed to high heat for only a few hours its core and reinforcements are not significantly affected (Young et al., 1998). Concrete slabs which have spalled, cracked or have large deformations, require replacement since the resulting decomposition of hydration products will cause a development of internal stress within the slabs (Young et al., 1998). Typically, when a fire occurs, the concern lies in the reinforcing steel used in the concrete rather than in the concrete itself. It has been suggested that when working with concrete, the strength of concrete decreases to zero when a temperature of 500°C is reached (Buchanan, 2002). However, Anderberg (1993) suggests that the strength of concrete is 90% when the temperature is below 400°C, 70% when the temperature is between 400°C and 600°C and zero when the temperature is 600°C. Up to temperatures of 480°C concrete will not lose much of its compressive strength, however, when temperatures exceed 650°C, its compressive strength is thought to be reduced by approximately 50% (Barry, 2002).

2.6 Insurance

Companies can be insured for potential losses from fire which include indirect losses and direct losses. Five to ten percent of direct and indirect losses are not insured (Schaenman et al., 1994). Insurance companies take into consideration factors such as the type of occupancy, the building contents, building construction type, and building finishes (Canadian Wood Council, 2002). What is not insurable is the market loss that a company will endure if a disaster should happen. As a rule of thumb in the insurance industry, for every dollar of direct damage, there are two dollars of indirect damage which the insurance company may not entirely cover (Yuill, 2004).

Fire insurance makes up 21% of total insurance costs (Hall, 1989). Sprinkler systems can reduce insurance rates by approximately 60% to 70% according to Dittman (1988), and 50% to 60% according to the Canadian Wood Council (2002). Many insurance companies will not insure a building if a sprinkler system is not present (Dittman, 1988).

If a small fire occurs, many businesses will not report the fire to the insurance company over fear of increased premiums. It is for this reason that insurance rates may vary greatly and are not easily determined.

2.7 Fire protection systems

There are two main types of fire protection systems. The first type of system is active fire protection which will react to changing conditions, control smoke spread and is involved in the detection and extinguishing of fires. The second type of system is passive fire protection which includes elements that are usually part of the building (i.e., ventilation systems, fire separations, etc.) and is primarily used to protect the building structure so that evacuation, in the event of a fire, is possible. Increasing the amount of fire protection in a building will result in less damage to the building. Although many of the fire protection systems do not directly aid in extinguishing a fire, they do help indirectly by decreasing the fire department notification time (see Table 19). Table 19 also demonstrates the different components of fire protection systems and their impacts on controlling fires, both small and large.

Table 19: Fire protection systems relationship with aid in extinguishing fires and the notification of the fire department.

Fire protection system	Direct aid in extinguishing large fires	Direct aid in extinguishing small fires	Aid in speeding up notification of fire department
Alarm systems			X
Heat detectors			X
Smoke detectors			X
Manual extinguishers		X	
Fire hose/standpipes	X	X	
Sprinklers	X		X
Smoke control systems			
Passive fire resistance			

The effectiveness of some types of fire protection systems are shown in Table 20. Effectiveness can be defined as the ability for a system to complete its intended task given the operation of the system (see Glossary). Table 20 shows that sprinklers are the most effective fire protection measure.

Table 20: Effectiveness of different fire protection measures (Bennetts and Thomas, 2002).

Component	Effectiveness
Sprinklers	0.60-0.82
Detectors	0.34-0.66
Fire protection construction	0.23-0.59

Table 21 shows the cost of fire protection as a percentage of the total building cost. This cost varies with the type of building, the amount of protection and country. It should be noted that the accuracy of the cost of fire protection systems as a percentage of building costs is unknown and therefore, it should be assumed that Table 21 provides crude estimates only (Silcock, 1967 and 1968). The total cost of implementing fire protection systems is rarely considered (Chubb and Williamson, 1999).

Table 21: The cost of fire protection systems as a percentage of the total building cost for various occupancies.

Reference	Occupancy	Cost of fire protection systems (%)
Fry, 1964 (United Kingdom)	-	1.0-5.0
Hurley, 2000 (General)	-	2.0-4.0
Hurley, 2000 (USA)	Housing	1.5
	Non-residential	12.0
Hall, 1989 (USA)	Private residential	2.5
	Private non-residential	9.0
	Public building construction	4.0
	Other private construction	3.0
Woodward, 1989 (United Kingdom)	Housing	1.0
	Offices	2.0
	Industrial buildings	7.0
Silcock, 1967, 1968 (United Kingdom)		
Private sector	Housing	1.0
	Schools and Universities	3.0
	Garages	1.0
	Offices	2.0
	Shops	2.0
	Entertainment	5.0
	Industry	7.0
	Miscellaneous	1.0
Public sector	Housing	1.0
	Schools and Universities	3.0
	Health office	3.0
	Factories	5.0
	Miscellaneous	1.0

Table 21 continued...

Reference	Occupancy	Percentage of building cost
(Schaenman et al., 1994) (Canada)	Industrial	6.0%
	Low-rise concrete office	
	• Passive	1.5%
	• Active	1.5%
	(no sprinklers)	
	Low-rise steel office	
	• Passive	5.0%
	• Active	1.5%

In a Canadian study of a six story concrete commercial building, it was estimated that the cost of fire protection was 4.3% more than a similar building that did not have fire protection (does not include fire protection that is inherent in the structure) (Schaenman et al., 1994). From this study it was predicted that if this building had been made of steel instead of concrete the cost of fire protection would have been 11.4% more than a similar building with no fire protection present (Schaenman et al., 1994). Concrete has inherent passive fire protection and as a result the cost of active fire protection systems in a concrete structure is estimated to be 1.5 to 2.0 times greater than passive fire protection (Schaenman et al., 1994). For steel construction, more passive fire protection is required increasing passive costs to two times the cost of active fire protection (Schaenman et al., 1994). Table 22 shows the cost of the building and the cost of fire protection as a percentage of the building costs from a study conducted by NRC/Hanscomb Consultants (Schaenman et al., 1994). The

estimates shown in Table 22 do not include additional fees that can be incurred from the building's contents and electrical and mechanical systems (Schaenman et al., 1994).

Table 22: The cost of fire protection as a percentage of the total building cost (Schaenman et al., 1994).

Building type	Unit base price (\$/m ²)	Cost of fire protection (%)	Cost of passive fire protection (%)	Cost of active fire protection (%)
High-rise office building (concrete)	923.24	4.4	1.5	2.9
High-rise office building (steel)	893.10	11.4	8.4	3.0
Apartment building (concrete)	570.46	13.3	5.3	8.0

Silcock (1967 and 1968) describes two methods used to determine the cost of fire protection. The first method compares a building design with no regard to fire safety to one that is fire safe (Silcock, 1967). The second method separates the cost of fire protection from the cost of basic building construction. In reality, it is not possible to design a building that does not have some inherent fire protection. Silcock applies the second method to two case studies. The first case study shown in Table 23 describes a

shop that is 42,000 ft² (3,902 m²) and has two floors. The second case study, shown in Table 24, is based on three typical reinforced concrete slab type office blocks with staircases at each end of the blocks. Tables 23 and 24 provide some insight as to how the costs in Table 21 could have been calculated. Tables 23 and 24 also show that the cost of fire protection varies greatly with the different types of fire protection implemented in a building.

Table 23: Cost of fire protection for a two floor 42,000 ft² (3,902 m²) shop (Silcock, 1967).

Fire protection provided	Percentage of building cost (%)
Structural fire protection	
• Dry cladding (see Glossary)	0.83
• Non-fire resisting false ceiling, staircases, partitions and doors	0.62
Services	
• Fusible link dampers	0.50
• Smoke extraction	0.20
Egress	
• Staircases, doors, roof access, etc. ^A	0.40
Fire-fighting equipment and facilities	
• Sprinklers	2.20
• Hydrants, fire extinguishers, exit signs, etc.	0.30
Total	5.05

^A – Small number since a shop will contain many exits and entrances.

Table 24: Cost of fire protection for three typical reinforced concrete slab type office blocks with staircases at each end (Silcock, 1967).

Fire protection provided	Percentage of building cost (%)
Structural fire protection	
• Reinforced concrete frame ^A	0.00
• Enclosures, doors, roof accesses, etc.	0.10
Services	
• Ducting, shafts, fire stopping	0.10
Egress	
• Staircases, doors, etc.	0.70
Fire-fighting equipment and facilities	
• Hose reels, foam inlets, roadways, etc.	0.50
Total	1.40

^A – Normal requirement, therefore, given a value of zero.

When it comes time for a buyer to choose fire protection systems, the information based on the performance, reliability and cost of a particular system is lacking (Miller, 1974). There are however, three areas which must be examined prior to deciding the level of fire protection one requires. These areas include (Miller, 1974):

1. Identify hazards that need to be removed or increase the fire protection
2. Design a system that will perform to a predefined standard that is reliable and cost-effective
3. Have an independent party check to ensure that the fire protection systems are reliable

Maintenance costs are also important when selecting active fire protection systems.

Some maintenance costs are shown in Table 25.

Table 25: Maintenance costs of some fire protection equipment (Schaenman et al., 1994).

Components	Service life (Years)	Annual cost of maintenance
Smoke detectors ^A	5-7	\$0.3/m ²
Thermal detectors	8-10	\$0.2/m ²
Smoke detectors (attached to central alarm)	8-10	\$0.5/m ²
Sprinklers		
• Light hazard	-	\$0.2/m ²
• Ordinary hazard	-	\$0.3/m ²
Standpipe		
• Standpipe pump	-	\$150/unit
• Fire hose and extinguishers	-	\$0.1/m ²
Smoke control		
• Smoke control and stair pressurization	-	\$90 per fan per shaft
• Fans	-	\$40 per damper per floor

^A – Detector coverage 40 m²/detector. It is estimated that a building that has an area of 5,700 m² will need 430 smoke alarms (Schaenman et al., 1994).

2.7.1 Passive fire protection

The main duties of passive fire protection systems are to protect the building's structure if a fire occurs, as well as to prevent fire and smoke spread and allow sufficient time for the occupants to evacuate. Many fire protection systems have more than one use as is the case with fire separations and staircases which are not only used for the separation of rooms (fire separations) and exits/entrances (staircases) but are also used for controlling fire spread and for additional egress routes for the safety of the occupants (Nakamura, 1986). Many factors should be examined when evaluating passive fire resistance such as unprotected openings, any differences in the application of fire protection, and movement or loss of the fire protection (Lie, 1979).

Ideally, the amount of passive fire protection should be high even though sometimes this they may not be economically feasible (Lie, 1972b). By providing passive fire protection to structural members, although costly, the loss in strength of a member can be minimized (Lie, 1979). Structural fire protection is not justified economically when a building is less than three stories high and additional fire protection for these buildings is for life safety reasons only (Lie, 1979).

The cost of passive structural fire protection depends on many factors including type of protection material, amount of protection, and what is being protected (Lie, 1972b). For example, post-flashover fires, where the temperatures are high enough and cover a large area for a long period of time, will damage the ability of floors,

walls, doors, windows, and columns to operate in a functional way and therefore, illustrates the importance of implementing passive fire resistance (Babrauskas and Williamson, 1978).

2.7.2 Active fire protection

In this section, fire extinguishers, sprinklers, alarm systems, detectors and fire hose/standpipes systems will be examined. Special attention will be given to sprinklers as they are considered one of the most important active fire protection measures in reducing damage.

2.7.2.1 Fire Extinguishers

Fire extinguishers are used exclusively in the early stages of fire to prevent fire growth. They also become useful when dealing with fires such as electrical fires where water should not be used (Clark, 2000). It is up to the individual in the corresponding situation to decide if it is possible to extinguish the fire manually. Small fires can be handled by manual suppression with minimal risk to the occupant. The typical flow rate of discharge of an extinguisher is very small and it takes about 10 to 15 seconds to discharge all of the contents of an extinguisher (Dieken, 2000). An example of a fire that can be contained through manual extinguishment is a small confined waste paper basket fire. Four types of fire extinguishers are described in

Table 26. The types of extinguishers correspond to the class of fire in which they are used.

Table 26: Types of fire extinguishers (Blair, 1983).

Extinguisher type/fire type	Description	Contents of extinguisher
A	<ul style="list-style-type: none"> • For fires that involve dry combustibles 	<ul style="list-style-type: none"> • Water or weak chemical solution
B	<ul style="list-style-type: none"> • For fires that involve flammable liquids 	<ul style="list-style-type: none"> • Dry chemicals, foam or CO₂
C	<ul style="list-style-type: none"> • For electrical fires 	<ul style="list-style-type: none"> • Dry chemicals that are not conductive
ABC	<ul style="list-style-type: none"> • For A, B or C fire 	<ul style="list-style-type: none"> • Dry chemicals that are not conductive

2.7.2.2 Sprinklers

The use of sprinklers is one of the most, if not the most, important active fire protection measure. Sprinklers not only provide the means to control a fire in its early stages of growth but also provide a way to detect a fire which increases the time that occupants have to evacuate (Ramachandran, 1993). Automatic sprinklers are the only form of fire protection that will sound an alarm, fight the fire, and operate until

the fire is extinguished (Dittman, 1988). This section will provide a detailed look at sprinklers.

As mentioned previously, the purpose of sprinklers is to detect and control a fire that is in the initial growth stage before the fire can spread and cause more damage (Hasofer and Tat, 1997, Dieken, 2000). By controlling a fire in its infant stages, sprinklers reduce smoke ultimately lowering the cost of damages to both the external and internal cladding of a building (Dowling et al., 1993). Since sprinklers reduce property damage, they therefore make good investments.

There are many different types of sprinkler systems. For example, wet-pipe sprinkler systems are recommended by Factory Mutual Engineering and Research (1990) to protect such contents as paintings, drawings, etc. (Factory Mutual Engineering and Research, 1990). Pre-action systems have a reduced chance of being activated due to mechanical failure since their sprinklers are activated when smoke or heat is detected, only (Factory Mutual Engineering and Research, 1990). In supermarkets, 99% of sprinklers are wet-pipe sprinkler systems (Dittman, 1988). Dry-pipe systems are installed when freezing at the location is a concern (Dittman, 1988).

Sprinklers can also be used as an alternative to halon (see Glossary) systems in a computer environment and are the best alternative (Johnston, 1990) as halon has been phased out due to environmental concerns (Chattaway, 1997). The water from the

sprinklers does not seem to add to further corrosion of electrical equipment (Tewarson, 2003) and as a result, sprinklers provide an alternative to halon systems.

2.7.2.2.1 The Effect of having sprinklers

In one in ten fires, buildings with sprinklers will have a fire area that can grow to over 16 m², whereas in buildings without sprinklers, this figure jumps to 47 m² (Dowling et al., 1993). Sprinklers can reduce direct fire damage by 85% in some industries (Woodward, 1989) or, as suggested by Lie (1979), sprinklers can reduce damages caused by large fires by 50% or more. Statistically, sprinklers will detect and suppress a fire in more than 95% of all reported cases (Hadjisophocleous and Bénichou, 1999). Table 27 shows the sprinkler behaviour and the percentage of fires that cause heat damage to a building's structure in industrial and commercial sprinklered buildings in the United Kingdom. If sprinklers fail to control the fire or do not operate, the probability of damage to a building's structure, from heat, is 0.39 (Melinek, 1993).

Table 27: Sprinkler behaviour and the percentage of fires that cause heat damage to a building's structure in industrial and commercial sprinklered buildings in the United Kingdom (Melinek, 1993).

Sprinklers behaviour	Percentage of fires that cause heat damage to a building's structure (%)
Did not operate (fire is too small)	6
Extinguished fire	10
Controlled fire	30
Operated but failed to control fire	43
Did not operate (reasons other than fire was too small)	38
No indicated behaviour	20
All fires in sprinklered industrial and commercial buildings	17
All fires in unsprinklered industrial and commercial buildings	41

It is shown in Table 28 that in general, the presence of sprinklers will significantly decrease the losses in a fire. The types of construction shown in Table 28 are as follows: fire resistive, heavy timber, unprotected wood frame, protected wood frame, unprotected ordinary, protected ordinary, unprotected noncombustible and protected noncombustible. From the data in Table 28, it can be concluded that sprinklers do help in reducing property and structural damage. They also tend to reduce the average

losses in buildings with more than a single story (Melinek, 1993). It should be noted that in Table 28 it appears that when sprinklers are installed for unprotected wood frame buildings the losses due to fire increase. This result can be explained by the fact that unprotected wood frame buildings usually do not have sprinkler protection, and therefore since the sample size is small, a few large fires can skew the results (Canadian Wood Council, 2002).

Table 28: Percentage decrease in losses per fire when sprinklers are present versus not present (for 1989 to 1998) (Canadian Wood Council, 2002).

Type of construction ^A	Percentage decrease in losses per fire (%)
Fire resistive	23
Heavy timber	27
Protected noncombustible	43
Unprotected noncombustible	13
Protected ordinary	27
Unprotected ordinary	25
Protected wood frame	42
Unprotected wood frame	-2

^A – Type of construction definitions can be seen in National Fire Protection Association (NFPA) Standard 220. Definitions also provided in the Glossary.

Fontana et al. (1999) found from their study of 40,000 building fires in Switzerland that large fire losses were not found in buildings that had full sprinkler protection. Buildings that had partial or no sprinkler system experienced some fires that could not be controlled. It should be noted that care must be taken when comparing buildings that are sprinklered versus buildings that are not sprinklered since buildings with sprinklers may have different functions than those without sprinklers.

In many cases, the cost of indirect damage is large when no sprinklers are present. For example, if a fire is out of control and causes pollution, calculating the cost of the indirect damage that the fire is responsible for may prove difficult (Stephens, 1995).

2.7.2.2.2 The Operation of sprinklers

Sprinklers have little effect on fire until a fire reaches an area of about 3 m² (Melinek, 1993). It is at this size of fire that sprinklers are most useful in reducing the probability that a fire will grow over 100 m² (Melinek, 1993). Sprinklers will typically operate when the fire reaches an area of approximately 5 m² (Melinek, 1993).

The recommended operating temperatures for sprinklers depend on the maximum ceiling temperature conditions which may be encountered in a compartment under

normal conditions as shown in Table 29. Table 30 shows the different temperature classifications for sprinklers and their temperature ratings.

Table 29: Types of sprinklers, including maximum ceiling temperature and range of operation (Hasofer et al., 1997).

Type of sprinkler	Maximum normal ceiling temperature (°C)	Range of operation (°C)
Ordinary	37.8	54.0-73.9
Intermediate	65.6	79.4-100.0
High	>246	N/A

Table 30: Temperature class and temperature ratings (Clark, 2000).

Temperature Class (°C)	Temperature Rating (°C)
Ordinary	57-77
Intermediate	79-107
High	121-149
Extra high	163-191
Very extra high	204-246
Ultra high	260-302
Ultra high	343

2.7.2.2.3 The Reliability and effectiveness of sprinklers

Sprinklers are reliable and effective, and only in rare cases do they falsely activate. However, what is defined as reliable and effective may vary. Typically, reliability is defined as the ability of the system to operate as intended (i.e., sprinklers will activate if there is a fire) whereas effectiveness refers to the operation of the system in that the system will complete its intended task (i.e., sprinklers will control a fire if activated). The reliability of sprinklers can be estimated to be approximately 90% (Dowling et al., 1993). Bennetts and Thomas (2002) have suggested that effectiveness of sprinklers can be even greater than the combination of detectors and fire protection for construction. Table 31 shows the reliability of sprinklers. The effectiveness of sprinklers is shown in Table 32. It should be noted that the number of events in Table 31 is small and therefore the data might not be entirely representative. The chance that a sprinkler head (not the sprinkler system) may fail is very low. It is estimated that one in every 16 million sprinkler heads will fail (Dieken, 2000) which demonstrates that sprinklers are reliable. When examining statistics for fire protections systems, it is important to note that sometimes if a system works successfully, and a business does not want its insurance premiums to increase, a sprinkler activation may go unreported and therefore will not be included in the data set.

Table 31: Reliability of sprinkler systems (Dowling et al., 1993) and (Miller, 1974).

Source of information	Reliability (%)
Australia and New Zealand (1886-1968)	99.8
Australia and New Zealand (1968-1977)	99.3
FMRC ^A (1970-1972)	85.0
FMRC ^A (1970-1977)	86.1
NFPA ^B (1897-1924)	95.8
NFPA ^B (1925-1964)	96.2
NFPA ^B 1970-1974	96.2
U.S. Navy	94.8

^A – Factory Mutual Research Corporation.

^B – National Fire Protection Association.

Table 32: Effectiveness of sprinkler systems from 1970-1972 Factory Mutual Research Corporation data (Miller, 1974).

Sprinklers systems	Number of events	Effective (%)
Wet	1072	86
Dry	250	83
Deluge	24	63
Shut-in-winter	2	50
Open manual	1	00
Pre-action	1	100
Non-freeze	5	60
Total	1355	85

2.7.2.2.4 Accidental sprinkler activation

Although a major concern is that sprinklers will activate when there is no fire present, this probability is very low (one in 2.5 million systems) (Dieken, 2000). Table 33 describes the five conditions that must be considered when discussing accidental sprinkler activation.

The accidental discharging of sprinklers is mainly due to either human error or the design of the sprinkler system (Dowling et al., 1993). If sprinklers act early in a fire, the probability that the sprinklers will extinguish the fire is increased (Vining, 1985), however, increasing the sensitivity of the sprinklers may also increase false activations.

Table 33: Reasons for sprinkler activation in the absence of fire (Plant Engineering, 2001).

Condition	Description
Overheating	Sprinklers that are located close to heaters, skylights or other areas and can be exposed to higher temperatures, might overheat, and therefore, must install sprinklers that are rated for higher temperatures
Freezing	In wet-pipe systems, water in the pipes can freeze and break fittings, as well as cause valve caps to open which can lead to sprinkler discharge or leaking when thawing occurs
Mechanical damage	When installing and handling the sprinklers, damage can occur weakening the sprinkler system that can cause a malfunction at a later date
Deliberate sabotage	Can cause the sprinkler system to activate
Manufacturing defects	Very rare (<1,000,000/year (Dowling et al., 1993))

2.7.2.2.5 Cost of sprinklers

If a sprinkler system is designed to meet the requirements set out by an insurance company alone, the system may not be properly designed (Dittman, 1988). Although the system may comply with insurance company's requirements, it must also satisfy the requirements of the building code.

Sprinklers have an average life of 40 years in low-rise residential buildings and 45 years in high-rise residential buildings (IBI Group and Larden Muniak Consulting Inc., 1993). The capital savings due to the installation of sprinklers and the corresponding reduction in insurance rates in residential buildings was found to be \$0.38/ft² (\$4.09/m²) of the floor area of the building (IBI Group and Larden Muniak Consulting Inc., 1993). Marvin (1993) shows that by conducting a cost-benefit analysis on sprinklers, the cost involved in having a sprinkler system will be recovered in five years. After five years, having a sprinkler system is actually profitable for the owner because of reduced insurance premiums. Dittman (1988) states that due to the reduced insurance premiums as a result of having sprinklers, sprinklers will pay themselves off in three to five years. However there are exceptions, for example, it was found that in multi-unit residential buildings sprinklers were not cost-effective (Rousseau, 1996).

There are large variations in the cost of sprinkler systems due to the fact that different types of systems are installed and therefore, different considerations must be made (Dowling et al., 1993). These considerations can include factors such as: type of construction of the building, fire risk, water supply, amount of divisions in the building and the aesthetics of the building (i.e., if the sprinklers pipes are visible or not) (Dittman, 1988). In high-rise and low-rise residential buildings, design fees are 5.0% and 6.5% of the construction costs, respectively (IBI Group and Larden Muniak Consulting Inc., 1993). The cost of sprinklers in a commercial application is about

15% of the total installed cost (Vining, 1985). Generally, sprinklers, which are installed after the building is constructed, cost from 33% to 100% more than sprinklers which are installed during the construction phase of the building (Dittman, 1988).

Consideration must also be given to the maintenance of sprinkler systems which includes, servicing the systems regularly, cleaning, draining and repainting the system (McQueen, 2001). In a study performed by IBI Group and Larden Muniak Consulting Inc. (1993) on low-rise and high-rise residential buildings, testing and inspection costs were \$250 per year and \$950 per year, respectively where it was assumed that the replacement of sprinkler heads would be 5% of the initial cost in the 11th, 21st, 31st and 41st year of operation.

2.7.2.2.6 Water damage caused by sprinklers

There remains a public perception that sprinklers will cause more water damage than the damage that occurs from smoke and heat and that influences the decision to install sprinklers. A factor which influences sprinkler installation in a retrofit situation is the fact that there will be some interruptions during the installation of the sprinkler system (Factory Mutual Engineering and Research, 1990). In general, the idea that sprinklers will increase the damage when present than if not present is a misconception.

Hasofer and Tat (1997) surveyed the fire literature and found no quantitative model for water damage caused by sprinklers. The water damage that sprinklers cause is much less than damages that would have occurred from smoke and heat if sprinklers were not installed. This is due to the fact that most sprinkler systems (with the exception of deluge systems) will activate when the temperature rise of an individual head is high enough (Dowling et al., 1993). Hasofer and Tat (1997) made two different assumptions when dealing with sprinkler water damages. In the first they assumed that water damage is proportional to the integral over time of the water spray rate. The second assumption is that water damage is proportional to the integral of the square of the water spray rate. The second assumption is based on the view that water damage is minimal at the initial stages after activation of the sprinklers since the water used will be absorbed by the fire and vaporized into steam.

In a study done by Factory Mutual Research Corporation, it was shown that 56% of fires are controlled with three or less sprinklers heads which discharge water at a rate of 227 L/min (approximately 76 L/min/head) affecting an area of 37 m² (Dieken, 2000). In another study, it was shown that 60% of fires are controlled or extinguished by four or less sprinkler heads and that 95% of fires are controlled or extinguished by five sprinkler heads or less (Dowling et al., 1993).

In the case of a small fire, the damage from water may be greater than the damage caused by the fire as sprinklers will continue to operate until the sprinkler water

source is turned off by the fire department (Hasofer and Tat, 1997). Therefore, there is the possibility that the sprinklers will still operate even though the fire has been extinguished. Water damage from sprinklers will most certainly be less than the damage that is caused by the fire department's fire hoses (Marvin, 1993). The flow from a fire hose can be over 10 times greater than that of a sprinkler system (Dowling et al., 1993).

2.7.3 Alarm systems

Alarm systems are another important active fire protection measure. They provide an early indication of fire, which not only provides more time for occupant evacuation but also reduces damages since the arrival of the fire department will be sooner.

There are many types of fire alarm systems which include: conventional systems, digital addressable systems, analogue addressable systems and distributed intelligence systems (see Table 34) (DLE Engineering, 1998).

Table 34: Examples of different types of alarm systems (DLE Engineering, 1998).

Alarm systems	Description
Conventional systems	<ul style="list-style-type: none"> • Detectors trigger alarm when detector condition is greater than a defined threshold value and detectors are in zones, therefore, the fire zone will be identified • Used for low fire risk situations
Digital addressable systems	<ul style="list-style-type: none"> • Detectors trigger alarm when detector condition passes a defined threshold value and the exact location of the detector is sent back to the control panel • Used in buildings where fires can start where there are unoccupied or enclosed areas
Analogue addressable systems	<ul style="list-style-type: none"> • Used in high quality commercial buildings • Can identify exact location of device that activates alarm • Can have alerts so that the cause of the alarm can be determined before the fire department is called
Distributed intelligence systems	<ul style="list-style-type: none"> • Used in buildings that require accurate detection and where false alarms can have serious effects

If a system is over-designed, the initial cost, yearly costs and potential false alarms will increase (DLE Engineering, 1998). This is why when selecting a fire alarm system three factors should be considered: fire risk, factors that can interfere with the correct detection of a fire and effects of a false alarm (DLE Engineering, 1998).

Microprocessor-based alarm systems will add flexibility to alarm systems and can aid in reducing the cost of damage through automatic control of signals and shutoffs that control smoke movement (Woodford, 1988). Fontana et al. (1999) shows from a study of 40,000 building fires in Switzerland, that the fire loss in buildings that have automatic detection systems is less than in buildings with no active fire protection.

2.7.4 Detectors

The purpose of detectors is primarily for life-safety. If smoke detectors are fitted and spaced properly, they provide approximately one extra minute of escape time (Craig, 1990). The property protection that may ensue as a result of detector activation is seen as a plus. This influence on property damage occurs when building occupants are able to manually extinguish the fire (Craig, 1990) or the alarm system is activated which causes the fire department to arrive to the fire sooner. It can be expected that before the detectors are activated there will be some property damage (DLE Engineering, 1998).

There are many types of detectors which respond to either smoke, heat, or light (DLE Engineering, 1998). Detector false alarms can happen for many reasons which include high air velocities, high temperatures, humidity, and fumes (DLE Engineering, 1998). Flame detectors can provide the most rapid detection of flaming fires but do not detect smouldering fires (DLE Engineering, 1998) which can result in

an expensive cleanup. In the case of smouldering fires, which include synthetic materials, smoke is more concentrated and is more important to detect since it can cause more damage than the damage produced by heat (Chow and Wong, 1994). Smoke and heat detectors are never restored but replaced after a fire has occurred (Security Magazine, 2000).

2.7.5 Fire hose/standpipe

Generally there are three classes of standpipe systems. Class I is to be used by the fire department only and provides a minimum flow of 1,890 L/min and an extra 945 L/min for each additional riser (Clark, 2000). No hose is provided for Class I (Clark, 2000). Class II can be used by the fire department, as well as building occupants and provides a minimum flow of 378 L/min (Clark, 2000). A 1 inch (25 mm) or 1 ½ inch (38 mm) hose is provided for a Class II standpipe (Clark, 2000). A Class III system can be used by either the occupants of the building or the fire department but provides the same flow rate as Class I systems (Clark, 2000).

2.8 Literature correlations

In this section, correlations found in the literature relating to damages are discussed.

2.8.1 Probability of structural failure

The probability of structural failure of an element in office buildings is defined in equation (1). Equation (1) (Baldwin, 1974) can be readily used but is only applicable to an office building's structural elements and not the entire building. Different methods can be used to predict fire severity (see Glossary). However, the result is only as good as the assumptions made (Charters, 1998). To obtain the most accurate results, full-scale testing should be conducted however it can be costly and time consuming (Charters, 1998).

$$p_f = e^{\frac{-R}{S_0}} \quad (1)$$

p_f = Probability of failure of a structural element

R = Fire resistance of the structural element (min)

S_0 = Mean fire severity (min)

The mean fire severity S_0 is calculated by taking the mean of the distribution of the fire severity using a Monte Carlo simulation or a theoretical calculation.

2.8.2 Indirect losses

The indirect losses from fires are usually large when compared to direct losses. Equation (2) (Ramachandran, 1998) provides a correlation which determines the indirect losses for different occupancies (constants for equation (2) are shown in Table 35). Equation (2) is readily used if the direct losses are known. The definition of indirect losses varies and therefore, this model should be used with caution.

$$IL = c(DL)^b \quad (2)$$

IL = Indirect losses

c = Constant

DL = Direct losses

b = Constant

Table 35: Constants c and b for indirect losses correlation (Ramachandran, 1998).

Property type	c	b
Mercantile	0.109	0.889
Non-Manufacturing	0.069	0.874
Manufacturing	0.135	0.890
Warehouses	0.147	0.804

2.8.3 Corrosion rate

Corrosion in a telecommunications central office can be a result of burning cables and/or switch racks (see Glossary) (Tewarson, 2003). The corrosion rate for metal surfaces is shown in equation (3) (Tewarson, 2003). Equation (3) cannot be readily used to determine damages since it only applies to telecommunication offices and the relationship between corrosion rate and damage is not readily evident.

$$R_{corr} = \mu \cdot C_j^w \quad (3)$$

R_{corr} = Corrosion rate (angstrom (A) /min)

μ = Constant (2.02)

C_j = Concentration of the corrosive compounds (g/m³)

w = Constant (0.61)

2.8.4 Water requirements

In the following sections, different methods for determining water requirements for the extinguishment of a fire are discussed.

It has been suggested by Särqvist and Holmstedt (2000), in a study done in London that the flow rate required to extinguish a fire is proportional to the square root of the

fire area. Water requirements estimated for Great Britain and the United States are shown in equation (4) (Baldwin, 1970).

$$W = (1.24)A^{0.664} \quad (4)$$

W = Flow rate of water required to extinguish a fire (L/s)

A = Fire area (m²)

Water requirements estimated for Sweden are shown in equations (5-7) (Bengtson and Laufke, 1979/1980), where three different categories of water flow rate are described.

$$W_{\text{minimum}} = (0.06)A^{0.664} \quad (5)$$

$$W_{\text{average}} = (0.30)A^{0.664} \quad (6)$$

$$W_{\text{maximum}} = (1.40)A^{0.664} \quad (7)$$

W_{minimum} = Minimum flow rate of water required to extinguish a fire (L/s)

W_{average} = Average flow rate of water required to extinguish a fire (L/s)

W_{maximum} = Maximum flow rate of water required to extinguish a fire (L/s)

A = Fire area (m²)

The Insurance Service Office method is shown in equation (8) (Anderson, 1986 and Linder, 1981).

$$NFF_i = (C_i)(O_i)(X + P)_i \quad (8)$$

NFF_i = Needed fire flow for part i of building

C_i = Building construction factor for part i of building

O_i = Occupancy factor for part i of building

X_i = Adjacent exposed buildings factor for part i of building

P_i = Communication paths within buildings factor for part i of building

The method in equation (8) takes into consideration parts of the building that have different characteristics by using a weighted average corresponding to the size of the part of the building.

The Iowa State University method is shown equation (9) (Royer and Floyd).

$$\dot{W} = \frac{V}{0.75} \quad (9)$$

$\dot{W}$ = Flow rate of water required to extinguish a fire (L/min)

V = Volume of air in the building (m^3)

The Illinois Institute of Technology method used for residential occupancies is shown equation (10) (Linder, 1981).

$$\dot{W} = 0.0395A^2 + 20.38A \quad (10)$$

$\dot{W}$ = Flow rate of water required to extinguish a fire (L/min)

A = Fire area (m^2)

The New Zealand Fire Engineering Design Guide method to determine the flow rate of water is shown in equation (11) (Buchanan, 1994).

$$\dot{W} = \frac{\dot{Q}}{\eta_{ab} \cdot Q_w} \quad (11)$$

$\dot{W}$ = Flow rate of water required to extinguish a fire (L/s)

$\dot{Q}$ = Heat release rate of the fire (MW)

η_{ab} = Efficiency that the water absorbs energy from the fire ($0 < \eta_{ab} < 1$)

Q_w = Theoretical energy absorption rate of water (2.605 MW/L/s)

Equations (4-11) are all feasible ways to determine the flow rate of water to extinguish a fire in given area, however, they do not consider the length of time this flow rate must be maintained to extinguish the fire. The total amount of water that affects the contents of a compartment is an important variable in determining the damage to the contents. A variation of equation (11) is used to determine the amount of water applied in a fire and is shown in Chapter 5 (Methodology).

2.8.5 Optimal economical level of safety

The model shown in equation (12) can be used to find the expected property damage proposed by Baldwin and Thomas (1973) and is shown in its entirety in Bengtson and

Laufke (1979/1980). The damages and probabilities in equation (12) are not readily available making this model difficult to use.

$$E = p_y (1 - p_2)(1 - p_1 \cdot p_3)S_1 + p_y (1 - p_2)(p_1 \cdot p_3 \cdot S_2) + (p_y \cdot p_2)(1 - p_0 \cdot p_3)S_3 + (p_0 \cdot p_2 \cdot p_3 \cdot S_4) \quad (12)$$

E = Expected damage to property

p_y = Probability of a fire occurring in a building per year

p_2 = Probability that the active fire protection systems fail when a fire occurs

p_1 = Probability that the structure becomes damaged due to the inability of the active fire protection systems to control the fire

p_3 = Probability that the structure becomes damaged due to the failure of passive fire protection

S_1 = Corresponding cost of the fire damage related to given probabilities

S_2 = Corresponding cost of the fire damage related to given probabilities

p_0 = Probability that structure becomes damaged due to the absence or failure of active fire protection systems

S_3 = Corresponding cost of the fire damage to related given probabilities

S_4 = Corresponding cost of the fire damage to related given probabilities

The variables S_1 , S_2 , S_3 and S_4 are not well defined by Bengtson and Laufke (1979/1980).

2.8.6 Property damage

Property damage (PD) can be defined by equation (13).

$$PD = (\theta \cdot FD) + (\phi \cdot WD) \quad (13)$$

PD = Property damage

θ = Calibration factor

FD = Damage caused by flames

ϕ = Calibration factor

WD = Water damage

(Hasofer and Tat, 1997)

The above model does not consider smoke damage. Smoke damage can include corrosion, discoloration (contents and linings), odour (contents and linings) and electrical damages (Watts, 2001). The calibration factors (θ, ϕ) are not readily available.

Flame damage can be defined by equation (14).

$$A(t) = A(0)\exp[\beta_a t_a + \beta_b t_b] \quad (14)$$

$A(t)$ = Damaged floor area in t minutes from ignition

$A(0)$ = Initial floor area ignited

β_a = Fire growth parameter

t_a = Time from ignition to when fire department arrives

β_b = Fire growth parameter

t_b = Time from when the fire department arrives to when the fire is under control

(Ramachandran, 1986)

Hasofer and Tat (1997) proposed the use of equation (15) when sprinklers are present.

$$A(t) = A(0)\exp[\beta_i t_i + \beta_s t_s] \quad (15)$$

$A(t)$ = Damaged floor area in t minutes from ignition

$A(0)$ = Initial floor area ignited

β_i = Fire growth parameter

t_i = Time from ignition to when sprinklers activate

β_s = Fire growth parameter

t_s = Time from when sprinklers activate to when fire is extinguished

The parameters in both equations (14) and (15) are not readily available and are difficult to estimate.

2.8.7 Monetary Loss Expectation

A model has been developed by Lie (1979) to calculate the monetary loss expectation which takes into account the loss of contents, indirect losses, insurance, cost of fire suppression systems and cost to repair damages.

The model is based upon three assumptions.

1. Losses are proportional to the area that is involved in the fire
2. If there is structural failure, it is assumed that a part or all of the building is to be replaced and that the value of the building is the depreciated value (using a linear relationship for depreciation)
3. If there is no structural failure, it is assumed that the loss is only to the compartment where the fire originated and that the loss will be small.

Equation (16) is the model developed by Lie (1979) for the monetary loss expectation.

$$MLE = K_1 [1 - \exp(-(\alpha + i - f)t_D)] + K_2 [1 - \exp(-(p_m + i - f)t_D)] + K_3 \quad (16)$$

Where K_1 , K_2 and K_3 are defined by equations (17), (18) and (19).

$$K_1 = \left(\frac{N_L}{N_C} \right) \left(\frac{\alpha}{\alpha + 1} \right) \left[m - \frac{1}{t_D(\alpha + 1)} A_B (C_{BF} + C_{FPF}) \right] \quad (17)$$

$$K_2 = \left(\frac{1}{N_C} \right) \left(\frac{p_m}{p_m + 1} \right) (1 - p_{sf}) [(m + 1) A_B (C_{BF} + C_{FPF})] \quad (18)$$

$$K_3 = \left(\frac{N_L}{N_C} \right) \left(\frac{\alpha}{\alpha + 1} \right) A_B (C_{BF} + C_{FPF}) \quad (19)$$

MLE = Monetary loss expectation

α = $p_{sf} \cdot p_m$ = Mean number of failures per unit time

p_{sf} = Conditional probability of structural failure given a large fire

p_m = $N \cdot A_B$ = Mean rate of occurrence of large fires

N = Mean number of large fires per unit floor area of the building per unit time

A_B = Total floor area of the building

i = Interest rate as a fraction

f = Inflation rate as a fraction

t_D = Planned service life of the building

N_L = Number of compartments lost by fire

N_C = Number of compartments in the building

m = Ratio of the sum of loss of contents and indirect losses to the building

C_{BF} = Cost of building per unit floor area not including fire protection

C_{FPF} = Cost of fire protection measures per unit floor area of the building

The derivation of the above equations is shown in Lie (1972b). Although Lie's (1979) model is based on sound principles, some of the parameters are not easily estimated or readily found.

2.8.8 Cost index factor

A loss cost index has been provided by Platt et al., (1994), which can be used to compare different fire scenarios. The model is shown in equation (20).

The model is based on four assumptions.

1. Damages can only occur in the compartments that have been exposed to the fire
2. Damage is proportional to the floor area
3. When fire reaches a compartment, the compartment is assumed to be entirely damaged
4. The total damage to a building is the combination of damage of the individual compartments

$$CI_L = \frac{100(P/A, r, N)}{A_B} (1 + \lambda + \beta)(\gamma + \varphi) \sum_{\text{for all } j} A_{F_j} \cdot P(\text{FireIn}_j) \quad (20)$$

CI_L = Loss cost index

$(P/A, r, N)$ = Continuous uniform series present worth factor as defined by equation (21)

A_B = Total floor area of the building (m²)

λ = Cost of passive fire protection as a ratio of the capital value of the building

β = Capital value of the sprinklers as a ratio of the capital value of the building

γ = Indirect loss as a ratio of the capital value of the building

φ = Repair cost as a ratio of the capital value of the building

A_{F_j} = Floor area of compartment j (m^2)

$P(\text{FireIn}_j)$ = Probability that during the year, compartment j experiences a fire

Equation (21) is used to determine the present worth of expected losses using continuous compounding of interest (see Glossary).

$$(P/A, r, N) = \frac{e^{rN} - 1}{e^{rN}(e^r - 1)} \quad (21)$$

$(P/A, r, N)$ = Continuous uniform series present worth factor

r = Nominal annual interest rate as a fraction

N = Design life of the building (years)

If all of the above parameters are readily available, the model provides a good means of comparing different fire scenarios but should only be used to compare fire scenarios and not for absolute estimates of damages.

2.9 Summary

From the literature, it is shown that more research should be done to calculate the expected losses from fires. Losses should be more specific and not just estimates of the country's overall projected losses due to fire. Water and smoke damage will be a major factor if a fire occurs, therefore, more research should be done to deduce the

impact of smoke and water on a building and its contents. More research should also be done in relation to property protection. Most of the correlations found in the literature cannot be used due to the fact that the variables, parameters and constants in the equations are either not readily determined or estimated.

3.0 DESCRIPTION OF THE ECONOMIC COMPUTER MODEL

The economic computer model is a sub-model of a fire hazard and fire risk analysis computer model that is being developed at Carleton University¹. Figure 1 shows the models that are part of the fire hazard and fire risk analysis computer model and the relationships that exist between the sub-models. The economic loss and the building costs sub-models form the economic model and are shown in grey in Figure 1. The output of the economic computer model is used by the fire cost expectation computer module to perform a cost-effectiveness analysis. The economic computer model implemented uses the programming language Visual Basic 6.0.

A general outline of the input and output files of the economic computer model are shown in Appendix A. Figure 2 shows the input and output files of the economic computer model.

The economic computer model requires several inputs from the user which must be known at the time the model is run. Default values are provided to the user so that the model can still run even though the user does not know the precise input. These default values are obtained from the literature, current cost estimates and/or engineering judgement and are shown in Appendix B.

¹ Carleton University – Department of Civil and Environmental Engineering,
1125 Colonel By Drive Ottawa Ontario K1S 5B6 Canada

The output of the economic computer model includes the total cost of the building, fire protection systems and contents, the total annual cost for maintenance, inspection and replacement of active fire protection systems and emergency systems, and the total cost of damages and downtime for each compartment.

The economic computer model uses information from other sub-models of the fire hazard and fire risk analysis computer model. Information needed from other sub-models for each compartment include:

- Temperature data (for temperature damage)
- Smoke concentration data (for smoke damage)
- Heat release rate of the fire data (for water damage)
- Dimensions of the compartment
- Initial temperatures in the compartment

Figure 1: The relationship between the fire hazard and fire risk analysis computer model and the economic computer model.

Figure 2: Input and output files for the economic computer model.

3.1 Components of the economic computer model

Background information will be given on all of the major inputs used in the economic computer model including building components, fire protection systems, and building contents.

3.1.1 Building components details

The building components are described in relation to the economic computer model. A brief background will be given on five areas that are thought to be the most representative of the building components. The five areas that comprise the building components are listed below and are described in Table 36:

- Site development
- Substructure
- Roof
- Stairs
- Services

Table 36: Description of building components.

Building component	Description
Site development	<ul style="list-style-type: none">• Cost of arranging the construction site layout• Cost of site remediation• Details on how the construction site can work in terms of wastes and paths to areas within the site• Capital cost of the land
Substructure	<ul style="list-style-type: none">• Cost of foundation, slabs, excavation for the basements and the basement walls
Roof	<ul style="list-style-type: none">• Cost of roof construction• Cost of finishing the roof• Cost of openings needed in the roof
Stairs	<ul style="list-style-type: none">• Cost of stairs
Services	<ul style="list-style-type: none">• Cost of electrical services, water management, plumbing fixtures, security, elevators and escalators

Interior wall assemblies, exterior wall assemblies, floor assemblies, ceiling assemblies, doors and windows are not considered as part of the building components but are considered as basic building construction and additional passive fire protection.

3.1.2 Background to fire protection systems

In this section, a brief background to the components of the active fire protection systems, the passive fire protection systems and the emergency systems will be given. Emergency systems will be considered as part of the fire protection systems. Some components of the passive fire protection systems will be described with regards to individual compartments because this format is used in the economic computer model input files.

3.1.2.1 Description of active fire protection systems

A brief description of all of the active fire protection systems in the economic computer model will be shown. All of the components of the active fire protection systems are shown in Figure 3 and are described in Table 37. The economic computer model uses the most common types of active fire protection systems and their descriptions are shown in Table 37. These descriptions have been obtained from the Canadian Fire Alarm Association (1992), personal correspondence (Kuffner, 2003b) and common knowledge.

Figure 3: Tree diagram of the active fire protection systems in the economic computer model.

Table 37: Description of active fire protection systems.

Component	Description
<i>Alarm systems</i>	
Single stage	All alarm signals will be set off when the alarm activates.
Dual stage	In the first stage, alarm will set off a warning signal. In the second stage, alarm signal will be set off (can be manual or automatic activation).
Other components	
• Manual pull bar stations	Located on walls and are used to activate the alarm in case of fire. Useful if occupants detect a fire.
• Voice communications	System which allows information to be given to occupants through speakers.
• Emergency telephone system	Telephone that can be used in case of an emergency.
• Speaker or mini-horn/alarm bell	Equipment used to give information to the occupants or to sound warnings.
<i>Detection systems</i>	
Heat detectors	
• Dual action	Activates when there is an increase in the rate of temperature rise (i.e., 6°C/min) or will activate when the air reaches a certain temperature.
• Fixed temperature	Activates when the air temperature reaches a certain temperature (i.e., 57°C and 90°C are the most common trigger levels). Used in a space where there might be high normal temperatures.
• Line or strip type	Detects over a length usually made up of two cables that when heated come together causing activation.

Table 37 continued...

Component	Description
Smoke detectors	
• Beam	Good for large areas up to a distance of 100 m. A transmitter is on one wall while a receiver is on another wall. Will activate if smoke disrupts the communication between the transmitter and the receiver.
• Photoelectric	Smoke enters the sensing chamber and blocks the light source in the chamber to reach the light sensor causing activation.
• Ionization	Detects aerosols as a result of the combustion process which changes the flow of electrical current in the sensing chamber causing activation.
<i>Suppression Systems</i>	
Manual extinguishers	
• Type A	Manually operated device used for extinguishing small class A fires.
• Type B	Manually operated device used for extinguishing small class B fires.
• Type C	Manually operated device used for extinguishing small class C fires.
• Type ABC	Manually operated device used for extinguishing small class A, B or C fires.
Fire hose/standpipes	Cabinets seen throughout building which contain hoses and nozzles that can be used to extinguish fires.
Kitchen hood extinguishing systems	Common in commercial applications and usually not installed in residential occupancies. Most fires in commercial buildings are from commercial cooking equipment.
Sprinklers	
• Dry-pipe	Does not contain water in sprinklers pipes. Good for areas where freezing of the pipes can be a problem.
• Wet-pipe	Contains water under pressure in sprinkler pipes.
• Deluge	All sprinkler heads will open when activated. Good for hazardous occupancies.
• Pre-action	Water may or may not be under pressure in sprinkler pipes. Sprinklers will activate when a smoke or heat detector detects the fire. Good for areas where water damage can be a problem.

Table 37 continued...

Component	Description
Other costs	
• Supply	Basic water and pressure supply for sprinklers systems.
• Pressure tanks	Used when local water supply is not adequate or when the pressure is too low.
• Elevated gravity tanks	Used to supply the sprinkler system with adequate water and water pressure.
• Fire pumps	Used to provide the sprinkler systems with adequate water and water pressure.
Smoke control management systems	
Smoke management systems	
• Atrium smoke exhaust	Used to exhaust smoke to the outside of the building.
Smoke control systems	
• Elevator shaft pressurization	Pressurization system used to prevent smoke from spreading via the elevator shaft.
• Stair shaft pressurization	Pressurization system used to prevent smoke from entering the stair shaft.
• Zone pressurization	Pressurization system used to prevent smoke from spreading into defined zones.

3.1.2.2 Description of passive fire protection systems

Most of the passive fire protection systems are considered on a compartment by compartment basis. This is due to the fact that the calculation of the damages to the building components and to the other systems (active, passive² and emergency) is

² Applied to the whole building (i.e., egress routes). Not including additional passive fire protection.

based on the damage to each individual compartment. Wall, floor and ceiling assemblies, as well as doors and windows are considered as part of the basic building construction but since they may have more than an inherent fire resistance they are also considered as part of the passive fire protection systems. Figure 4 shows the different components of the passive fire protection systems. The cost of egress routes will be calculated for the entire building instead of by a compartmental basis.

*Compartment_i refers to each compartment of the building

Figure 4: Tree diagram of passive fire protection components.

3.1.2.3 Description of emergency systems

The emergency systems that are considered in the economic computer model shown in the tree diagram in Figure 5 are emergency lighting, exit signs and posted emergency floor plans. Emergency systems are considered as part of the fire protection systems.

Figure 5: Tree diagram of emergency systems.

3.1.3 Building contents

The contents of the building are considered in the calculation of the expected damages if a fire occurs in the building. Contents are categorized by their sensitivities to temperature, smoke, and water. For example, if there is a fire that involves polypropylene in a clean room of a microelectronics manufacturing plant, the smoke released will cause a significant amount of damage as compared to the damage that smoke causes to books in a compartment. Also, other contents may vary in their sensitivity to smoke.

The contents of the building are divided into 11 major categories. The user will be given the option to add more content categories. Even though the user is given flexibility to add content categories, other categories might not be needed if the contents in other categories have similar sensitivities to temperature, smoke and water. In the case of contents of major cost which do not fit into the predefined categories, the user may consider those items individually. These 11 major categories include books, electronic equipment, clothes, food, appliances, upholstered furniture, wood furniture, plastics, machinery, interior linings and finishes, as well as lighting which are defined in Table 38. The categories developed include contents that could readily be found in commercial buildings where each category is grouped so that the total value of the contents in an individual category is over \$1,000.

Table 38: Typical contents in different content categories.

Content Category	Typical contents
1. Books	<ul style="list-style-type: none">• Includes all paper and cardboard products
2. Electronic equipment	<ul style="list-style-type: none">• Includes computers, stereos, televisions, radios, etc.
3. Clothes	<ul style="list-style-type: none">• Includes anything made out of textile materials not including furniture or interior linings
4. Food	<ul style="list-style-type: none">• Includes all edible items
5. Appliances	<ul style="list-style-type: none">• Includes major appliances such as refrigerators, stoves, microwave ovens, toaster ovens, etc.
6. Upholstered furniture	<ul style="list-style-type: none">• Includes all furniture that is covered by textile materials such as beds, couches, etc.
7. Wood furniture	<ul style="list-style-type: none">• Includes all items made of wood
8. Plastics	<ul style="list-style-type: none">• Includes all items made out of plastic that do not fit in the other categories
9. Machinery	<ul style="list-style-type: none">• Includes cash register, special equipment, etc.
10. Interior linings and finishes	<ul style="list-style-type: none">• Includes linings and finishes to walls, floors and ceilings (can also include false ceilings)
11. Lighting	<ul style="list-style-type: none">• Includes lighting fixtures

3.1.4 Downtime

In the event of a fire, there can be a period where, for example, the retailer cannot operate due to the fact that repairs of fire damages will have to be done to the retail space. The time that it takes for a retailer to resume normal operations after a fire has occurred is called downtime. The economic computer model calculates downtime and the resultant economic loss.

3.1.5 Damages

There are many factors that can affect the amount of damage that occurs in a building in the event of a fire. The following list represents the most important factors affecting the level of damage that can occur to a building and its contents.

- 1) Size of the fire.
- 2) Location of the fire (i.e., if the fire is in the middle of the room, corner, etc.).
- 3) Radiant heat fluxes (from fire or hot upper layer).
- 4) The floor that the fire occurs on.
- 5) Type of materials involved in the fire.
- 6) Availability of a sprinkler system.
- 7) Time that it takes for the fire department to arrive.
- 8) Type of building construction (i.e., concrete, wood, steel).
- 9) Amount of water used to extinguish the fire.
- 10) Extent of fire spread.

- 11) Contents' and fire protection systems' sensitivity to temperature, smoke and water damage.
- 12) Water spread due to the activation of sprinkler systems or due to fire department operations. For example, if sprinklers are activated on the seventh floor of the building, the water will travel downward and the floors underneath could potentially suffer water damage.
- 13) The combination of moisture and the products of combustion. For example, if (polyvinylchloride) PVC is burned, the products of the combustion process combine with the moisture in the air to form hydrochloric acid. The gaseous hydrochloric acid may damage electronic equipment, metallic surfaces and may also cause yellowing of plastics.
- 14) Time of year that the fire occurs. For example, if a small fire occurs in the winter, and the fire is extinguished, the porous materials will have their pores closed until it gets warmer at which point they may open releasing bad odours.

Items 1) to 8) in the above list are considered in the smoke computer model and are implicitly considered in the economic computer model. Items 8) to 11) of the above list are considered explicitly by the economic computer model. Items 12) to 14) of the above list are not considered by the economic or smoke computer models and will be left for future consideration. The relationships between the items in the list, the smoke computer model and economic computer model are shown in Figure 6.

Figure 6: Relationship between the smoke computer model and the economic computer model.

4.0 INPUT DATA FOR THE ECONOMIC COMPUTER MODEL

In order for the economic computer model to run, input data is needed from either the user or from the list of default values provided. Six input data areas will be explored in great detail, which include: building components, active fire protection, passive fire protection, emergency systems, building contents and general input data. Some of the data collected are not used directly in the economic computer model but will be used by other components of the fire hazard and fire risk analysis computer model (i.e., fire cost expectation computer module). The capital and labour costs should be entered in \$/ft² as this is the format which is used by the economic computer model. Input estimates are shown in Appendix B.

4.1 Building components inputs

The building component inputs all have the same general format. The inputs for the building components are as follows:

- Capital costs and labour costs (\$/ft²) ($C_{CA} + L_C$)
- Contingency fees (% of $C_{CA} + L_C$)
- Retrofit factor (% of $C_{CA} + L_C$)
- Replacement time (days)
- Downtime factor (a factor between zero and one inclusive)

Definitions of the inputs are shown in Table 39. There is one exception to the general format of the inputs and that is for the site development category which should only have fields for the capital cost, retrofit factor and contingencies since the other input fields are not practical.

4.2 Active fire protection systems and emergency systems inputs

For active fire protection systems and emergency systems inputs, the following input data are needed (definitions of the inputs are described in Table 39):

- Number of components or area of operation (number of components or ft²)
- Capital cost C_{CA} (\$/component or \$/ft²)
- Labour cost L_C (\$/component or \$/ft²)
- Contingency fees (% of $C_{CA} + L_C$)
- Commissions / testing fees (% of $C_{CA} + L_C$)
- Design and other fees (% of $C_{CA} + L_C$)
- Retrofit factor (% of $C_{CA} + L_C$)
- Annual maintenance cost (\$/year)
- Annual inspection cost (\$/year)
- Annual replacement cost (\$/year)
- Replacement time (days)
- Downtime factor (a factor between zero and one, inclusive)

- Temperature threshold category
- Smoke threshold category
- Water threshold category

For each fire protection system there is an upper threshold and a lower threshold with respect to temperature, smoke and water which corresponds to a given sensitivity.

The units of the thresholds for temperature, smoke, and water that are used in the economic computer model are listed in Table 40.

Table 39: Description of various inputs for building components and fire protection systems components.

Input	Definition
Capital cost	Initial amount of money (capital) that is needed.
Labour cost	Amount of money needed to install various components.
Contingency fees	Reserve fund set aside for occurrences where an underestimate of the final cost of the component is made.
Commissions/testing fees	Cost associated with the verification that the component is either built or installed correctly and is functional (as is the case with most active and emergency systems).
Design and other fees	Cost associated with the design of the component and other costs that do not fit into the other input fields.
Retrofit factor	Factor that is used if the component already exists and must be upgraded or if the component is to be added to a building (i.e., adding sprinklers to a building that has already been constructed).
Annual maintenance cost	Cost associated with the upkeep of the component.
Annual inspection cost	Cost to ensure that the component meets the required standard(s) for functionality.
Annual replacement cost	Cost associated with the replacement of a component.
Downtime factor	The importance of the component in relation to the entire business (i.e., if component X is not repaired, the business will not resume normal operations after a fire, which corresponds to a high downtime factor).
Replacement time	Amount of time that is needed to replace the component.

Table 40: Temperature, smoke and water threshold units.

Threshold	Threshold units
Temperature	(°C)
Smoke	(ppm) ^A
Water	(L/m ²)

^A – Calculated using a mass basis.

For the costs of fire protection systems, the user can choose a lumped sum cost or if specific data are available, the user can use individual costs to get a more accurate estimate. A tree diagram showing the available cost options is shown in Figure 7.

Figure 7: Tree diagram of available cost options.

4.3 Passive fire protection inputs

The inputs for passive fire protection components are on a compartment by compartment basis with the exception of the egress routes which have the same inputs as active fire protection systems. Egress routes follow the same cost template as outlined in section 4.2.

The passive fire protection components inputs by compartment are the following:

- Four wall assemblies (East, West, North, South)
- Floor assembly
- Ceiling assembly
- Doors
- Windows

The inputs for each component are as follows:

- Area or amount (ft² or number of doors or windows)
- Cost (\$/ft² or \$/door or \$/window)
- Fire Resistance Rating (see Glossary) or fire rating (see Glossary) of component (minutes)
- Replacement time (days)
- Downtime factor (a factor between zero and one inclusive)

4.4 Building contents inputs

In this section the input values pertaining to the building contents will be discussed.

The contents of the building have a capital cost, as well as temperature, smoke and water thresholds. For each category of contents there is an upper threshold and a lower threshold. The units of the thresholds for temperature, smoke, and water that are used in the economic computer model are listed in Table 40. If possible, the cost

of the contents will be the actual cost of the contents (i.e., the depreciated cost of the contents and not the original cost of the contents) but it will be up to the user to estimate this cost.

4.5 General data inputs

The general data inputs are separated into three sections which include: the economic factors, building characteristics and extinguishment which are shown in Table 41.

Table 41: Description of the different general data inputs.

General data	Description
Economic factors	
• Inflation rate	Inflation rate (%) will be used in the fire cost expectation computer module to perform a cost-benefit analysis.
• Interest rate	Interest rate (%) will be used in the fire cost expectation computer module to perform a cost-benefit analysis.
• Downtime cost	Downtime cost is the cost of not having a business operational, cost of legal fees, etc. per day (\$/day).
• Rush construction factor	Factor used to increase the total amount of damages used to repair the building so that businesses can go back to normal operating conditions sooner.
• Reduction of downtime factor	Factor used to decrease the total cost of downtime associated with rush construction to get back to normal operating conditions sooner.
Building characteristics	
• Building component calibration factor	Factor used to adjust the probability of damage to building components.
• Building life	Time that the building is expected to be useful which will be used in the fire cost expectation computer module (years).
• Floor area	Floor area of the entire building (m ²).
• Building construction calibration factor	Factor used to adjust the probability of damage to basic building construction including additional passive fire protection.
Extinguishment	
• Efficiency of extinguishment	Fraction used to determine how efficient the water is to extinguish the fire.
• Specific heat capacity of water	Property needed to determine the amount of water needed to extinguish the fire (kJ/kg°C).
• Heat of vaporization of water	Property needed to determine the amount of water needed to extinguish the fire (kJ/kg).
• Temperature change	Temperature change of water from a liquid to a gas (i.e., from 20°C to 100°C).
• Extinguishment calibration factor	Factor used to adjust the amount of water calculated to extinguish the fire.

Table 41 continued...

General data	Description
Basic costs	
• Walls	Basic wall assembly cost for East, West, North and South walls (\$/ft ²).
• Ceiling	Basic ceiling assembly cost (\$/ft ²).
• Floor	Basic floor assembly cost (\$/ft ²).
• Doors	Basic door cost (\$/door).
• Windows	Basic window cost (\$/window).

5.0 METHODOLOGY

The methodology used to develop the economic computer model is described in this chapter. The initial costs, damages and downtime as a result of a fire are described in this chapter in relation to building construction, fire protection systems, and building contents. Metric units are not used since North American construction is still performed in imperial units. The methodology described was implemented using the programming language Visual Basic 6.0. The description of the computer code developed and user manual to the economic computer model can be seen in the Carleton University report entitled "Supplemental material to thesis: Economic Impact of Fires in Buildings" by Esposito (2004).

5.1 Cost of the building

The initial costs of the building can be separated into four categories which are as follows: cost of building construction, cost of additional passive fire protection, cost of contents (including finishes) and cost of fire protections systems (does not include additional passive fire protection). Therefore, equation (22) represents the total cost of a building.

$$C_{Total} = C_{Building} + C_{FP} + C_{TFPC} + C_{Contents} \quad (22)$$

C_{Total} = Total cost of the building (\$)

$C_{Building}$ = Cost of building construction (\$)

C_{FP} = Cost of fire protection systems (\$)

C_{TFPC} = Total cost of additional passive fire protection in the building (\$)

$C_{Contents}$ = Cost of the contents of the building (\$)

There are also annual costs associated with the fire protection systems in a building which are represented by equation (23).

$$C_Y = \sum_{i=1}^n C_{Y_i} \quad (23)$$

C_Y = Total annual cost of fire protection systems (\$/year)

n = Number of fire protection system components with annual costs

C_{Y_i} = Annual cost of fire protection system component i (\$/year)

5.1.1 Initial costs of building construction

The economic computer model allows the user to define the cost of a basic wall assembly, floor assembly, ceiling assembly, door or window. The basic cost is defined as the cost associated with the simplest form of the assembly, door or window

and any additional cost being used to increase the fire resistance of an assembly, door or window is considered as additional passive fire protection. The wall, ceiling and floor assemblies, as well as the windows and doors have an inherent fire resistance. Every assembly has a Fire Resistance Rating (FRR), which is the amount of time that an assembly can withstand a standard fire in testing. Doors and windows have a fire rating which is similar to the FRR. Special testing is done to determine the FRR of assemblies, as well as the fire rating of doors and windows. In Canada, the standard that is used to determine the FRR is CAN/ULC (Underwriters' Laboratories of Canada)-S101-M89 which is based on ASTM (American Society for Testing and Materials) E119 (Buchanan, 2002). There are three failure criteria used to determine the FRR which are stability, integrity and insulation (Buchanan, 2002). For stability, the test specimen (assembly) must carry all applied loads and not collapse (Buchanan, 2002). For integrity, the assembly must not allow hot gases to pass through the test specimen (assembly). For insulation, the cold side of the test specimen (assembly) must not go over a certain temperature (Buchanan, 2002).

Example

The cost of a basic wall which has a FRR of 30 minutes is \$80 but the wall that is placed in the compartment has a FRR of 60 minutes at a cost of \$120. Therefore, the cost of basic construction is \$80 and the cost of additional passive fire protection is \$40 (\$120 minus \$80).

Equation (24) shows the calculation for the cost of building construction, which is the sum of the cost of the building components plus the cost of basic building construction.

$$C_{Building} = \sum_{i=1}^n C_{BC_i} + \sum_{i=1}^r C_{BBC_i} \quad (24)$$

$C_{Building}$ = Cost of building construction (\$)

n = Number of building components

C_{BC_i} = Cost of building component i (\$)

r = Number of basic building components

C_{BBC_i} = Cost of basic building construction component i (\$)

When calculating the initial cost of building components, equation (25) is used.

$$C_{BC_i} = (C_{CA_i} + L_{C_i}) \left[1 + \frac{CF_i + CT_i + DO_i + f_{R_i}}{100} \right] \quad (25)$$

C_{BC_i} = Cost of building component i (\$)

C_{CA_i} = Capital cost of building component i (\$/ft² or \$/component)

L_{C_i} = Labour cost of building component i (\$/ft² or \$/component)

CF_i = Contingency fees for building component i (% of total capital and labour cost)

CT_i = Commission and testing fees for building component i (% of total capital and labour cost)

DO_i = Design and other fees for building component i (% of total capital and labour cost)

f_{R_i} = Retrofit factor for building component i (%)

To calculate the total cost of the basic building construction, equation (26) is used, which states that the total cost of the building components is the sum of the cost of the individual components.

$$\begin{aligned}
 C_{BBC_j} = & (C_{BasicW} \cdot H_j \cdot Dep_j)_E + (C_{BasicW} \cdot H_j \cdot Dep_j)_W + (C_{BasicW} \cdot H_j \cdot W_j)_N \\
 & + (C_{BasicW} \cdot H_j \cdot W_j)_S + (C_{BasicC} \cdot W_j \cdot Dep_j) + (C_{BasicF} \cdot W_j \cdot Dep_j) \\
 & + (N_{D_j} \cdot C_{BasicD}) + (N_{W_j} \cdot C_{BasicWi})
 \end{aligned} \quad (26)$$

C_{BBC_j} = Cost of basic building construction in compartment j (\$)

C_{BasicW} = Cost of a basic wall assembly (\$/ft²)

H_j = Height of compartment j (ft)

Dep_j = Depth of compartment j (ft)

W_j = Width of compartment j (ft)

C_{BasicC} = Cost of basic ceiling assembly (\$/ft²)

C_{BasicF} = Cost of basic floor assembly (\$/ft²)

N_{D_j} = Number of doors in compartment j

C_{BasicD} = Cost of a basic door (\$/door)

N_{W_j} = Number of windows in compartment j

$C_{BasicWi}$ = Cost of a basic window (\$/window)

Subscripts E , W , N and S stand for East, West, North and South.

5.1.2 Initial cost of additional fire protection in compartments

In this section the initial cost of additional passive fire protection³ will be discussed. For the additional passive fire protection of the building, costing will be done per compartment since damages are calculated by compartment. Equation (27) represents the cost of passive fire protection measures in a single compartment.

³ Does not include egress routes, costing of which is done by considering the entire building.

$$\begin{aligned}
C_{FPC_j} = & (C_{WE_j} - C_{BasicW}) \cdot (H_j \cdot Dep_j) + (C_{WW_j} - C_{BasicW}) \cdot (H_j \cdot Dep_j) \\
& + (C_{WN_j} - C_{BasicW}) \cdot (H_j \cdot W_j) + (C_{WS_j} - C_{BasicW}) \cdot (H_j \cdot W_j) \\
& + (C_{Ceiling_j} - C_{BasicC}) \cdot (W_j \cdot Dep_j) + (C_{Floor_j} - C_{BasicF}) \cdot (W_j \cdot Dep_j) \\
& + (C_{Doors_j} - C_{BasicD}) \cdot (N_{D_j}) + (C_{Windows_j} - C_{BasicWi}) \cdot (N_{W_j})
\end{aligned} \tag{27}$$

C_{FPC_j} = Cost of additional passive fire protection in compartment j (\$)

C_{WE_j} = Cost of East wall assembly in compartment j (\$/ft²)

C_{BasicW} = Cost of a basic wall assembly (\$/ft²)

H_j = Height of compartment j (ft)

Dep_j = Depth of compartment j (ft)

C_{WW_j} = Cost of West wall assembly in compartment j (\$/ft²)

C_{WN_j} = Cost of North wall assembly in compartment j (\$/ft²)

W_j = Width of compartment j (ft)

C_{WS_j} = Cost of South wall assembly in compartment j (\$/ft²)

$C_{Ceiling_j}$ = Cost of ceiling assembly in compartment j (\$/ft²)

C_{BasicC} = Cost of basic ceiling assembly (\$/ft²)

C_{Floor_j} = Cost of floor assembly in compartment j (\$/ft²)

C_{BasicF} = Cost of basic floor assembly (\$/ft²)

C_{Doors_j} = Cost of doors in compartment j (\$/door)

C_{BasicD} = Cost of a basic door (\$/door)

N_{D_j} = Number of doors in compartment j

$C_{Windows_j}$ = Cost of windows in compartment j (\$/window)

C_{BasicW} = Cost of a basic window (\$/window)

N_{W_j} = Number of windows in compartment j

If a compartment has only three walls (for example), the fourth wall terms will all be set to zero which will result in no added costs for the fourth wall.

If the basic cost of a component is greater than the actual cost of a component, this will result in a negative number (see equation (27)). If this is the case, the basic cost is set to the actual cost which results in no added cost for additional passive fire protection. However, the cost that goes toward the total cost of building construction is the actual cost of the components since this cost is less than the basic cost.

The total cost of the passive fire protection in compartments is the sum of the total cost of the individual compartments as shown by equation (28).

$$C_{TFPC} = \sum_{j=1}^n C_{FPC_j} \quad (28)$$

C_{TFPC} = Total cost of additional passive fire protection in building (\$)

n = Number of compartments

C_{FPC_j} = Cost of additional passive fire protection in compartment j (\$)

5.1.3 Initial cost of contents

The initial cost of contents in a single compartment is the sum of the cost of the contents in each content category as shown by equation (29).

$$C_{CC_j} = \sum_{i=1}^n C_{CG_i} \quad (29)$$

C_{CC_j} = Cost of contents in compartment j (\$)

n = Number of content categories

C_{CG_i} = Cost of contents in content category i (\$)

The total cost of the contents in the building is the sum of the contents in each compartment as shown by equation (30).

$$C_{Contents} = \sum_{j=1}^n C_{CC_j} \quad (30)$$

$C_{Contents}$ = Cost of the contents of the building (\$)

n = Number of compartments

C_{CC_j} = Cost of contents in compartment j (\$)

5.1.4 Initial cost of fire protection systems

To calculate the initial cost of the components of the fire protection systems, equation (31) is used. The initial cost of fire protection systems does not include additional passive fire protection associated with the wall assemblies, floor assembly, ceiling assembly, doors and windows of a compartment.

$$C_{FP_i} = A_i \cdot (C_{CA_i} + L_{C_i}) \left[1 + \frac{CF_i + CT_i + DO_i + f_{R_i}}{100} \right] \quad (31)$$

C_{FP_i} = Cost of fire protection system component i (\$)

A_i = Area covered by component i or number of components

C_{CA_i} = Capital cost of component i (\$/ft² or \$/component)

L_{C_i} = Labour cost of component i (\$/ft² or \$/component)

CF_i = Contingency fees for component i (% of total capital and labour cost)

CT_i = Commission and testing fees for component i (% of total capital and labour cost)

DO_i = Design and other fees for component i (% of total capital and labour cost)

f_R = Retrofit factor for component i (%)

The following example will demonstrate how to cost a sprinkler system (same process is also used for other components).

Example

What is the cost for a wet-pipe sprinkler system that covers an area of 45,000 ft² (4,181 m²)?

Given data:

Capital cost: \$1.37/ft² (\$14.75/m²)

Labour cost: \$2.18/ft² (\$23.47/m²)

Contingency fees: 5%

Commission and testing: 1.2%

Design and other fees: 20%

Annual maintenance costs: \$550

Annual inspection costs: \$550

Annual replacement costs: \$550

Retrofit factor: 20%

Solution:

Annual costs:

$$C_Y = \sum_{i=1}^n C_{Y_i} = 550 + 550 + 550 = \$1,650$$

Initial cost of sprinklers:

$$\begin{aligned} C_{\text{Sprinklers}} &= A \cdot (C_C + L_C) \left[1 + \frac{CF + CT + DO + f_R}{100} \right] \\ &= 45,000 \text{ ft}^2 \cdot \left(\frac{\$1.37}{\text{ft}^2} + \frac{\$2.18}{\text{ft}^2} \right) [1 + 0.05 + 0.012 + 0.20 + 0.20] \\ &= \$233,555 \end{aligned}$$

$C_{\text{Sprinklers}}$ = Cost of sprinklers (\$)

Therefore the initial cost of sprinklers is \$233,555 and the annual cost is \$1,650.

5.2 Cost of damages

In this section, the calculation of damages will be discussed with relation to smoke spread (i.e., using the results of the smoke computer model where it is assumed that there is a fire in only one compartment and there is no fire spread). Fire spread calculations are basically the same as the calculations done for smoke spread only but take into account the probability of fire spread. Calculations that take into account the probability of fire spread will be discussed in section 5.5. Damages to each

compartment, the building components, the compartment contents and the fire protection systems will be discussed. The total cost of damages is computed by equation (32). In equation (32), finishes are considered as contents of the building. Damages from temperature, water and smoke are considered direct damage, while downtime is considered indirect damage.

$$C_D = C_{TDB} + C_{TDFP} + C_{TDC} + C_{TCD} \quad (32)$$

C_D = Total cost of damage to the entire building (\$)

C_{TDB} = Total cost of damage to building components (\$)

C_{TDFP} = Total cost of damage to the building's fire protection systems (not including additional passive fire protection) (\$)

C_{TDC} = Total cost of damage to additional passive fire protection and basic building construction (\$)

C_{TCD} = Total cost of damage to contents in the entire building (\$)

It is noted that egress routes are included in the cost of damage to the building's fire protection systems and not in the cost of damage to additional passive fire protection in compartments.

5.2.1 Cost of damages to a compartment's assemblies, doors and windows

The cost of damages to each compartment includes the damage to a compartment's components (i.e., wall assemblies, ceiling assembly, floor assembly, as well as the doors and windows). For each compartment, an input file from one of the sub-models (smoke computer model) of the fire hazard and fire risk analysis computer model, which has data dealing with the temperature in the compartment at different time steps, is used. Using this temperature-time data, as well as the FRR or fire rating of the various components of the compartment, the cost of damage is calculated. A compartment's wall assemblies, ceiling assembly, floor assembly, doors and windows will be considered in the basic building construction costs, as well as in the additional passive fire protection costs. However, in the calculation of damages, the total cost of the assembly, door or window is considered.

To determine the damage, the real fire curve is compared to the standard fire curve. The equal area method is used to relate the severity of the standard fire curve to the real fire curve. Finding the real fire's equivalent severity is accomplished by taking the ratio of the area under the real fire curve to the area under the standard fire curve above a certain reference temperature (Buchanan, 2002). To find the area under the standard fire curve, temperature-time data for the standard fire curve is required. This is calculated by using equation (33) developed by Lie (Buchanan, 2002). It is noted that equation (33) approximates the ASTM E119 standard.

$$T = 750 \left(1 - e^{-3.79533 \sqrt{t_h}} \right) + 170.41 \sqrt{t_h} + T_0 \quad (33)$$

T = Temperature using the standard fire curve (°C)

t_h = Time (hours)

T_0 = Ambient temperature (°C)

There are problems with the equal area method which are as follows (Buchanan, 2002):

- Comparison of areas under the curves do not have theoretical meaning as can be seen with the units of area
- Poor comparison of heat transfer with fires that have different temperature-time curves⁴

For the calculation of the damages to the components in the compartment, the equal area method is modified as described below and considered adequate although the aforementioned problems still exist. A better approach is to use the heat flux-time data but these data are not available from the smoke computer model.

⁴ Radiation is the most dominant form of heat transfer from the fire to the assembly and since radiation is proportional to the fourth power of temperature (absolute), one can see that a short hot fire and a long cool fire may have the same area under the time-temperature curve but in reality their severities are not equal (Buchanan, 2002).

To calculate the probability of damages to component i , the area under the real fire curve is divided by the area under the standard fire curve to the time related to the FRR (or fire rating) of a component and then multiplied by a building construction calibration factor as shown in equation (34). The building construction calibration factor is used to adjust the probability of damage to a compartment's assemblies, doors and windows if it is shown that different types of construction have an affect on the probability of damage. Currently the building construction calibration is set to one and is included in the economic computer model for future flexibility. The temperature-time data in a compartment that has no temperature change will still produce an area under the temperature-time curve and because there is an area, there will be a probability of damage which is not practical if the temperature in the compartment stays at the compartment's initial temperature. Therefore, the areas under both the standard fire curve and the real fire curve are adjusted using the initial temperature in the compartment as a baseline value.

$$P_{DC_i} = \left(\frac{A_{Real_j}}{A_{Standard_i}} \right) \cdot f_c \quad (34)$$

P_{DC_i} = Probability of damages to component i

A_{Real_j} = Area under the real fire curve for compartment j

$A_{Standard_i}$ = Area under the standard fire curve related to the FRR or fire rating of component i

f_c = Building construction calibration factor

Figure 8 shows the standard fire curve used with a hypothetical real fire lasting two hours. An example of a wall with a one hour FRR exposed to a two hour real fire is also shown in Figure 8. What is not shown in Figure 8 is the adjustment of areas to account for the compartment's initial temperature. If the user enters a value of zero for the FRR or fire rating, the area under the standard fire curve will be zero. To have a conservative estimate in relation to temperature damage to the assemblies, doors or windows when the FRR or fire rating is set to zero, the probability of damage will be considered to be one, if the temperature in the compartment is equal or greater than 100°C. If the area under the standard fire curve is zero and the temperature in the compartment is less than 100°C, the probability of damage will be considered zero.

Figure 8: Standard and real fire temperature-time curves.

To calculate the cost of damage to a compartment's walls, ceiling and floor assemblies, as well as the compartment's doors and windows, equation (35) is used. Equation (35) states that the cost of damages to component i is the probability of damage to component i multiplied by the cost (basic construction and additional passive fire protection) of an assembly, door or window.

$$C_{DC_i} = P_{DC_i} \cdot C_i \quad (35)$$

C_{DC_i} = Cost of damage to component i (\$)

P_{DC_i} = Probability of damage to component i

C_i = Cost of component i (\$)

The total cost of damage to additional passive fire protection and basic building construction is shown in equation (36).

$$C_{TDC} = \sum_{j=1}^n \left(\sum_{i=1}^r C_{DC_i} \right) \quad (36)$$

C_{TDC} = Total cost of damage to additional passive fire protection and basic building construction (\$)

n = Number of compartments

r = Number of components in compartment j

C_{DC_i} = Cost of damage to component i (\$)

To find the areas under the curves, the simple trapezoidal rule for integration is used, which uses discrete temperature-time points given in the output of the smoke computer model. Other methods can be used for integration but the trapezoidal rule provides a simple way to deal with the evenly spaced data.

The trapezoidal rule works on the premise that the approximate integral of a function (or the area under a curve) can be characterized by trapezoids (Hughes-Hallett et al., 1994). These trapezoids are formed when a secant is drawn from the endpoints (Gerald and Wheatley, 1997). To calculate $\int_a^b f(x) dx$, divide the interval a to b into n subintervals (Gerald and Wheatley, 1997). The trapezoidal rule can be applied to data which is not equally spaced but when the data is equally spaced, the formula becomes simpler. Equation (37) represents the trapezoidal rule.

$$\int_{x_i}^{x_{i+1}} f(x) dx \cong \frac{f(x_i) + f(x_{i+1})}{2} (\Delta x) = \frac{h}{2} (f_i + f_{i+1}) \quad (37)$$

h = Constant Δx

Since temperature-time data will be given in tabular form, the composite trapezoidal rule will be used as shown in equation (38) where $[a, b]$ are subdivided into n subintervals of size h (Gerald and Wheatley, 1997).

$$\begin{aligned} \int_a^b f(x) dx &\cong \sum_{i=0}^{n-1} \frac{h}{2} (f_i + f_{i+1}) = \frac{h}{2} (f_0 + f_1 + f_1 + f_2 + \cdots + f_{n-1} + f_n); \\ \int_a^b f(x) dx &\cong \frac{h}{2} (f_0 + 2f_1 + 2f_2 + \cdots + 2f_{n-1} + f_n) \end{aligned} \quad (38)$$

h = Constant Δx

There are disadvantages to using the trapezoid rule which are as follows:

- There is a large error in the finding of the integral if the step size used is very large since the curve would be represented by straight line segments
- If the integral of the function to be estimated is concave down, the trapezoid will underestimate the area under the curve whereas if the function is concave up, the trapezoid rule overestimates the function (Hughes-Hallett et al., 1994).

Equation (38) is adjusted to account for the area under the curve if the temperature in the compartment did not change, therefore, the area calculated is subtracted by the initial temperature in the compartment and multiplied by the duration of the fire (simulation time).

To find the area under the standard fire curve, the integral of the standard fire curve is used. Instead of using a numerical solution to find the area under the standard fire curve the analytical solution was determined which gives a more accurate answer and is simpler to work with than a list of data. The analytical solution of the integral of the standard fire is shown next. The equation for the standard fire curve is shown in equation (33) and is re-written for clarity in equation (39).

$$T = 750 \left(1 - e^{-3.79533 \sqrt{t_h}} \right) + 170.41 \sqrt{t_h} + T_0 \quad (39)$$

T = Temperature using the standard fire curve ($^{\circ}\text{C}$)

t_h = Time (hours)

T_0 = Ambient temperature ($^{\circ}\text{C}$)

The solution is determined by taking the integral of the equation of the standard fire curve as shown in equation (40).

$$\int_a^b \left\{ 750 \left(1 - e^{-3.79533 \sqrt{t_h}} \right) + 170.41 \sqrt{t_h} + T_0 \right\} dt_h \quad (40)$$

Expand equation (40) to obtain equation (41).

$$\int_a^b \left\{ 750 - 750 \cdot \left[e^{-3.79533 \sqrt{t_h}} \right] + 170.41 \sqrt{t_h} + T_0 \right\} dt_h \quad (41)$$

The integrals of the first, third and fourth terms are readily determined, but the integral of the second term is found by substitution and integration by parts.

Let $w = \sqrt{t_h}$ and $\alpha = -3.79533$. Therefore $dw = \frac{1}{2}t_h^{-1/2}dt_h$ and $dt_h = 2w \cdot dw$.

Substitute back into expression for the second term as shown in equation (42).

$$\int_{\sqrt{a}}^{\sqrt{b}} (-750e^{\alpha \cdot w}) 2w \cdot dw \quad (42)$$

Perform integration by parts which is defined by equation (43).

$$\int uv' \cdot dw = uv - \int u'v \cdot dw \quad (43)$$

Let $u = -1500w$ and $v' = e^{\alpha \cdot w}$. Therefore the integration by parts then looks like equation (44).

$$\int uv' \cdot dw = (-1500w) \left(\frac{1}{\alpha} \right) e^{\alpha \cdot w} - \int (-1500) \left(\frac{1}{\alpha} \right) e^{\alpha \cdot w} \cdot dw \quad (44)$$

The integral of the second term in equation (43) is shown in equation (45) where C is a constant.

$$\int (-1500) \left(\frac{1}{\alpha} \right) e^{\alpha \cdot w} \cdot dw = \left(\frac{-1500}{\alpha} \right) \left(\frac{1}{\alpha} \right) e^{\alpha \cdot w} + C \quad (45)$$

The full solution for equation (44) is shown in equation (46).

$$\int_{\sqrt{a}}^{\sqrt{b}} uv' \cdot dw = -1500 \cdot e^{\alpha \cdot w} \left[(\alpha^{-1} \cdot w) - (\alpha^{-2}) \right] \Big|_{\sqrt{a}}^{\sqrt{b}} \quad (46)$$

Combining everything together, and substituting back for w and α the integral of equation (39) is shown in equation (47).

$$\begin{aligned} \int_a^b \left\{ 750 \left(1 - e^{-3.79533 \sqrt{t_h}} \right) + 170.41 \sqrt{t_h} + T_0 \right\} dt_h = \\ \left\{ \begin{aligned} &750(b) - \left[1500 e^{(-3.79533)(\sqrt{b})} \left[((-3.79533)^{-1} \cdot (\sqrt{b})) - (3.79533^{-2}) \right] \right] \\ &+ \left[\left(\frac{2}{3} \right) 170.41 (b)^{3/2} \right] + T_0 \cdot b \end{aligned} \right\} - \quad (47) \\ \left\{ \begin{aligned} &750(a) - \left[1500 e^{(-3.79533)(\sqrt{a})} \left[((-3.79533)^{-1} \cdot (\sqrt{a})) - (3.79533^{-2}) \right] \right] \\ &+ \left[\left(\frac{2}{3} \right) 170.41 (a)^{3/2} \right] + T_0 \cdot a \end{aligned} \right\} \end{aligned}$$

t_h = Time (hours)

T_0 = Ambient temperature (°C)

Equation (47) is adjusted to account for the area under the curve resulting from the temperature being constant at the compartment's initial temperature as shown in equation (48).

$$\begin{aligned}
 \text{Adjusted } \int = & \left(\left\{ \begin{aligned} & 750(b) - \left[1500 e^{(-3.79533)(\sqrt{b})} \left[(-3.79533)^{-1} \cdot (\sqrt{b}) - (3.79533^{-2}) \right] \right] \right. \\ & \left. + \left[\left(\frac{2}{3} \right) 170.41(b)^{3/2} \right] + T_0 \cdot b \right\} - \right. \\ & \left. \left\{ \begin{aligned} & 750(a) - \left[1500 e^{(-3.79533)(\sqrt{a})} \left[(-3.79533)^{-1} \cdot (\sqrt{a}) - (3.79533^{-2}) \right] \right] \right. \\ & \left. + \left[\left(\frac{2}{3} \right) 170.41(a)^{3/2} \right] + T_0 \cdot a \right\} \right) \\ & - (T_0 \cdot (b - a))
 \end{aligned} \right. \quad (48)
 \end{aligned}$$

Adjusted $\int$ = Adjusted integral of the standard fire curve adjusted for a baseline temperature

t_h = Time (hours)

T_0 = Ambient temperature (°C)

5.2.2 Cost of damages to building components

To calculate the cost of damage to building components, data from the damage to each compartment is used. It is assumed that the construction components will have at

least the same FRR as the highest FRR of any assembly in the compartment. For example, any wall assembly will have at least the same FRR as the substructure. It is also assumed that that building components will be the last components to be affected by fire. For example, pipes can be behind a wall assembly. If the previous assumptions are not valid in the building being analyzed, building components can be considered a content of a compartment. To calculate the probability of damage to the building components, the cost of damages to a compartment's component with the highest FRR (or fire rating) is divided by the initial cost of the compartment's component with the highest FRR (or fire rating) as shown in equation (49). This equation determines the probability of damage using the areas under the real fire curve and standard fire curve as shown in section 5.2.1. It is unlikely that a door or window will have a higher fire rating than an assembly's FRR.

$$P_{DCC_i} = \frac{C_{DP_j}}{C_{CP_j}} \quad (49)$$

P_{DCC_i} = Probability of damage to building component i

C_{DP_j} = Cost of damage to the component with the highest FRR or fire rating in
compartment j (\$)

C_{CP_j} = Initial cost of component with the highest FRR or fire rating in
compartment j (\$)

Therefore, to calculate the damages to the building components, the cost of the building component i is multiplied by the probability of damage and then multiplied by the building component calibration factor as seen in equation (50). In equation (50) the component factor is used to adjust the building component's tolerance to fire. This factor is currently set to one and is included in the economic computer model for future flexibility.

$$C_{DB_i} = C_{BC_i} \cdot P_{DCC_i} \cdot f_B \quad (50)$$

C_{DB_i} = Cost of damage to building component i (\$)

C_{BC_i} = Cost of building component i (\$)

P_{DCC_i} = Probability of damage to building component i

f_B = Building component calibration factor

The total cost of damages to building components per compartment is shown in equation (51). As shown in equation (51), the cost of damage is adjusted for the area of the compartment in relation to the area of the building, using an area adjustment factor as shown in equation (52). It is noted that the cost of site development is not included in the calculation of damages to building components since site development is not affected by fire.

$$C_{CDB_j} = \left(\sum_{i=1}^n C_{DB_i} \right) \cdot f_{A_j} \quad (51)$$

C_{CDB_j} = Cost of damage to building components in compartment j (\$)

n = Number of components

C_{DB_i} = Cost of damage to building component i (\$)

f_{A_j} = Area adjustment factor for compartment j

$$f_{A_j} = \frac{A_{Comp_j}}{A_{Total}} \quad (52)$$

f_{A_j} = Area adjustment factor for compartment j

A_{Comp_j} = Floor area of compartment j (m²)

A_{Total} = Total building floor area (m²)

The total cost of damage to building components is shown in equation (53).

$$C_{TDB} = \sum_{j=1}^n C_{CDB_j} \quad (53)$$

C_{TDB} = Total cost of damage to building components (\$)

C_{CDB_j} = Cost of damage to building components in compartment j (\$)

n = Number of compartments

5.2.3 Cost of damages to contents

For damages to contents, each content category will have as an input, lower and upper thresholds in relation to temperature, smoke and water sensitivity. Damages to contents will be calculated using linear interpolation between the lower and upper threshold for temperature, smoke and water. These probabilities are between zero and one inclusive. It is assumed that up to and including the lower threshold value, the probability of damage to the contents is zero. The probability above the lower threshold value will vary linearly until the upper threshold value at which the probability of damage is one. Figure 9 demonstrates how the probability of damage changes with different values. If the probability of damage is calculated to be less than zero, the probability of damage will be set to zero. If the probability of damage is calculated to be greater than one, the probability of damage will be set to one. If the upper and lower thresholds are given as the same value and the threshold is less than the value of the compartment condition (for temperature, smoke or water), the probability of damage will be set to zero. If the upper and lower thresholds are given as the value same and the threshold is greater than the compartment condition (for temperature, smoke or water) then the probability of damage is set to one.

Figure 9: Probability of damage versus threshold limits.

5.2.3.1 The probability of individual damages

Linear interpolation is used to find the individual damages due to temperature, smoke and water. Assume that point (x_1, y_1) and point (x_2, y_2) can be joined to form a straight line (equation (54)), where x is the independent variable and y is the dependant variable. In the case of damages, y represents the probability of damages and x represents the temperature, water or smoke threshold.

$$y = mx + b \quad (54)$$

y = Dependant variable

m = Slope of a straight line

x = Independent variable

b = y intercept

The slope m is defined by equation (55).

$$m = \frac{y_2 - y_1}{x_2 - x_1} \quad (55)$$

m = Slope of a straight line

It is desired to find the value of x_A given y_A . Using point (x_2, y_2) , the y intercept (b) is given by equation (56).

$$b = y_2 - \left(\frac{y_2 - y_1}{x_2 - x_1} \right) x_2 \quad (56)$$

b = y intercept

Substitute (x_A, y_A) for (x, y) to obtain equation (57).

$$y_A = \left(\frac{y_2 - y_1}{x_2 - x_1} \right) \cdot x_A + \left(y_2 - \left(\frac{y_2 - y_1}{x_2 - x_1} \right) \cdot x_2 \right) \quad (57)$$

If the value of y is between zero and one, equation (57) reduces to equation (58).

$$y_A = \left(\frac{x_A - x_1}{x_2 - x_1} \right) \quad (58)$$

In the case of damages due to temperature, smoke and water, the probability of damage is between zero and one. Equation (58) can be written in terms of temperature thresholds, as shown in equation (59), and is similarly written in terms of smoke and water thresholds.

$$P_{DT_i} = \left(\frac{T_{Max_j} - T_{L_i}}{T_{U_i} - T_{L_i}} \right) \quad (59)$$

P_{DT_i} = Probability of damage to contents in content category i as a result of the temperature in a compartment j

T_{Max_j} = Maximum temperature in compartment j (°C)

T_{L_i} = Lower temperature threshold for contents in content category i (°C)

T_{U_i} = Upper temperature threshold for contents in content category i (°C)

5.2.3.2 The probability of total damages to contents

Damages due to temperature, smoke and water are not mutually exclusive (i.e., damages from temperature, smoke and water can occur at the same time). However these events are independent (i.e., the damages due to smoke are not related to the damages caused by the temperature rise or the amount of water used for extinguishment). Therefore, to calculate the total damage, equation (60) is used. In Figure 10, the Venn diagram shown relates the damages from temperature, smoke and water.

$$P_{DTC_i} = P_{DT_i} + P_{DS_i} + P_{DW_i} - (P_{DT_i} \cdot P_{DS_i}) - (P_{DS_i} \cdot P_{DW_i}) - (P_{DT_i} \cdot P_{DW_i}) + (P_{DT_i} \cdot P_{DS_i} \cdot P_{DW_i}) \quad (60)$$

P_{DTC_i} = Probability of damage to contents in content category i as a result of the temperature, smoke and water conditions in a compartment j

P_{DT_i} = Probability of damage to contents in content category i as a result of the temperature conditions in a compartment j

P_{DS_i} = Probability of damage to contents in content category i as a result of the smoke conditions in a compartment j

P_{DW_i} = Probability of damage to contents in content category i as a result of the water conditions in a compartment j

Figure 10: Venn diagram representing the relationship between probabilities of damages.

5.2.3.3 Values for compartment conditions

In order to calculate the probabilities of damage from temperature, smoke and water, the compartment conditions have to be known. The temperature that is used for the compartment condition is the highest temperature that is reached in the upper layer while the highest concentration of soot is used for smoke compartment condition. Therefore, the temperature is a conservative estimate since the lower layer

temperature is not considered. The smoke concentration is also a conservative estimate because the smoke layer depth is not considered, and since there may be contents that are below the level of smoke that do not come in contact with the smoke. Both temperature and smoke data are obtained from the smoke computer model.

For the amount of water, the larger the fire is, the more water has to be used to control and extinguish the fire. If the heat release rate of the fire is known, a calculation can be done to determine how much water is needed to extinguish the fire. This calculation takes into account the water spread on the fire that directly turns into steam that is carried away in the hot gases and is similar to the New Zealand Fire Engineering Design Guide method shown in equation (11) in Chapter 2 (Literature review). To determine the amount of water needed, some assumptions have to be made which are as follows:

1. Water used is at 20°C and is in the form of liquid droplets
2. Density of the water is 1,000 kg/m³ (there will be a small change in density as the temperature changes from 20°C to 100°C but this is not considered)
3. Specific heat capacity is 4.182 kJ/kg°C (there will be small change in specific heat as temperature changes from 20°C to 100°C but this is not considered)
4. Heat of vaporization is 2,260 kJ/kg

W is defined as the rate of application of water needed to extinguish fire. Therefore,

W (L/s) is defined by equation (61).

$$W = \frac{Q}{\chi H} \quad (61)$$

W = Flow rate of water required to extinguish a fire (kg/s)

Q = Heat release rate of the fire (kW)

χ = Efficiency (<1) of water being applied (i.e., if the efficiency is 0.5, 50% of the water is being vaporized)

H = The heat absorbed as 1 kg of water is heated from 20°C to 100°C (steam) defined by equation (62)

$$H = C_p \Delta T + H_v \quad (62)$$

H = Heat absorbed as 1 kg of water is heated from 20°C to 100°C (steam) (kJ/kg)

C_p = Specific heat capacity of water (4.182 kJ/kg°C)

ΔT = Temperature change from 20°C to 100°C

H_v = Heat of vaporization of water (2,260 kJ/kg)

With the rate of application of water needed to extinguish a fire, the amount of water used can be determined using equation (63) where the area under the heat release rate-time curve is determined using the trapezoidal rule as described in section 5.2.1. It is noted that some of the water may evaporate and/or more water could be applied than needed by the fire department or by the sprinklers but this is not considered in equation (63). However, if a very low efficiency of water being applied is used, this will give a conservative estimate for the amount of water in a compartment. The extinguishment calibration factor can also be used to adjust the amount of water. Currently the extinguishment calibration factor is set to one and is included in the economic computer model for future flexibility.

$$W_j = \left(\frac{\left(\frac{A_{QT_j}}{\chi H} \right) \left(\frac{1}{f_{Ex}} \right)}{A_{Comp_j}} \right) \left(\frac{1}{\rho_{Water}} \right) \cdot \frac{1000L}{1m^3} \quad (63)$$

W_j = Amount of water needed to extinguish a fire in compartment j (L/m²)

A_{QT_j} = Area under the heat release-time curve for compartment j (kJ)

χ = Efficiency (<1) of water being applied (i.e., if the efficiency is 0.5, 50% of the water is being vaporized)

H = The heat absorbed as 1 kg of water is heated from 20°C to 100°C (steam)
(kJ/kg)

f_{Ex} = Extinguishment calibration factor

A_{Comp_j} = Floor area of compartment j (m^2)

ρ_{Water} = Density of water (assumed to be 1,000 kg/m³)

5.2.3.4 Total cost of damages to contents

By knowing the probability of damage to contents in a given content category, as a result of the temperature, smoke and water in the compartment, the cost of the damage to the contents can be calculated using equation (64).

$$C_{DTC_i} = P_{DTC_i} \cdot C_{CG_i} \quad (64)$$

C_{DTC_i} = Cost of the damages to contents in content category i as a result of temperature, smoke and water conditions in compartment j (\$)

P_{DTC_i} = Probability of damage to contents in content category i as a result of the temperature, smoke and water conditions in a compartment j

C_{CG_i} = Cost of contents in content category i (\$)

Once the cost of damages to the contents in each category is calculated, these costs are simply summed to obtain the total cost of damages to the contents in a compartment as shown by equation (65).

$$C_{DCT_j} = \sum_{i=1}^n C_{DTC_i} \quad (65)$$

C_{DCT_j} = Total cost of the damages to the contents in compartment j (\$)

n = Number of content categories

C_{DTC_i} = Cost of the damages to contents in content category i as a result of temperature, smoke and water conditions in compartment j (\$)

To find the total damages of the contents in the building, the total cost of the damages in each compartment is summed as shown in equation (66).

$$C_{TCD} = \sum_{j=1}^n C_{DCT_j} \quad (66)$$

C_{TCD} = Total cost of damage to the contents in the entire building (\$)

n = Number of compartments

C_{DCT_j} = Total cost of the damages to the contents in compartment j (\$)

5.2.4 Cost of damages to fire protection systems

Damages to fire protection systems will be calculated in a similar fashion to the damage to contents (i.e., using threshold values). Damages to fire protection systems are generally not considered when calculating the cost of damages to the building

(Bénichou et al., 2002) but the damages to the fire protection systems are considered in the economic computer model since their cost is fairly large and considering the systems will only make the cost of damage to the building more detailed and accurate.

It is expected that most of the damages to fire protection systems will be from the temperature rise in a compartment. For example, if the temperature in the compartment causes a detector link to melt, the entire detector must be replaced. In the case where sprinklers activate because the temperature of the ceiling jet is as high as the activation temperature of a sprinkler head, then the sprinkler head will have to be replaced.

The damage to the fire protection systems will be calculated similarly to the damages to the compartment contents with the exception of an area adjustment factor that is included to determine the cost of damages per compartment. The cost of damage to the building's fire protection systems is the cost of fire protection systems multiplied by the probability of damage to the system and then multiplied by an area adjustment factor as shown in equation (67). Equation (68) defines the area adjustment factor.

$$C_{FPDC_i} = C_{FP_i} \cdot P_{DFP_i} \cdot f_{A_j} \quad (67)$$

C_{FPDC_i} = Cost of damages to fire protection system i in compartment j (\$)

C_{FP_i} = Cost of fire protection system i (\$)

P_{DFP_i} = Probability of damage to fire protection system i as a result of the temperature, smoke and water conditions in compartment j (Equation (60))

f_{A_j} = Area adjustment factor for compartment j

$$f_{A_j} = \frac{A_{Comp_j}}{A_{Total}} \quad (68)$$

f_{A_j} = Area adjustment factor for compartment j

A_{Comp_j} = Floor area of compartment j (m²)

A_{Total} = Total building floor area (ft²)

The total cost of damage to the building's fire protection systems, not including additional passive fire protection damage, is shown in equation (69).

$$C_{TDFP} = \sum_{j=1}^n \left(\sum_{i=1}^r C_{FPDC_i} \right)_j \quad (69)$$

C_{TDFP} = Total cost of damage to the building's fire protection systems (not including additional passive fire protection) (\$)

n = Number of compartments

r = Number of fire protection systems

C_{FPDC_i} = Cost of damages to fire protection system i in compartment j (\$)

5.3 Cost of downtime

In this section, the calculation of downtime will be discussed. A method to calculate downtime and the costs associated with this time is discussed. It is noted that the calculations do not include the downtime that is caused as a result of the fire spreading to other compartments which will be discussed in section 5.5.

To calculate the amount of downtime from the damage to a single component of the building (i.e., building component, fire protection system, or content), equation (70) is used. An area adjustment factor, defined in equation (68), is used to find the amount of downtime per compartment as the probabilities of damage vary from compartment to compartment. The factor used to adjust the downtime period is a factor between zero and one. The more important a component is to a business, the higher the downtime factor is since the most important components must be replaced

first. The area adjustment factor for the downtime caused from damages to the contents of a single compartment and downtime from the damage to assemblies, doors and windows is one since both are specific to each compartment.

$$D_{T_i} = Days_i \cdot f_{DT_i} \cdot P_{D_i} \cdot f_{A_j} \quad (70)$$

D_{T_i} = Downtime of component i (days)

$Days_i$ = Number of days that it will take to repair or replace component i (days)

f_{DT_i} = Factor used to adjust downtime period for component i

P_{D_i} = Probability of damage to component i (i.e., building components, fire protection systems, contents)

f_{A_j} = Area adjustment factor for compartment j (defined in equation (68))

To calculate the total amount of downtime for the entire building, equation (71) is used which is the sum of all the downtimes from the various components. There can be concurrent repairs to a building and this should be taken into account when deciding downtime factors.

$$D_T(Total) = \sum_{i=1}^r D_T(D_{BC_i}) + \sum_{j=1}^n D_T(D_{BBC} + D_{FPC})_j + \sum_{i=1}^r D_T(D_{FP_i}) + \sum_{j=1}^n D_T(D_{CC_j}) \quad (71)$$

$D_T(Total)$ = Total amount of downtime (days)

r = Number of components

$D_T(D_{BC_i})$ = Downtime from the damages to building component i (days)

n = Number of compartments

$D_T(D_{BBC} + D_{FPC})_j$ = Downtime from the damages to basic building construction
and additional passive fire protection in compartment j (days)

$D_T(D_{FP_i})$ = Downtime from the damages to fire protection system
component i not including damage to additional passive fire
protection (days)

$D_T(D_{CC_j})$ = Downtime from the damages to the contents in compartment j
(days)

To calculate the cost of downtime, equation (72) is used.

$$C_{D_T(Total)} = D_T(Total) \cdot C_{DD} \quad (72)$$

$C_{D_T(Total)}$ = Total cost of downtime (\$)

$D_T(Total)$ = Total amount of downtime (days)

C_{DD} = Cost of downtime per day (\$/day)

5.4 Other calculations

In this section other calculations that can be seen in the output of the economic computer model will be described. With respect to the calculations for the estimates of damage due to temperature, smoke and water, these calculations are only estimates and should only be used to give some indication of the damage caused by temperature, smoke or water.

5.4.1 Approximate damage to the contents as a percentage of the total damages to the contents

An estimate of the damage due to temperature, smoke and water to the contents is given to the user. This approximation is only an estimate since the damages due to temperature, smoke and water, are independent but not mutually exclusive. Therefore, the approximation can only give a feeling as to what has been damaged by these conditions. The calculation of the cost of damage from temperature, smoke and water are shown in equations (73, 74 and 75) respectively.

$$EC_{TD_j} = \sum_{i=1}^n \left(\frac{P_{DT_i}}{P_{DT_i} + P_{DS_i} + P_{DW_i}} \right) \cdot (C_{DTC_i}) \quad (73)$$

$$EC_{SD_j} = \sum_{i=1}^n \left(\frac{P_{DS_i}}{P_{DT_i} + P_{DS_i} + P_{DW_i}} \right) \cdot (C_{DTC_i}) \quad (74)$$

$$EC_{WD_j} = \sum_{i=1}^n \left(\frac{P_{DW_i}}{P_{DT_i} + P_{DS_i} + P_{DW_i}} \right) \cdot (C_{DTC_i}) \quad (75)$$

EC_{TD_j} = Estimate of the cost of temperature damage to contents in compartment j
(\$)

n = Number of content categories

P_{DT_i} = Probability of damage to contents in content category i as a result of the
temperature in compartment j

P_{DS_i} = Probability of damage to contents in content category i as a result of the
smoke in compartment j

P_{DW_i} = Probability of damage to contents in content category i as a result of the
water in compartment j

C_{DTC_i} = Cost of the damages to contents in content category i as a result of
temperature, smoke and water conditions in compartment j (\$)

EC_{SD_j} = Estimate of the cost of smoke damage to contents in compartment j (\$)

EC_{WD_j} = Estimate of the cost of water damage to contents in compartment j (\$)

The calculations for the estimate of damage from temperature, smoke and water for the contents in each compartment as a percentage of the total damage to the contents in each compartment are shown in equations (76-78).

$$EC_{TD_j} (\%) = \left(\frac{EC_{TD_j}}{EC_{TD_j} + EC_{SD_j} + EC_{WD_j}} \right) \times 100 \quad (76)$$

$$EC_{SD_j} (\%) = \left(\frac{EC_{SD_j}}{EC_{TD_j} + EC_{SD_j} + EC_{WD_j}} \right) \times 100 \quad (77)$$

$$EC_{WD_j} (\%) = \left(\frac{EC_{WD_j}}{EC_{TD_j} + EC_{SD_j} + EC_{WD_j}} \right) \times 100 \quad (78)$$

$EC_{TD_j} (\%)$ = Estimate of the temperature damage to the contents in compartment j
as a percentage of the total damage to the contents in compartment j
(%)

EC_{TD_j} = Estimate of the cost of temperature damage to contents in
compartment j (\$)

EC_{SD_j} = Estimate of the cost of smoke damage to contents in compartment j (\$)

EC_{WD_j} = Estimate of the cost of water damage to contents in compartment j (\$)

$EC_{SD_j} (\%)$ = Estimate of the smoke damage to the contents in compartment j as a
percentage of the total damage to the contents in compartment j (%)

$EC_{WD_j}(\%)$ = Estimate of the water damage to the contents in compartment j as a percentage of the total damage to the contents in compartment j (%)

The calculations for the estimate of the damage from temperature, smoke and water to all of the contents in the building as a percentage of the total damage to the contents in the building are shown in equations (79-81).

$$EAC_{TD} = \left(\frac{\sum_{j=1}^n EC_{TD_j}}{\sum_{j=1}^n EC_{TD_j} + \sum_{j=1}^n EC_{SD_j} + \sum_{j=1}^n EC_{WD_j}} \right) \times 100 \quad (79)$$

$$EAC_{SD} = \left(\frac{\sum_{j=1}^n EC_{SD_j}}{\sum_{j=1}^n EC_{TD_j} + \sum_{j=1}^n EC_{SD_j} + \sum_{j=1}^n EC_{WD_j}} \right) \times 100 \quad (80)$$

$$EAC_{WD} = \left(\frac{\sum_{j=1}^n EC_{WD_j}}{\sum_{j=1}^n EC_{TD_j} + \sum_{j=1}^n EC_{SD_j} + \sum_{j=1}^n EC_{WD_j}} \right) \times 100 \quad (81)$$

EAC_{TD} = Estimate of the temperature damage to all of the contents in the building as a percentage of the total damage to the contents in the building (%)

n = Number of compartments

EC_{TD_j} = Estimate of the cost of temperature damage to contents in compartment j
(\$)

EC_{SD_j} = Estimate of the cost of smoke damage to contents in compartment j (\$)

EC_{WD_j} = Estimate of the cost of water damage to contents in compartment j (\$)

EAC_{SD} = Estimate of the smoke damage to all of the contents in the building as a
percentage of the total damage to the contents in the building (%)

EAC_{WD} = Estimate of the water damage to all of the contents in the building as a
percentage of the total damage to the contents in the building (%)

5.4.2 Approximate damage to the entire building as a percentage of the total damages

It is assumed that the building components, basic building construction and additional passive fire protection can only be damaged by temperature and not by smoke or water. In reality this is not entirely true, but most damage to the aforementioned components is by temperature. The fire protection systems (not including additional passive fire protection) and the contents of a building can be damaged by temperature, water or smoke. The estimate of temperature, smoke and water damage as a percentage of the total damage to the entire building, its fire protection systems and its contents is only an estimate since when calculating the damage to fire

protection systems and contents it is assumed that temperature, smoke and water are independent but not mutually exclusive.

The calculation of the estimate of temperature, smoke and water damage as a percentage of the total damage to the building, its fire protection systems and its contents is shown in equations (82, 83 and 84) respectively. This approximation will only be given for the entire building. It is noted that the estimate of the cost of damage to the fire protection systems is calculated using the same method as that for the contents (see section 5.4.1).

$$ETD_{TD} = \left(\frac{C_{TDB} + C_{TDC} + \sum_{j=1}^n EC_{TD_j} + \sum_{i=1}^r EFP_{TD_i}}{C_{TDB} + C_{TDC} + \sum_{j=1}^n EC_{TD_j} + \sum_{j=1}^n EC_{SD_j} + \sum_{j=1}^n EC_{WD_j} + \sum_{i=1}^r EFP_{TD_i} + \sum_{i=1}^r EFP_{SD_i} + \sum_{i=1}^r EFP_{WD_i}} \right) \times 100 \quad (82)$$

$$ETD_{SD} = \left(\frac{\sum_{j=1}^n EC_{SD_j} + \sum_{i=1}^r EFP_{SD_i}}{C_{TDB} + C_{TDC} + \sum_{j=1}^n EC_{TD_j} + \sum_{j=1}^n EC_{SD_j} + \sum_{j=1}^n EC_{WD_j} + \sum_{i=1}^r EFP_{TD_i} + \sum_{i=1}^r EFP_{SD_i} + \sum_{i=1}^r EFP_{WD_i}} \right) \times 100 \quad (83)$$

$$ETD_{WD} = \left(\frac{\sum_{j=1}^n EC_{WD_j} + \sum_{i=1}^r EFP_{WD_i}}{C_{TDB} + C_{TDC} + \sum_{j=1}^n EC_{TD_j} + \sum_{j=1}^n EC_{SD_j} + \sum_{j=1}^n EC_{WD_j} + \sum_{i=1}^r EFP_{TD_i} + \sum_{i=1}^r EFP_{SD_i} + \sum_{i=1}^r EFP_{WD_i}} \right) \times 100 \quad (84)$$

ETD_{TD} = Estimate of the temperature damage as a percentage of the total damage to the building, its fire protection systems and its contents (%)

C_{TDB} = Total cost of damage to building components (\$)

- C_{TDC} = Total cost of damage to passive fire protection and basic building construction (\$)
- n = Number of compartments
- EC_{TD_i} = Estimate of the cost of temperature damage to contents in compartment j (\$)
- r = Number of fire protection components
- EFP_{TD_i} = Estimate of the cost of temperature damage to the fire protection system component i (not including additional passive fire protection) (\$)
- EC_{SD_i} = Estimate of the cost of smoke damage to contents in compartment j (\$)
- EC_{WD_i} = Estimate of the cost of water damage to contents in compartment j (\$)
- EFP_{SD_i} = Estimate of the cost of smoke damage to the fire protection system component i (not including additional passive fire protection) (\$)
- EFP_{WD_i} = Estimate of the cost of water damage to the fire protection system component i (not including additional passive fire protection) (\$)
- ETD_{SD} = Estimate of the smoke damage as a percentage of the total damage to the building, its fire protection systems and its contents (%)
- ETD_{WD} = Estimate of the water damage as a percentage of the total damage to the building, its fire protection systems and its contents (%)

5.4.3 Ratio of damages to building cost

A ratio of damages to building cost is provided in the economic computer model and is simply the total damages to the building, fire protection systems and contents divided by the total cost of the building, fire protection systems and contents as is shown in equation (85).

$$R_{DC} = \frac{C_D}{C_{Total}} \quad (85)$$

R_{DC} = Ratio of total damages to total building cost

C_{Total} = Total cost of the building, fire protection systems and contents (\$)

C_D = Total cost of damage to the entire building (\$)

5.4.4 Rush construction and reduction of downtime

The rush construction factor and reduction of downtime factor can be used to adjust the cost of direct damages and the cost of downtime. If a business owner wants to get back to normal operating conditions sooner, more workers will have to be hired or work overtime. As a result, the cost of downtime will be reduced and it could be possible for that business to save money if they return to normal operation conditions sooner, although the cost of reconstruction may be higher. The use of the rush construction factor and the reduction of downtime factor is shown in equations (86) and (87) respectively.

$$RCD = C_D \cdot f_{RC} \quad (86)$$

RCD = Damages using rush construction (\$)

C_D = Total cost of damage to the entire building (\$)

f_{RC} = Rush construction factor

$$RDC = C_{D_T(Total)} \cdot f_{RD} \quad (87)$$

RDC = Reduction in downtime cost (\$)

$C_{D_T(Total)}$ = Total cost of downtime (\$)

f_{RD} = Reduction of downtime factor

5.5 Damages and downtime due to fire spread

The economic computer model calculates the damages to the building, fire protection systems and contents due to fire spread. The fire spread computer model has not been developed and therefore, a simplified method will be used to perform the calculations.

A matrix has been developed which contains the probabilities of fire spreading from the compartment of fire origin to other compartments. These probabilities are rough estimates. An example of the set up of the matrix is shown in Table 42 where the probabilities are listed within the table and the fire spread is from compartment f to compartment g . For example, using Table 42, if the compartment of fire origin is

compartment two, the probability of fire spread from compartment two to compartment three is 0.5 (as shown in grey in Table 42). The economic computer model assumes that the fire will spread from only one compartment to another and the conditions where there is fire spreading from more than one source is not considered. The compartment of fire origin (compartment f) must be known. If it is desired not to have fire spread to other compartments and consider only smoke spread, zeros should be used for all probabilities of fire spread.

Table 42: Example of fire spread probability matrix.

To compartment number (g)	From compartment number (f)							
		1	2	3	4	5	6	n
	1	1.0	0.2	0.5	0.4	0.6	0.2	
	2	0.3	1.0	0.6	0.7	0.3	0.9	
	3	0.6	0.5	1.0	0.7	0.6	0.2	
	4	0.7	0.4	0.7	1.0	0.2	0.5	
	5	0.2	0.1	0.2	0.5	1.0	0.1	
	6	0.6	0.3	0.9	0.6	0.2	1.0	
	n							1.0

The smoke computer model is run for each compartment individually with the assumption that there will be a fire in each compartment to simulate fire spread. For each of the runs produced by the smoke computer model, the economic computer model is run to obtain the following data for each compartment:

1. Damage to the building and fire protection systems (\$)
2. Damage to contents (\$)
3. Amount of downtime (days)
4. Estimate of the cost of damage to contents due to temperature (\$)
5. Estimate of the cost of damage to contents due to smoke (\$)
6. Estimate of the cost of damage to contents due to water (\$)
7. Cost of damage to building construction (includes building components, basic building construction and additional passive fire protection) (\$)
8. Estimate of the cost of damage to fire protection systems due to temperature (\$)
9. Estimate of the cost of damage to fire protection systems due to smoke (\$)
10. Estimate of the cost of damage to fire protection systems due to water (\$)

The above data is automatically entered into a text file and is used to simulate the effect of fire spread where the cost of damage, estimate of damage or amount of downtime for compartment j can be calculated using equation (88). Equation (88) assumes that the damages from smoke spread and fire spread are mutually exclusive. The calculations shown in the previous sections with respect to the cost of damages,

estimate of damages and downtime are performed twice, once assuming that there is only smoke spread throughout the building and the second, assuming that there is a fire in each compartment. These calculations are combined using equation (88).

$$TFS(j) = DamageSS(j) \times [1 - P_{FS}(i, j)] + DamageFS(j) \times [P_{FS}(i, j)] \quad (88)$$

$TFS(j)$ = Total cost of damage, estimate of damage or amount of downtime for compartment j taking into account smoke spread and fire spread

$DamageSS(j)$ = Cost of damage, estimate of damage or the amount of downtime for compartment j taking into account only smoke spread

$DamageFS(j)$ = Cost of damage, estimate of damage or the amount of downtime if there is a fire in compartment j

$P_{FS}(i, j)$ = Probability of fire spreading from compartment i to compartment j

6.0 PREDICTIONS OF THE ECONOMIC COMPUTER MODEL

In this chapter, predictions made by the economic computer model will be discussed using a case study. The effects of changing the values of the calibration factors will also be examined. Appendix D illustrates the statistics on fire damage. It was found that these statistics cannot be readily compared to any case studies since their value range is large and the data is limited in most cases. The data analyzed from the Ontario Fire Marshall's office seems to indicate that utilizing these fire statistics for losses will not provide an indication of the damages for any given scenario. Therefore, these scenarios are only comparable to each other.

6.1 Case study description

A case study was performed to assess the economic computer model's performance and usefulness. The building chosen for the case study was the Carleton Technology and Training Centre (CTTC) building located on the Carleton University Campus. This CTTC building has four floors and is a typical office/commercial type building. The CTTC building is also used in case studies for the smoke computer model and the occupant behaviour and evacuation computer models. The CTTC building will be used in the future in a case study to assess the entire fire hazard and fire risk analysis computer model.

Figures 11-14 represent the floor plans of the CTTC building. The diagrams are not to scale and do not physically represent the actual floor plans but are merely the assumed floor plans as they are applied to the smoke computer model, the occupant behaviour and evacuation computer model and the economic computer model.

In the economic computer model, compartments are represented by rectangles. However, in Figures 11-14, non-rectangular compartments are shown for clarity. What is labelled as closed (Figures 11-14), are compartments that are always closed and therefore, are not available for analysis. Dotted lines are drawn (Figures 11-14) where there are no walls. Table 43 shows the dimensions of each compartment.

Figure 11: Floor plan of the first floor of the CTTC building.

Figure 12: Floor plan of the second floor of the CTTC building.

Figure 13: Floor plan of the third floor of the CTTC building.

Figure 14: Floor plan of the fourth floor of the CTTC building.

Table 43: Description of the compartments in the CTTC Building.

Description	Room ID	Width (m)	Depth (m)	Ceiling Height (m)
First floor				
Co-op office	1	19.0	20.0	3.0
E-Academy (now Virtual Wave)	2	12.0	13.0	3.0
Parking services	3	15.0	10.0	3.0
Prescription pharmacy	4	8.0	7.0	3.0
South corridor	5	11.0	3.0	3.0
Landing area	6	11.0	1.3	3.0
Landing area	7	11.0	1.3	3.0
Atrium 1-3	8	6.0	5.0	11.5
Atrium 1-2 (East Entrance)	9	10.0	3.0	7.5
Exit 1	33	12.0	1.3	3.0
Exit 2	34	21.0	1.3	3.0
West corridor	35	3.0	12.0	3.0
East corridor	36	3.0	18.0	3.0
West entrance	46	5.0	3.0	3.0
Second floor				
Health and counselling	10	28.0	20.0	3.5
Soft Capital Inc.	11	13.0	10.0	3.5
Office	12	10.0	16.0	3.5
Dental clinic	13	12.0	11.0	3.5
Virtual Wave (now part of Dental clinic)	14	14.0	9.0	3.5
Treats Coffee	15	8.0	12.0	3.5
South corridor	16	11.0	3.0	3.5
Landing area	17	11.0	1.3	3.5
Landing area	18	11.0	1.3	3.5
West corridor	37	3.0	19.0	3.5
East corridor	38	3.0	19.0	3.5
North corridor	39	11.0	3.0	3.5
West entrance	47	5.0	3.0	3.5

Table 43 continued...

Description	Room ID	Width (m)	Depth (m)	Ceiling Height (m)
Third floor				
CAOT	19	19.0	21.0	3.0
Bayer Inc.	20	13.0	20.0	3.0
IAPA Training	21	9.0	11.0	3.0
THSAO	22	11.0	21.0	3.0
South corridor	23	11.0	3.0	3.0
Landing area	24	11.0	1.3	3.0
Landing area	25	11.0	1.3	3.0
West corridor	40	3.0	19.0	3.0
East corridor	41	3.0	19.0	3.0
North corridor	42	11.0	3.0	3.0
Fourth floor				
Tempest	26	14.0	21.0	3.0
Building manager	27	16.0	21.0	3.0
Biology department (East)	28	15.0	15.0	3.0
Forintek	29	10.0	15.0	3.0
South corridor	30	11.0	3.0	3.0
Landing area	31	11.0	1.3	3.0
Landing area	32	11.0	1.3	3.0
West corridor	43	3.0	19.0	3.0
East corridor	44	3.0	19.0	3.0
Biology department (North)	45	29.0	13.0	3.0
Extra corridor	48	15.0	3.0	3.0

Table 44 shows the details of the parameters used in the smoke computer model for the different fire scenarios analyzed. Table 45 shows the scenarios that were analyzed using the economic computer model. What is shown in brackets in Table 45 is the probability of the event occurring. The probability of each scenario is derived by multiplying the probabilities given in each row.

Fires in four compartments are considered for the analysis: compartments 3, 15, 22 and 26. A medium t-squared (t^2) fire (see Glossary) is used for the fire scenarios in compartments 3, 15 and 22 while a fast t^2 fire is used for the fire scenarios in compartment 26. A t^2 fire is defined by equation (89) where the values of the growth factors for a medium and fast t^2 fire are $300 \text{ s}/(\text{MW})^{1/2}$ and $150 \text{ s}/(\text{MW})^{1/2}$, respectively (Buchanan, 2002). Medium t^2 fires can be compared to real fires where solid wood desks are burning along with furniture that contains small amounts of plastic. A fast t^2 fire can be compared to real fires where upholstered furniture is burning, as well as thin wood furniture (Buchanan, 2002). The type of fire is used as an input to the smoke computer model. Conservative estimates are used for the maximum heat release rate, fire department notification time, fire response time and fire department setup time.

$$Q = \left(\frac{t}{k} \right)^2 \quad (89)$$

Q = Heat release rate of the fire (MW)

k = Growth factor $s/(MW)^{1/2}$

t = Time (s)

Table 44: Details of the different fire scenarios analyzed.

1 st Floor Parking Office Compartment 3	<ul style="list-style-type: none"> • Medium t^2 fire • Maximum heat release rate of 5 MW • Length of fire is 30 minutes • Fire department notification time is 1 min • Fire department response time is 3 min • Fire department setup time is 5 min
2 nd Floor Restaurant Compartment 15	<ul style="list-style-type: none"> • Medium t^2 fire • Maximum heat release rate of 5 MW • Length of fire is 30 minutes • Fire department notification time is 1 min • Fire department response time is 3 min • Fire department setup time is 5 min
3 rd Floor THSAO Compartment 22	<ul style="list-style-type: none"> • Medium t^2 fire • Maximum heat release rate of 5MW • Length of fire is 30 minutes • Fire department notification time is 1 min • Fire department response time is 3 min • Fire department setup time is 5 min
4 th Floor TEMPEST Compartment 26	<ul style="list-style-type: none"> • Fast t^2 fire • Maximum heat release rate of 5 MW • Length of fire is 30 minutes • Fire department notification time is 1 min • Fire department response time is 3 min • Fire department setup time is 5 min

Table 45: The scenarios run for the CTTC building using the economic computer model.

Fire Room	Sprinkler ^A	Fire Department ^B	Alarm ^C	Scenario probability	Scenario Number
1 st Floor Parking Office Compartment 3 (0.25)	Yes (0.95)	Yes (0.6)	Yes (0.9)	0.12825	1
			No (0.1)	0.01425	2
		No (0.4)	Yes (0.9)	0.08550	3
			No (0.1)	0.00950	4
	No (0.05)	Yes (0.6)	Yes (0.9)	0.00675	5
			No (0.1)	0.00075	6
		No (0.4)	Yes (0.9)	0.00450	7
			No (0.1)	0.00050	8
2 nd Floor Treats Coffee Compartment 15 (0.25)	Yes (0.95)	Yes (0.6)	Yes (0.9)	0.12825	9
			No (0.1)	0.01425	10
		No (0.4)	Yes (0.9)	0.08550	11
			No (0.1)	0.00950	12
	No (0.05)	Yes (0.6)	Yes (0.9)	0.00675	13
			No (0.1)	0.00075	14
		No (0.4)	Yes (0.9)	0.00450	15
			No (0.1)	0.00050	16
3 rd Floor THSAO Compartment 22 (0.25)	Yes (0.95)	Yes (0.6)	Yes (0.9)	0.12825	17
			No (0.1)	0.01425	18
		No (0.4)	Yes (0.9)	0.08550	19
			No (0.1)	0.00950	20
	No (0.05)	Yes (0.6)	Yes (0.9)	0.00675	21
			No (0.1)	0.00075	22
		No (0.4)	Yes (0.9)	0.00450	23
			No (0.1)	0.00050	24
4 th Floor Tempest Compartment 26 (0.25)	Yes (0.95)	Yes (0.6)	Yes (0.9)	0.12825	25
			No (0.1)	0.01425	26
		No (0.4)	Yes (0.9)	0.08550	27
			No (0.1)	0.00950	28
	No (0.05)	Yes (0.6)	Yes (0.9)	0.00675	29
			No (0.1)	0.00075	30
		No (0.4)	Yes (0.9)	0.00450	31
			No (0.1)	0.00050	32

^A – Sprinklers activate or do not activate.^B – Fire department arrives within specified time or does not arrive.^C – Alarm activates or does not activate.

The predictions of the damages calculated by the economic computer model do not change if there is a fire alarm system but are included since these conditions are required for the completeness of the inputs that are applied to the fire hazard and fire risk analysis computer model. In most cases the activation of a fire alarm will cause a message to be sent to the fire department indicating to them that a fire alarm has went off. This notification is not considered in adjusting the fire department notification time input in the smoke computer model.

When creating the input file for the economic computer model using the smoke computer model and assuming there is a fire in each compartment, the smoke computer model was manually run for each compartment. A fire was simulated in each compartment by closing any openings to the rest of the building and assuming that there was a door opened to the ambient air of size 2.0 m by 0.9 m. The fire assumed in compartments, other than the compartment of fire origin, was a medium t^2 fire with a maximum heat release rate of 3 MW. The maximum heat release rate in compartments other than the compartment of fire origin ensures that fires in the other compartments will not be as large as the fire in the compartment of fire origin. The probabilities of fire spreading for scenarios that do not have sprinklers that activate are shown in Table 46. These probabilities are crude estimates that were calculated using the method described in Section 8.0, Appendix B, and using engineering judgement. After the probabilities were calculated, they were multiplied by a factor of two (having a maximum final probability of one) so that the estimates could be

considered conservative. Discretion should be used when using these calculated probabilities. It should be noted that these probabilities will be considered more accurate when a fire spread computer model is developed. In the cases where sprinklers activate, the probability of fire spread is zero.

The sensitivity categories of the contents in the compartment of fire origin were all set to the threshold category of very high sensitivity. This was done so that a conservative estimate of damages to the contents in the compartment of fire origin could be obtained. The sensitivities in the compartment of fire origin were not hard coded in the programming code of the economic computer model to give the user more flexibility.

Table 46: Probabilities of fire spread for different scenarios.

Compartment	Scenario number							
	5/6	7/8	13/14	15/16	21/22	23/24	29/30	31/32
1	0.04	0.05	0.02	0.06	0.01	0.02	0.10	0.05
2	0.02	0.04	0.02	0.03	0.00	0.00	0.00	0.00
3	1.00	1.00	0.01	0.10	0.03	0.05	0.00	0.00
4	0.02	0.05	0.26	0.16	0.00	0.05	0.00	0.00
5	0.36	0.46	0.10	0.14	0.09	0.09	0.01	0.00
6	0.22	0.37	0.06	0.38	0.05	0.02	0.00	0.01
7	0.26	0.39	0.05	0.40	0.04	0.02	0.01	0.01
8	0.04	0.07	1.00	1.00	0.11	0.17	0.02	0.01
9	0.08	0.13	0.01	0.02	0.02	0.10	0.00	0.03
10	0.01	0.02	0.38	0.39	0.02	0.03	0.09	0.00
11	0.01	0.02	0.49	0.62	0.04	0.07	0.01	0.09
12	0.06	0.09	0.39	0.56	0.07	0.13	0.00	0.01
13	0.18	0.21	0.52	0.62	0.35	0.42	0.01	0.01
14	0.07	0.10	1.00	1.00	1.00	1.00	0.01	0.01
15	0.03	0.05	1.00	1.00	0.39	0.51	0.01	0.01
16	0.14	0.19	1.00	1.00	0.11	0.17	0.02	0.01
17	0.03	0.05	1.00	1.00	0.09	0.18	0.02	0.03
18	0.03	0.05	1.00	1.00	0.09	0.18	0.02	0.03
19	0.00	0.00	0.14	0.18	0.14	0.18	1.00	1.00
20	0.00	0.00	0.17	0.26	0.17	0.26	0.24	0.34
21	0.02	0.03	0.29	0.35	0.29	0.35	0.23	0.31
22	0.00	0.00	1.00	1.00	1.00	1.00	0.14	0.16
23	0.00	0.00	0.58	0.73	0.58	0.73	0.84	0.95
24	0.00	0.00	0.25	0.39	0.25	0.39	0.36	0.51
25	0.00	0.00	0.25	0.39	0.25	0.39	0.36	0.51
26	0.00	0.00	0.00	0.00	0.01	0.01	1.00	1.00
27	0.00	0.00	0.00	0.00	0.01	0.01	0.28	0.28
28	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.08
29	0.00	0.00	0.03	0.04	0.18	0.21	0.14	0.16
30	0.00	0.00	0.01	0.01	0.05	0.07	0.83	0.95
31	0.00	0.00	0.00	0.00	0.02	0.04	0.39	0.54
32	0.00	0.00	0.00	0.00	0.02	0.04	0.39	0.54
33	0.11	0.17	0.11	0.17	0.00	0.01	0.01	0.01
34	0.32	0.39	0.03	0.17	0.01	0.08	0.00	0.00
35	0.04	0.07	0.10	0.14	0.09	0.17	0.01	0.01
36	0.32	0.39	0.10	0.14	0.09	0.02	0.01	0.01

Table 46 continued...

Compartment	Scenario number							
	5/6	7/8	13/14	15/16	21/22	23/24	29/30	31/32
37	0.07	0.10	1.00	1.00	0.11	0.17	0.02	0.03
38	0.07	0.10	1.00	1.00	0.11	0.17	0.02	0.03
39	0.10	0.10	1.00	1.00	0.11	0.17	0.02	0.03
40	0.00	0.00	0.58	0.73	0.58	0.73	0.84	0.95
41	0.00	0.00	0.58	0.73	0.58	0.73	0.84	0.95
42	0.00	0.00	0.58	0.73	0.58	0.73	0.84	0.95
43	0.00	0.00	0.01	0.01	0.05	0.07	0.83	0.95
44	0.00	0.00	0.01	0.01	0.05	0.07	0.83	0.95
45	0.00	0.00	0.00	0.01	0.03	0.04	0.10	0.12
46	0.04	0.07	1.00	1.00	0.11	0.17	0.02	0.03
47	0.07	0.10	1.00	1.00	0.11	0.17	0.02	0.03
48	0.00	0.00	0.01	0.01	0.05	0.07	0.83	0.95

Two cases will be explored in detail to illustrate the capabilities of the economic computer model. These cases include scenarios 3/4 and scenarios 7/8. It should be noted that scenario 3 and 4 will obtain the same results, as well as scenario 7 and 8. This is because the smoke computer model and the economic computer model do not take into consideration the automatic deployment of the fire department when the alarm is activated. Appendix C shows the input files used for scenarios 3/4 for the economic computer model, and the output file produced. What is not shown is the output file of the smoke computer model, the input file of the smoke computer model and the input file for the probability of fire spread (since in scenario 3/4 there are sprinklers and the probability of fire spread is considered zero).

For all scenarios, the cost of building components were determined from Table B3 and Appendix B using the two to four story reinforced concrete frame category and linear interpolation to determine the costs for a building of size 56,400 ft² (5,240 m²). Site development data, as well as downtime data for building components were estimated using engineering judgement.

Most of the contents in the compartments are typical office contents. The contents in the office spaces were adjusted proportionally to the area of the compartments for the following items: books, electronic equipment, upholstered furniture, wood furniture and lighting. The cost of partitions was determined by examining the original floor plans, determining the partition area, and multiplying by a factor of \$2.65/ft² (\$28.52/m²) (cost for 30 min for FRR walls made out of drywall/steel stud framing, see Table B8 and Appendix B). The cost of finishes (\$/ft²) was determined from Table B3 and Appendix B, and multiplied by the floor area of the compartment to obtain the cost per compartment. For compartments that are not typical office compartments (for example Treats Coffee), different contents were added or taken away in the input file depending on the occupancy of the compartment. Threshold categories were determined from Table B19 and Appendix B.

A walk through the CTTC building was done to determine what fire protection systems the building had. Conservative estimates were made and costs and amount of downtime were determined from Table B5 and Appendix B. Threshold categories for

fire protection systems were determined using engineering judgement, for example, when a sprinkler head activates the sprinkler head is considered to be 100% damaged or when plastic reaches its melting point, detectors are considered to be 100% damaged. Yearly maintenance, inspection and replacement costs were determined by either using Table 25 or by assuming that these costs were each 0.5% of the sum of the labour and capital cost.

Interior walls were assumed to have a FRR of 60 minutes at a cost of \$4.27/ft² (\$45.96/m²) and made of drywall/steel stud framing (see Table B8 and Appendix B). Exterior walls were assumed to have a FRR of 120 minutes and an average cost of \$48.00/ft² (\$516.67/m²) (see Table B10 and Appendix B). Ceiling and floor assemblies were taken to be steel joists, beams and slab on columns with a 5/8 inch (15.9 mm) layer of gypsum board, an assumed FRR of 120 minutes at an average cost of 16.40/ft² (\$176.53/m²) (see Table B13 and Appendix B). Interior and exterior doors were assumed to have a 90 minute fire rating at a cost of \$330 and \$500 respectively. Windows were assumed to have a 20 minute fire rating at a cost of \$1,715. If a door or wall was shared between compartments, the cost of the component was determined through a weighted average. A weighted average can be taken for the cost and the FRR of a wall assembly if the wall has a portion which is an exterior wall where the other portion is an interior wall shared with another compartment (see section 5.1, Appendix B). For downtime factors, engineering judgement was used (i.e., walls are fairly important since a business in a building

cannot operate without them, therefore, a high downtime factor was chosen). For the repair/replacement times, it was assumed that it took half a day to build an assembly that was 600 ft² (55.74 m²), and therefore, using the areas of the assemblies, the repair/replacement times were determined.

Basic costs were as follows:

- Cost of a basic wall assembly was \$24.88/ft² (\$267.81/m²) (Table B10 and Appendix B)
- Cost of doors was half the cost of interior doors (i.e., \$165/door) since most doors are shared (Table B16 and Appendix B)
- Cost of basic window was \$1,715/window (Table B17 and Appendix B)
- Cost of basic ceiling and floor assemblies was \$10.24/ft² (\$110.22/m²) (Table B13 and Appendix B)

A rush construction factor of two and a reduction of downtime factor of 0.5 was used. These factors were based on judgement. For the building components calibration factor, the building construction calibration factor, as well as the extinguishment calibration factor, a factor of one was used as these factors are included in the economic computer model for future flexibility.

6.2 Compartment conditions

The compartment conditions in the compartment of fire origin for scenarios 3/4 and 7/8 as calculated by the smoke computer model are shown in Figures 15-17. The smoke computer model provides compartment conditions for all compartments in the building. The compartment conditions in the compartment of fire origin are given as a sample of the data used from the smoke computer model.

Figure 15 shows the temperature of the upper layer versus time curves for scenarios 3/4 and 7/8. Temperature-time data is used for the calculation of damages to a compartment's assemblies, doors and windows, building components, contents, and fire protections systems. When sprinklers activate (scenario 3/4) the temperature in the compartment of fire origin is less than when the sprinklers do not activate (scenario 7/8). The bump in the curve for scenario 7/8 at 520 seconds is a result of the sudden decrease of the heat release rate as shown in Figure 17.

Figure 15: Upper layer temperature-time curves obtained from the smoke computer model for the compartment of fire origin for scenarios 3/4 and 7/8.

Figure 16 shows the soot concentration versus time curves for scenarios 3/4 and 7/8.

The soot concentration is calculated using a mass basis. The highest concentration of soot is used to determine the damages to contents, fire protection systems (not including additional fire protection) and emergency systems. When sprinklers activate (scenario 3/4) the soot concentration in the compartment of fire origin is less than when the sprinklers do not activate (scenario 7/8).

Figure 16: Soot concentration-time curves obtained from the smoke computer model for the compartment of fire origin for scenarios 3/4 and 7/8.

Figure 17 shows the heat release rate versus time curves for scenarios 3/4 and 7/8. The area under the heat release rate-time curve is used in the calculation of the amount of water needed to extinguish the fire. When sprinklers activate (scenario 3/4) the heat release rate is less than when the sprinklers do not activate (scenario 7/8).

As shown in Figure 17 for scenario 7/8, an abrupt dip and subsequent climb in the heat release rate is observed. This phenomenon is caused by incomplete combustion in the compartment of fire origin (Fu, 2004). The smoke computer model is a two-zone

model (see Glossary). The smoke computer model assumes that if the upper layer oxygen concentration is less than 10% of the total concentration of gases, the oxygen in the upper layer will not be available for combustion (Fu, 2004). The calculation of the heat release rate is based on the available oxygen and since the smoke layer is fairly low at this point, not much oxygen can be provided to the fire by the lower layer causing the abrupt dip in the heat release rate (Fu, 2004). The subsequent climb in the heat release rate occurs due to the instability of the smoke computer model. After the small climb in the heat release rate the simulation stabilizes and the heat release rate curve becomes smooth (Fu, 2004).

For scenario 3/4, an unusual climb is observed at approximately 620 seconds. This phenomenon is related to the effectiveness of the sprinklers (Fu, 2004). Up until the activation temperature of the sprinklers, the heat release rate follows a medium t^2 relationship. The heat release rate is adjusted using the equation (90) (Fu, 2004).

$$\dot{Q}_A = \dot{Q}_S + (1 - S_{eff}) \cdot (\dot{Q}_O - \dot{Q}_S) \quad (90)$$

$\dot{Q}_A$ = Adjusted heat release rate (MW)

$\dot{Q}_S$ = Heat release rate assuming sprinklers are 100% effective (MW)

S_{eff} = Effectiveness of sprinklers

Q_o = Input heat release rate (MW)

A medium t^2 fire with a maximum heat release rate of 5 MW is the input heat release time curve. The effectiveness of the sprinklers was set to 0.9 in scenario 3/4. The heat release rate assuming sprinklers are 100% effective is decreasing after the activation of the sprinklers while Q_o increases until 671 seconds and then plateaus at 5 MW. Therefore, there will be a point where the heat release rate increases before 671 seconds (from approximately 620 seconds to 670 seconds) then starts to decrease again as shown in Figure 17.

Figure 17: Heat release rate-time curves obtained from the smoke computer model for the compartment of fire origin for scenarios 3/4 and 7/8.

6.3 Case study predictions

The results of the case studies performed using the economic computer model are shown in Tables 47-49 with the nomenclature used in the tables described at the bottom of the tables. When percentages are given in Tables 47-79, they may not add up to 100% due to rounding.

Table 47: Predictions of the economic computer model for scenarios (3/4) and (7/8).

Description	Predictions with sprinklers activating Scenario (3/4)	Predictions without sprinklers activating Scenario (7/8)
<u>Overall results</u>		
<i>Costs</i>		
• Total cost of the building (contents, fire protection systems and emergency systems included)	\$10,251,348.82	\$10,251,348.82
• Total annual cost for fire protection systems and emergency systems	\$14,295.00	\$14,295.00
<i>Damages</i>		
• Total cost of direct damages	\$82,372.20	\$261,848.27
<i>Downtime</i>		
• Total downtime days	2.0	63.0
• Total cost of downtime	\$30,000.00	\$945,000.00
• Total damages (direct + indirect)	\$112,372.20	\$1,206,848.27
<i>Ratio</i>		
• Ratio of direct damage/total building cost	0.008	0.026

Table 47 continued...

Description	Predictions with sprinklers activating Scenario (3/4)	Predictions without sprinklers activating Scenario (7/8)
<i>% Damages</i>		
<ul style="list-style-type: none"> Approximate damage to the entire building due to temperature as a percentage of the total damages 	81.8%	29.4%
<ul style="list-style-type: none"> Approximate damage to the entire building due to smoke as a percentage of the total damages 	6.1%	61.3%
<ul style="list-style-type: none"> Approximate damage to the entire building due to water as a percentage of the total damages 	12.1%	9.3%
<i>Factors</i>		
<ul style="list-style-type: none"> Cost of direct damages using a rush construction factor of 2 	\$164,744.40	\$523,696.54
<ul style="list-style-type: none"> Cost of indirect damages using a downtime reduction factor of 0.5 	\$15,000.00	\$472,500.00
<ul style="list-style-type: none"> Total cost of damages 	\$179,744.40	\$996,196.54
<i>Detailed results</i>		
<i>Costs</i>		
<ul style="list-style-type: none"> Building construction 	\$6,409,388.44	\$6,409,388.44
<ul style="list-style-type: none"> Contents 	\$2,085,767.00	\$2,085,767.00
<ul style="list-style-type: none"> Capital active fire protection systems 	\$542,212.95	\$542,212.95
<ul style="list-style-type: none"> Yearly active fire protection systems 	\$13,395.00	\$13,395.00
<ul style="list-style-type: none"> Capital passive fire protection systems 	\$1,191,432.90	\$1,191,432.90
<ul style="list-style-type: none"> Yearly passive fire protection systems 	\$0.00	\$0.00
<ul style="list-style-type: none"> Capital emergency fire protection systems 	\$22,547.52	\$22,547.52
<ul style="list-style-type: none"> Yearly emergency fire protection systems 	\$900.00	\$900.00

Table 47 continued...

Description	Predictions with sprinklers activating Scenario (3/4)	Predictions without sprinklers activating Scenario (7/8)
<u>Detailed results</u>		
<i>Damages</i>		
<ul style="list-style-type: none"> Cost of damages to building construction and fire protection systems 	\$31,878.87	\$110,235.31
<ul style="list-style-type: none"> Cost of damages to building contents 	\$50,493.33	\$151,612.96
<ul style="list-style-type: none"> Approximate damage to the contents due to temperature as a percentage of the total damages to the contents 	85.2%	20.5%
<ul style="list-style-type: none"> Approximate damage to the contents due to smoke as a percentage of the total damages to the contents 	7.4%	73.4%
<ul style="list-style-type: none"> Approximate damage to the contents due to water as a percentage of the total damages to the contents 	7.4%	6.1%

Table 48: Predictions of the economic computer model by compartment for scenario 3/4.

ID	Damage to building and FP systems	C_{CC}	C_{DCT}	Total damage	EC_{TD}	EC_{SD}	EC_{WD}	D_T (Total)
	(\$)	(\$)	(\$)	(\$)	(%)	(%)	(%)	(days)
1	352	160,175	0	352	0	0	0	0.0
2	155	64,595	0	155	0	0	0	0.0
3	24,335	49,190	49,190	73,525	33	33	33	1.9
4	14	80,835	920	934	100	0	0	0.0
5	1,365	5,505	0	1,365	0	0	0	0.0
6	0	1,695	0	0	0	0	0	0.0
7	7	1,225	0	7	0	0	0	0.0
8	131	3,765	0	131	0	0	0	0.0
9	56	3,885	0	56	0	0	0	0.0
10	127	240,950	0	127	0	0	0	0.0
11	29	57,570	0	29	0	0	0	0.0
12	33	65,720	0	33	0	0	0	0.0
13	28	103,650	0	28	0	0	0	0.0
14	59	107,670	0	59	0	0	0	0.0
15	52	91,925	383	435	100	0	0	0.0
16	27	4,235	0	27	0	0	0	0.0
17	10	1,695	0	10	0	0	0	0.0
18	10	1,695	0	10	0	0	0	0.0
19	166	167,085	0	166	0	0	0	0.0
20	55	109,740	0	55	0	0	0	0.0
21	33	34,835	0	33	0	0	0	0.0
22	113	97,180	0	113	0	0	0	0.0
23	28	4,235	0	28	0	0	0	0.0
24	15	1,695	0	15	0	0	0	0.0
25	11	1,695	0	11	0	0	0	0.0
26	6	119,230	0	6	0	0	0	0.0
27	7	140,701	0	7	0	0	0	0.0
28	11	59,770	0	11	0	0	0	0.0
29	2	63,630	0	2	0	0	0	0.0
30	8	4,235	0	8	0	0	0	0.0

Table 48 continued...

ID	Damage to building and FP systems	C_{CC}	C_{DCT}	Total damage	EC_{TD}	EC_{SD}	EC_{WD}	D_T (Total)
	(\$)	(\$)	(\$)	(\$)	(%)	(%)	(%)	(days)
31	12	1,695	0	12	0	0	0	0.0
32	6	1,695	0	6	0	0	0	0.0
33	0	1,835	0	0	0	0	0	0.0
34	26	3,250	0	26	0	0	0	0.0
35	548	4,590	0	548	0	0	0	0.0
36	3,564	6,940	0	3,564	0	0	0	0.1
37	66	7,295	0	66	0	0	0	0.0
38	41	7,295	0	41	0	0	0	0.0
39	27	4,235	0	27	0	0	0	0.0
40	76	7,295	0	76	0	0	0	0.0
41	41	7,295	0	41	0	0	0	0.0
42	28	4,235	0	28	0	0	0	0.0
43	9	7,295	0	9	0	0	0	0.0
44	20	7,295	0	20	0	0	0	0.0
45	3	153,040	0	3	0	0	0	0.0
46	117	2,353	0	117	0	0	0	0.0
47	40	2,353	0	40	0	0	0	0.0
48	10	5,765	0	10	0	0	0	0.0

C_{CC} = Cost of contents in compartment (\$)

C_{DCT} = Total cost of the damages in compartment (\$)

EC_{TD} (%) = Estimate of the temperature damage to all of the contents in the compartment (%)

EC_{SD} (%) = Estimate of the smoke damage to all of the contents in the compartment (%)

EC_{WD} (%) = Estimate of the water damage to all of the contents in the compartment (%)

D_T (Total) = Total amount of downtime (days)

Table 49: Predictions of the economic computer model by compartment for scenario 7/8.

ID	Damage to building and FP systems	C_{CC}	C_{DCT}	Total damage	EC_{TD}	EC_{SD}	EC_{WD}	D_T (Total)
	(\$)	(\$)	(\$)	(\$)	(%)	(%)	(%)	(days)
1	3,702	160,175	8,009	11,711	34	32	34	2.7
2	1,652	64,595	2,584	4,236	34	33	34	2.3
3	35,178	49,190	49,190	84,368	33	33	33	2.2
4	1,084	80,835	6,227	7,310	97	2	2	2.3
5	7,836	5,505	5,505	13,341	67	18	16	0.5
6	2,246	1,695	627	2,873	35	31	35	0.4
7	2,330	1,225	478	2,808	35	30	35	0.4
8	1,231	3,765	264	1,495	34	32	34	0.5
9	2,198	3,885	505	2,703	34	32	34	0.6
10	2,115	240,950	4,819	6,934	35	30	35	3.1
11	722	57,570	1,151	1,874	34	33	34	2.2
12	3,525	65,720	5,915	9,440	34	33	34	2.2
13	7,158	103,650	21,767	28,924	33	33	33	2.8
14	3,564	107,670	11,869	15,432	3	93	3	2.7
15	1,571	91,925	7,803	9,374	15	83	2	2.7
16	2,321	4,235	805	3,126	34	32	34	0.5
17	356	1,695	85	441	35	29	35	0.5
18	322	1,695	85	406	36	29	36	0.5
19	306	167,085	3,175	3,481	0	100	0	2.8
20	124	109,740	0	124	0	0	0	2.5
21	896	34,835	3,660	4,555	1	98	1	1.7
22	193	97,180	3,953	4,146	0	100	0	2.5
23	84	4,235	0	84	0	0	0	0.6
24	47	1,695	0	47	0	0	0	0.5
25	23	1,695	0	23	0	0	0	0.5
26	13	119,230	0	13	0	0	0	2.5
27	20	140,701	0	20	0	0	0	2.7
28	24	59,770	0	24	0	0	0	2.4
29	5	63,630	0	5	0	0	0	2.3
30	14	4,235	0	14	0	0	0	0.6

Table 49 continued...

ID	Damage to building and FP systems	C_{CC}	C_{DCT}	Total damage	EC_{TD}	EC_{SD}	EC_{WD}	D_T (Total)
	(\$)	(\$)	(\$)	(\$)	(%)	(%)	(%)	(days)
31	20	1,695	0	20	0	0	0	0.5
32	8	1,695	0	8	0	0	0	0.5
33	1,231	1,835	312	1,543	34	33	34	0.5
34	4,729	3,250	1,268	5,997	34	32	34	0.6
35	4,111	4,590	2,338	6,450	95	2	2	0.6
36	11,188	6,940	6,940	18,128	70	17	13	0.7
37	1,837	7,295	730	2,566	34	32	34	0.8
38	1,766	7,295	730	2,495	34	32	34	0.8
39	1,250	4,235	424	1,673	34	32	34	0.5
40	220	7,295	0	220	0	0	0	0.8
41	99	7,295	0	99	0	0	0	0.8
42	84	4,235	0	84	0	0	0	0.6
43	13	7,295	0	13	0	0	0	0.6
44	33	7,295	0	33	0	0	0	0.8
45	10	153,040	0	10	0	0	0	2.7
46	1,660	2,353	165	1,825	34	33	34	0.3
47	1,099	2,353	235	1,334	34	33	34	0.3
48	18	5,765	0	18	0	0	0	0.3

C_{CC} = Cost of contents in compartment (\$)

C_{DCT} = Total cost of the damages in compartment (\$)

EC_{TD} (%) = Estimate of the temperature damage to all of the contents in the compartment (%)

EC_{SD} (%) = Estimate of the smoke damage to all of the contents in the compartment (%)

EC_{WD} (%) = Estimate of the water damage to all of the contents in the compartment (%)

D_T (Total) = Total amount of downtime (days)

Figures 18-20 show the screen captures produced by the economic computer model for scenario 3/4 while Figures 21-23 show the screen captures produced by the economic computer model for scenario 7/8. Figure 18 shows the total damages per compartment for scenario 3/4. In scenario 3/4 most of the damage occurs in the compartment of fire origin since the probability of fire spread to other compartment is zero. As shown in Figures 18-20, most of the damage occurs in the compartment of fire origin with minimal damage occurring in other compartments if there are sprinklers which activate. The only major damages to contents were seen in the compartment of fire origin and compartment 36 which is the hallway right beside the compartment of fire origin. Negligible damage can be seen in compartments far from the compartment of fire origin.

Figure 21 illustrates the total damages per compartment for scenario 7/8. Damage is greatest in the compartment of fire origin and is lowest in compartments that are far away from the compartment of fire origin. Figure 22 and 23 illustrate that most of the direct and indirect damages occurs in the compartment of fire origin while the cost of damage in compartments far away from the compartment of fire origin is lower. The damage obtained is very dependant on the probabilities of fire spread.

Figure 18: Screen output for the total damages per compartment for scenario 3/4.

Figure 19: Screen output for the damages to contents and the damages to building construction and fire protection systems per compartment for scenario 3/4.

Figure 20: Screen output for the total amount of downtime per compartment for scenario 3/4.

Figure 21: Screen output for the total damages per compartment for scenario 7/8.

Figure 22: Screen output for the damages to contents and the damages to building construction and fire protection systems per compartment for scenario 7/8.

Figure 23: Screen output for the total amount of downtime per compartment for scenario 7/8.

6.4 Fire cost expectation description

In this section the fire cost expectation (defined by equation (91)) is discussed. In the future the fire cost expectation will be calculated by the fire cost expectation computer module.

$$FCE = (C_{FP} + C_{TFPC}) + (P/A, i_f, N) \quad (91)$$

FCE = Fire cost expectation (\$)

C_{FP} = Cost of fire protection systems (\$)

C_{TFPC} = Total cost of additional passive fire protection in building (\$)

$(P/A, i_f, N)$ = Present worth of annual costs and losses, defined by equation (92),
based on the continuous compounding of the market interest rate

i_f = Market interest rate as defined by equation (94)

N = Design life of the building (years)

The present worth of the total annual costs for fire protection systems and the expected annual fire loss of all scenarios is calculated using equation (92). Equation (92) assumes continuous compounding and single payments at the end of the year for the total annual costs for fire protection systems and their expected annual fire losses for all scenarios analyzed. It should be noted that continuous compounding will increase the importance of the interest rate (Riggs et al., 1997). A similar approach was used by Platt et al., (1994) in the development of their loss cost index shown by equation (20) (see Chapter 2, Literature review).

$$(P/A, i_f, N) = A \left(\frac{e^{i_f N} - 1}{e^{i_f N} (e^{i_f} - 1)} \right) \quad (92)$$

$(P/A, i_f, N)$ = Present worth of annuity amount (\$)

A = Annuity amount (\$/year) as described by equation (93)

i_f = Market interest rate as defined by equation (94)

N = Design life of building (years)

$$A = C_Y + F_{Loss} \quad (93)$$

A = Annuity amount (\$/year)

C_Y = Total annual costs for fire protection systems (\$/year)

F_{Loss} = Expected annual fire loss for all scenarios analyzed (\$/year)

$$i_f = (1 + i)(1 + f) - 1 \quad (94)$$

i_f = Market interest rate

i = Interest rate as a fraction

f = Inflation rate as a fraction

Similarly, equation (92) is used to adjust both the total cost of additional passive fire protection and the expected annual loss due to fire.

Equation (95) defines the expected annual fire loss.

$$AFL = Freq_{AF} \cdot F_{Loss} \quad (95)$$

AFL = Expected annual fire loss (\$/year)

$Freq_{AF}$ = Frequency of having a fire (fires/year)

F_{Loss} = Expected annual fire loss for all scenarios analyzed (\$/year) defined by equation (96)

$$F_{Loss} = \sum_{i=1}^n (P_{Scenario} \times C_D)_i \quad (96)$$

F_{Loss} = Expected annual fire loss for all scenarios analyzed (\$/year)

$P_{Scenario}$ = Probability of scenario i occurring

C_D = Total cost of damage to the entire building in scenario i (\$)

n = Number of scenarios

6.5 Fire cost expectation results

In this section the results for the calculations for the fire cost expectation will be shown. Four different variations of the CTTC building will be used in order to compare the impact of sprinklers systems and the arrival of the fire department. The buildings variations are named A, B, C and D. Building variation A will use all of the scenarios listed in Table 45. Table 50 shows the cost of the predicted total damage for all scenarios listed in Table 45. Building variation B will use the scenarios listed in Table 51. Table 51 also shows the cost of the predicted total damage for each of the scenarios in building variation B. Building variation C will use the scenarios listed in Table 52. Table 52 also shows the predicted total damage for each of the scenarios in building variation C. Building variation D will use the scenarios listed in Table 53. Table 53 also shows the total predicted damage for each of the scenarios in building variation D.

Table 50: The predicted cost of the total damage for all scenarios in CTTC building (variation A).

Scenario Number	Cost of damages \$1000
1	110.3
2	110.3
3	112.2
4	112.2
5	1103.6
6	1103.6
7	1206.8
8	1206.8
9	143.7
10	143.7
11	147.3
12	147.3
13	1905.5
14	1905.5
15	2082.8
16	2082.8
17	227.4
18	227.4
19	227.5
20	227.5
21	1609.2
22	1609.2
23	1753.6
24	1753.6
25	288.8
26	288.8
27	288.9
28	288.9
29	1914.3
30	1914.3
31	2002.9
32	2002.9

Table 51: The scenarios run for the CTTC building (variation B) using the economic computer model along with the predicted cost of the total damage.

Fire Room	Fire Department ^A	Alarm ^B	Scenario probability	Scenario Number	Cost of damages \$1000
1 st Floor Parking Office Compartment 3 (0.25)	Yes (0.6)	Yes (0.9)	0.135	1	1069.4
		No (0.1)	0.015	2	1069.4
	No (0.4)	Yes (0.9)	0.090	3	1170.2
		No (0.1)	0.010	4	1170.2
2 nd Floor Treats Coffee Compartment 15 (0.25)	Yes (0.6)	Yes (0.9)	0.135	5	1820.6
		No (0.1)	0.015	6	1820.6
	No (0.4)	Yes (0.9)	0.090	7	1988.6
		No (0.1)	0.010	8	1988.6
3 rd Floor THSAO Compartment 22 (0.25)	Yes (0.6)	Yes (0.9)	0.135	9	1549.6
		No (0.1)	0.015	10	1549.6
	No (0.4)	Yes (0.9)	0.090	11	1687.6
		No (0.1)	0.010	12	1687.6
4 th Floor Tempest Compartment 26 (0.25)	Yes (0.6)	Yes (0.9)	0.135	13	1826.7
		No (0.1)	0.015	14	1826.7
	No (0.4)	Yes (0.9)	0.090	15	1914.1
		No (0.1)	0.010	16	1914.1

^A – Fire department arrives within specified time or does not arrive.

^B – Alarm activates or does not activate.

Table 52: The scenarios run for the CTTC building (variation C) using the economic computer model along with the predicted cost of the total damage.

Fire Room	Sprinkler ^A	Alarm ^B	Scenario probability	Scenario Number	Cost of damages \$1000
1 st Floor Parking Office Compartment 3 (0.25)	Yes (0.95)	Yes (0.9)	0.21375	1	112.2
		No (0.1)	0.02375	2	112.2
	No (0.05)	Yes (0.9)	0.01125	3	1206.8
		No (0.1)	0.00125	4	1206.8
2 nd Floor Restaurant Compartment 15 (0.25)	Yes (0.95)	Yes (0.9)	0.21375	5	147.3
		No (0.1)	0.02375	6	147.3
	No (0.05)	Yes (0.9)	0.01125	7	2082.8
		No (0.1)	0.00125	8	2082.8
3 rd Floor THSAO Compartment 22 (0.25)	Yes (0.95)	Yes (0.9)	0.21375	9	227.5
		No (0.1)	0.02375	10	227.5
	No (0.05)	Yes (0.9)	0.01125	11	1753.6
		No (0.1)	0.00125	12	1753.6
4 th Floor Tempest Compartment 26 (0.25)	Yes (0.95)	Yes (0.9)	0.21375	13	288.9
		No (0.1)	0.02375	14	288.9
	No (0.05)	Yes (0.9)	0.01125	15	2002.9
		No (0.1)	0.00125	16	2002.9

^A – Sprinklers activate or do not activate.

^B – Alarm activates or does not activate.

Table 53: The scenarios run for the CTTC building (variation D) using the economic computer model along with the predicted cost of the total damage.

Fire Room	Alarm ^A	Scenario probability	Scenario Number	Cost of damages \$1000
1 st Floor Parking Office Compartment 3 (0.25)	Yes (0.9)	0.225	1	1206.8
	No (0.1)	0.025	2	1206.8
2 nd Floor Treats Coffee Compartment 15 (0.25)	Yes (0.9)	0.225	3	2082.8
	No (0.1)	0.025	4	2082.8
3 rd Floor THSAO Compartment 22 (0.25)	Yes (0.9)	0.225	5	1753.6
	No (0.1)	0.025	6	1753.6
4 th Floor Tempest Compartment 26 (0.25)	Yes (0.9)	0.225	7	2002.9
	No (0.1)	0.025	8	2002.9

^A – Alarm activates or does not activate.

In order to calculate the fire cost expectation, the capital costs and annual costs for fire protection systems (including additional passive fire protection), as well as the expected annual fire loss are needed and are shown in Table 54. A probability of 7.68×10^{-6} per m² of floor area per year is used for Canadian office buildings (Gaskin and Yung, 1993) and is used in the calculation of expected annual fire loss.

Table 54: Capital costs, annual costs and expected fire loss per year for different scenarios.

Building Variation	Building scenario	$C_{FP} + C_{TFPC}$ (\$)	C_Y (\$/year)	F_{Loss} (\$/year)
A	• Building includes sprinklers, alarm system and there is the potential for the fire department to respond to a fire	1,756,200	14,300	10,773
B	• Building includes alarm system and there is the potential for the fire department to respond to a fire	1,502,000	12,300	65,033
C	• Building includes sprinklers and alarm system	1,756,200	14,300	10,960
D	• Building includes alarm system	1,502,000	12,300	70,889

C_{FP} = Cost of fire protection systems (\$)

C_{TFPC} = Total cost of additional passive fire protection in building (\$)

C_Y = Total annual costs for fire protection systems (\$/year)

F_{Loss} = Expected annual fire loss for all scenarios (\$/year)

In order to calculate the fire cost expectation, the present worth of annual costs and expected fire losses must be calculated. Table 55 shows the present worth of annual costs and expected fire losses with fire cost expectations and the relative fire cost expectations for different scenarios using an interest rate of 7% and an inflation rate of 3%. Inflation will affect the fire cost expectation unless the inflation rate is between 2% and 4% per year in which case the inflation rate can be considered negligible (Riggs et al., 1997). Canada's current inflation rate policy as set out by the federal government and the Bank of Canada aims to keep the inflation rate between 1% and 3% per year (Government of Canada, 2004).

Table 55 shows intermediate data that are used in the calculations of the fire cost expectation, as well as the relative fire cost expectation using an interest rate of 7% and an inflation rate of 3%.

Table 55: Present worth of annual costs and expected fire losses with fire cost expectation and relative fire cost expectation for different scenarios using an interest rate of 7% and an inflation rate of 3%.

Building variation	P of C_y (\$)	P of F_{Loss} (\$)	FCE (\$)	Relative FCE
A	122,669	92,411	1,971,280	0.8897
B	105,513	557,868	2,165,381	0.9773
C	122,669	94,021	1,972,890	0.8904
D	105,513	608,108	2,215,620	1.0000
<p>A – Building includes sprinklers, alarm system and there is the potential for the fire department to respond to a fire.</p> <p>B – Building includes alarm system and there is the potential for the fire department to respond to a fire.</p> <p>C – Building includes sprinklers and alarm system.</p> <p>D – Building includes alarm system.</p> <p>P = Present worth (\$)</p> <p>FCE = Fire cost expectation (\$)</p>				

A summary of the fire cost expectations along with the relative fire cost expectations for the different building variations using different interest rates and inflation rates is shown in Table 56. By comparing the results shown in Tables 55 and 56 with respect to the fire cost expectation, it is shown that buildings with sprinklers do reduce the fire cost expectation when interest rates and inflation rates are low to moderately high, but when interest rates and inflation rates are high, sprinklers do not lower the fire cost expectation. As is shown in Tables 55 and 56, if the fire department responds

to the fire, the cost of damage is only slightly smaller than if the fire department did not respond. This is due to input values chosen for fire department notification time, fire response time and fire department setup time.

Table 56: Present worth of annual costs and expected fire losses with fire cost expectation and relative fire cost expectation for different scenarios.

Building variation	Interest rate = 3% Inflation rate = 0%		Interest rate = 7% Inflation rate = 7%		Interest rate = 10% Inflation rate = 10%	
	<i>FCE</i> (\$)	Relative <i>FCE</i>	<i>FCE</i> (\$)	Relative <i>FCE</i>	<i>FCE</i> (\$)	Relative <i>FCE</i>
A	2,190,591	0.744	1,912,705	0.946	1,862,933	1.004
B	2,841,813	0.966	1,984,715	0.982	1,831,201	0.987
C	2,193,842	0.745	1,913,876	0.947	1,863,732	1.004
D	2,943,280	1.000	2,021,272	1.000	1,856,132	1.000
A	– Building includes sprinklers, alarm system and there is the potential for the fire department to respond to a fire.					
B	– Building includes alarm system and there is the potential for the fire department to respond to a fire.					
C	– Building includes sprinklers and alarm system.					
D	– Building includes alarm system.					
<i>FCE</i>	= Fire cost expectation (\$)					

6.6 Effect of calibration factors

In this section the effect of the rush construction factor, the reduction of downtime factor, the building components calibration factor, the building construction calibration factor, as well as the extinguishment calibration factor will be examined. Scenario 7/8 of building variation A will be used in the analysis.

Table 57 shows the effect on damages due to different rush construction factors and, reduction of downtime factors. As shown in Table 57, the higher the rush construction factor or downtime factor, the higher the direct and indirect damages.

Table 57: Effect of rush construction factors and reduction of downtime factors on damages from fire.

Value of rush construction factor	Value of reduction of downtime factor	Direct damages using rush construction factor (\$)	Indirect damages using reduction of downtime factor (\$)	Total damages using adjustment factors (\$)
1	1	261,848.27	945,000.00	1,206,848.27
2	0.5	523,696.54	472,500.00	996,196.54
0.5	2	130,924.13	1,890,000.00	2,020,924.13

Table 58 shows the effect of the building construction calibration factor on the total cost of damage and the damages to building construction and fire protection systems which are coupled together. The higher the calibration factor, the higher the cost of direct damage.

Table 58: Effect of building construction calibration factor on damages from fire.

Value of building construction calibration factor	Total cost direct damage (\$)	Cost of direct damages to building construction and fire protection systems (\$)
0.5	994,780.37	78,167.41
1.0	1,206,848.27	110,235.31
1.5	1,418,878.96	142,266.00
2.0	1,630,877.38	174,264.42
10.0	3,591,662.06	545,049.11

Table 59 shows the effect of the building component calibration factor on the total cost of damage and the damages to building construction and fire protection systems which are coupled together. The higher the component calibration factor, the higher the cost of direct damage.

Table 59: Effect of building component calibration factor on damages from fire.

Value of building component calibration factor	Total cost of damage (\$)	Cost of damages to building construction and fire protection systems (\$)
0.5	\$1,130,510.50	\$93,897.54
1.0	\$1,206,848.27	\$110,235.31
1.5	\$1,283,187.14	\$126,574.18
2.0	\$1,359,524.90	\$142,911.94
10.0	\$2,610,936.95	\$404,323.99

The effects of the extinguishment calibration factor are shown in Tables 60 and 61. Tables 60 and 61 only show the fields that are different using the extinguishment calibration factor. An extinguishment calibration factor of 118 was used. This calibration factor was determined by calculating the largest volume of water per m² (L/m²) in any compartment to extinguish a fire and dividing this number by the calibration factor to obtain a value of 10 L/m² which is the upper threshold value for the category of no sensitivity to water damage for contents and fire protection systems (see Appendix B and Table B21). The cost of damages due to fire does not change but only the estimates for the damage as a percentage of the total damage change with the scenarios used because temperature and smoke will have caused the same amount of damage.

Table 60: Effect on predictions using different extinguishment calibration factors for scenario 7/8.

Description	Results calibration factor =1	Results calibration factor =118
<u>Overall results</u>		
<u>%Damages</u>		
<ul style="list-style-type: none"> Approximate % damage to building, fire protection systems and contents due to temperature 	29.4%	31.7%
<ul style="list-style-type: none"> Approximate % damage to building, fire protection systems and contents to smoke 	61.3%	64.8%
<ul style="list-style-type: none"> Approximate % damage to building, fire protection systems and contents to water 	9.3%	3.5%
<u>Detailed results</u>		
<u>Damages</u>		
<ul style="list-style-type: none"> Approximate percentage damage to entire building due to temperature 	19.2%	21.7%
<ul style="list-style-type: none"> Approximate percentage damage to entire building due to smoke 	78.2%	74.6%
<ul style="list-style-type: none"> Approximate percentage damage to entire building due to water 	2.5%	3.7%

Table 61: Results by compartment using different extinguishment calibration factors for scenario 7/8.

ID	Calibration factor =1			Calibration factor =118		
	EC_{TD}	EC_{SD}	EC_{WD}	EC_{TD}	EC_{SD}	EC_{WD}
	(%)	(%)	(%)	(%)	(%)	(%)
1	34	32	34	51	48	0
2	34	33	34	47	46	6
3	33	33	33	33	33	33
4	97	2	2	97	2	1
5	67	18	16	71	21	8
6	35	31	35	35	31	35
7	35	30	35	35	30	35
8	34	32	34	40	37	23
9	34	32	34	40	37	23
10	35	30	35	55	46	0
11	34	33	34	47	46	8
12	34	33	34	47	47	6
13	33	33	33	41	40	19
14	3	93	3	4	94	2
15	15	83	2	16	84	0
16	34	32	34	42	40	18
17	35	29	35	35	29	35
18	36	29	36	36	29	36
19	0	100	0	0	100	0
20	0	0	0	0	0	0
21	1	98	1	2	98	0
22	0	100	0	0	100	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0
25	0	0	0	0	0	0
26	0	0	0	0	0	0
27	0	0	0	0	0	0
28	0	0	0	0	0	0
29	0	0	0	0	0	0
30	0	0	0	0	0	0
31	0	0	0	0	0	0
32	0	0	0	0	0	0
33	34	33	34	34	33	34

Table 61 continued...

ID	EC_{TD}	EC_{SD}	EC_{WD}	EC_{TD}	EC_{SD}	EC_{WD}
	(%)	(%)	(%)	(%)	(%)	(%)
34	34	32	34	37	36	27
35	95	2	2	96	3	1
36	70	17	13	77	23	0
37	34	32	34	51	49	0
38	34	32	34	51	49	0
39	34	32	34	42	40	18
40	0	0	0	0	0	0
41	0	0	0	0	0	0
42	0	0	0	0	0	0
43	0	0	0	0	0	0
44	0	0	0	0	0	0
45	0	0	0	0	0	0
46	34	33	34	34	33	34
47	34	33	34	34	33	34
48	0	0	0	0	0	0

$EC_{TD}(\%)$ = Estimate of the damage to the contents due to temperature as a percentage of all damages in compartment (%)

$EC_{SD}(\%)$ = Estimate of the damage to the contents due to smoke as a percentage of all damages in compartment (%)

$EC_{WD}(\%)$ = Estimate of the damage to the contents due to water as a percentage of all damages in compartment (%)

7.0 CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS FOR FUTURE WORK

The following chapter gives a discussion of the conclusions, limitations and the future considerations as described by the economic computer model.

7.1 Conclusions

An economic computer model has been developed to calculate the cost of both direct and indirect damages to building construction, fire protection systems and contents that result from fire. The economic computer model also calculates the initial costs of building construction, fire protection systems and contents.

A case study was performed using a four story building located on the campus of Carleton University. The results of this study show that when sprinklers activate, they reduce the cost of damage. In scenario 3/4 (building variation A, sprinklers activated), the indirect losses were 1.4 times larger than the direct losses, while in scenario 7/8 (building variation A, sprinklers did not activate), the indirect losses were 4.6 times larger than the direct losses. As a rule of thumb in the insurance industry, for every dollar of direct damage, there are two dollars of indirect damage (Yuill, 2004). Scenario 3/4 (building variation A) underestimates the cost of indirect damage while scenario 7/8 (building variation A) overestimates the cost of indirect damage. The results for scenario 7/8 compare well to Meade's (1991) estimate that indirect losses

are between three to four times larger than direct losses. In scenario 3/4 (building variation A), the majority of the damage occurred because of temperature conditions, while in scenario 7/8 (building variation A), most of the damages were a result of smoke conditions. This is due to the fact that smoke spread was minimal in scenario 3/4 as opposed to scenario 7/8, where smoke spread was significant in affecting the contents in the building.

In terms of the capital cost of the building, using cost estimates and the default values provided for a building that is 50,000 ft² (4,645 m²), a building with the same characteristics as the CTTC building will cost \$5,951,725 which is comparable to the cost calculated by the economic computer model for building construction (\$6,409,388) since the CTTC building is larger (56,400 ft² or 5,240 m²).

With respect to the fire cost expectation, it is shown that buildings with sprinklers do reduce the fire cost expectation when interest rates and inflation rates are low to moderately high but when interest rates and inflation rates are high, sprinklers do not lower the fire cost expectation. The economic computer model does not consider the benefits of sprinkler systems in regards to the reduction of human injuries and deaths.

In general, it can be concluded that the developed economic computer model can be a useful tool when performing cost-effective calculations to determine optimum fire protection designs for buildings.

7.2 Limitations of the economic computer model

Many elements need to be considered when discussing direct and indirect damages caused by fires. This section describes the areas that were not considered by the economic computer model.

Indirect damages that are not considered by the economic computer model are those such as the value of a human life or the cost of injuries sustained in a fire. Authors such as Hall (1989) and Meade (1991), have attempted to estimate the cost of a human, however, it is highly debatable.

The economic impact to a community may be detrimental if a fire occurs at an important place of business. For example, if the building in which the fire occurs houses the majority of the jobs in a town, the local economy could potentially be destroyed. This impact on a community is not considered by the economic computer model.

Education to employees on procedures in case of a fire can greatly reduce damages due to fire. However, the economic computer model does not consider the cost of education, nor does it consider its subsequent reduction in damage.

Another limitation of the economic computer model is in not taking into account any openings in either the areas of walls, ceilings or floors. Although the costs can be modified to include the cost of an opening, this may be time consuming. Therefore, at the present, the model should give a conservative estimate for the cost of an assembly which excludes the cost of openings. It should be noted that costs may be higher for an assembly if the cost of placing an opening is more than the cost of not having one. The area of a compartment does not take into consideration a door or window embedded in the wall. In the case of basic cost of assemblies, there can be a large discrepancy between, for example, interior and exterior walls. A basic cost for an exterior wall should not be the same as the basic cost for an interior wall because they differ in function.

The model does not take into account firefighting operations that may damage the building, damage the environment from runoff water or cause explosions that may send toxic gases into the atmosphere (Woodward, 1989). The costs of such damage cannot be readily estimated.

The economic computer model does not consider the following:

- New technologies that are being developed (i.e., using close circuit television to detect smoke which can distinguish between smoke and vapour using analog cameras)
- Damage to buildings under construction
- Flow of water down from the fire floor to lower floors
- Spread of smoke in insulation
- Additional damages resulting from weather (i.e., winter)
- Reduction of insurance rates which reduce yearly costs

7.3 Recommendations for future work

The economic computer model does not take into account, the burning of different materials in contents. For example, toys made of polymeric materials, when burned can cause the production of smoke and toxic gases since polymeric materials undergo incomplete combustion (Chow et al., 2002). The contents listed in the economic computer model are not related to the input properties for the smoke computer model. This should be done using an input to the smoke computer model of the properties of the contents used in the economic computer model.

A fire spread computer model has not yet been developed and therefore the damage to a building cannot be properly assessed since the probabilities of fire spread used were

crude estimates. Therefore, files have to be manually created that assume that there is a fire in each compartment and which contain the probability of fire spread. A fire spread computer model is necessary to allow the economic computer model to provide better estimates of fire damages.

Currently, there is no relationship between active fire protection measures and the size of fire (except in the case of sprinklers). The smoke computer model should be modified to consider the impact of other active fire protection systems.

Data for replacement times, downtime factors, building component calibration factor, and building construction calibration factor are limited and require more research to obtain better estimates.

Provisions should also be made to determine clean-up costs if a building collapses. If this is the case, damage to the building will be 100% to 150% of the original building costs (Baldwin, 1974).

Data obtained from the smoke computer model must be equally spaced for the economic computer model to run. Provisions should be made to create a check that confirms that all the data follows the same spacing.

8.0 REFERENCES

- Alvares, N. and A.C. Fernandez-Pello, "Fire initiation and spread in overloaded communication system cable trays", *Experimental Thermal and Fluid Science*, 21, pp. 51-57 (2000).
- Ahrens, M., "Structure fires in selected occupancies: building characteristics, causal factors and incident details 1980-1998 annual averages", National Fire Protection Association, Report prepared for Leslie Richardson, Forintek, Quincy, Massachusetts (July, 2003).
- Anderberg, Y., "Computer simulations and a design method for fire exposed concrete columns", Report 92-50, Fire Safety Design, Lund, Sweden (1993).
- Anderson, G.C., "ISO commercial risk services", AWWA Seminar Proceedings – Fire Protection, American Water Works Association, Denver, Colorado (June, 1986).
- Ashby, M.F. and D.R.H. Jones, "Engineering materials 1: an introduction to their properties and applications", 2nd edition, Butterworth-Heinemann, Boston, Massachusetts (1996), p. 170.
- Babrauskas, V. and R.B. Williamson, "Post-flashover compartment fires: basis of a theoretical model", *Fire and Materials*, 2, 2, pp. 39-53 (1978).
- Baldwin, R., "The use of water in the extinction of fires by brigades", Joint Fire Research Organization, Note #803 (1970).
- Baldwin, R., "Economics of structural fire protection", Building Research Establishment, Based on lectures given at Edinburgh University, course on quantitative methods of risk management (April, 1974), and BRE Symposium on cost-effectiveness and fire protection (October, 1974).
- Baldwin, R. and P.H. Thomas, "Passive and active fire protection – the optimum combination", Fire Research Note number 963, Fire Research Station, London, United Kingdom (1973).
- Barry, T.F., "Risk-informed performance-based industrial fire protection: an alternative to prescriptive codes", Tennessee Valley Publishing, Knoxville, Tennessee (2002), pp. 5-22, 5-24, 5-25, 5-27, 5-48.
- Bengtson, S. and H. Laufke, "Methods of estimation of fire frequencies, personal safety and fire damage", *Fire Safety Journal*, 2, pp. 167-180 (1979/80).

- Bénichou, N., A. Kashef, B. Yager, J. Hum and G. Hadjisophocleous, "FIERASystem Theory report: economic model", Fire Risk Management Program Research Report #122, Institute for Research in Construction, National Research Council of Canada, Ottawa, Ontario (November, 2002).
- Bénichou, N., and M.A. Sultan, "Fire resistance performance of lightweight wood-framed assemblies", *Fire Technology*, 36, 3, pp. 184-219 (2000).
- Bennetts, I.D. and I.R. Thomas, "Design of steel structures under fire conditions", *Progress in Structural Engineering and Materials*, 4, pp. 6-17 (2002).
- Blair, W., "Fire! Survival and prevention", Barnes and Noble books, New York, New York (1983), pp. 63, 64, 65.
- Bolemen, R.A. Jr., "Managing the integration of safety in semiconductor manufacturing", *Solid State Technology*, pp. 63-69 (July, 1989).
- Bradford, M., "Smoke, corrosives damaging in fires", *Business Insurance*, p. 6 (May 28, 1990).
- Buchanan, A.H., "Fire engineering design guide", Centre for Advanced Engineering, University of Canterbury, New Zealand (1994).
- Buchanan, A.H., "Structural design for fire safety", John Wiley and Sons, Inc., Rexdale, Ontario (2002), pp. 31, 32, 33, 44, 45 96, 97, 99, 100, 108, 110, 111, 125.
- Canadian Fire Alarm Association, "Introduction to the fire diction and alarm industry – A reference manual", Prosafe Publications Limited, Markham, Ontario (1992), pp. 71-75, 78-81, 87-95.
- Canadian Wood Council, "Fire safety and insurance in commercial buildings", Canadian Wood Council, (2002).
- Chakrabarti, B., T. Yates and A. Lewry, "Effect of fire damage on natural stonework in buildings", *Construction and Building Materials*, 10, 7, pp. 539-544 (1996).
- Charters, D., "Focus on workplace fire safety – Fire safety at any price?", *Fire Prevention*, 313, pp. 12-15 (October, 1998).
- Chattaway, A., "The development of a hidden fire challenge", *Fire and Materials*, 21, pp. 219-228 (1997).

- Chow, W.K. and W.C.W. Wong, "Experimental studies on the sensitivity of fire detectors", *Fire and Materials*, 18, 4, pp. 221-230 (1994).
- Chow, W.K., B. Yao and M.Y. Ng, "Application of water mist fire suppression systems in small retail shops", *Journal of Fire Sciences*, 20, 6, pp. 479-503 (November, 2002).
- Chubb, M.D. and R.B. Williamson, "Value-based fire safety: a new regulatory model for mitigating human error", *Fire and Materials*, 23, pp. 291-296 (1999).
- Clark, S., "Firefighter's handbook – Essentials of firefighting and emergency response", Delmar Thomson Learning, Independence, Kentucky (2000), pp. 173, 175, 208, 257, 267, 268, 274, 275, 302, 312, 313.
- Clean Room, "What is a clean room?",
<http://www.mvent.com.ph/references/cleanroom.htm>, (2004).
- Cole, D., "Counting the cost", *Fire Chief*, 37, 6, pp. 41-47 (June, 1993).
- Cote, A.E., "Assessing the magnitude of the fire problem", *Fire Protection Handbook – 16th edition*, National Fire Protection Association, Quincy, Massachusetts (1986), pp. 1-1 - 1-15.
- Craig, J., "Smoke alarms are not enough", *Fire Prevention*, 233, pp. 22-23 (October, 1990).
- Daley, P., "Personal correspondence", MBA, P.Eng, Daley Ferraro Associates,
<http://www.dfa-Hovey.com> (2004).
- Dieken, D., "10 myths about industrial fire protection", *Plant Engineering*, pp. 80-86 (June, 2000).
- Dittman, C.R., "Selling management the best fire protection available", *Professional Safety*, pp. 21-26 (October, 1988).
- DLE Engineering, "Cost model, fire detection and alarm systems system analysis", *Building Services Journal*, pp. 21-23 (March, 1998).
- Dowling, J., J. Robinson and E. Crouch, "Sprinklers – The real story", *Fire Prevention*, 257, pp. 18-28 (March, 1993).

- Egan, M.D., "Concepts in building firesafety", John Wiley and Sons, Toronto, Ontario (1978), pp. 30, 79, 83, 104.
- Esposito, D.C., "Supplemental material to thesis: economic impact of fires in buildings", Department of Civil and Environmental Engineering, Carleton University, Ottawa, Ontario (2004).
- Factory Mutual Engineering and Research, "Preserving today's treasures for tomorrow", Fire Prevention, 229, pp. 20-23 (May, 1990).
- Firewise, "Determine the construction classification number", http://www.firewise.org/pubs/operationWater/determine_construction.html, (2004).
- Fontana, M., J.P. Favre and C. Fetz, "A survey of 40,000 building fires in Switzerland", Fire Safety Journal, 32, pp. 137-158 (1999).
- Fry, J.F., "The cost of fire", Fire, 56, pp. 591-594 (1964).
- Fu, Z., "Personal correspondence", Developer of the Carleton University smoke computer model, Carleton University, Ottawa, Ontario (2004).
- Gaskin, J. and D.Yung, "Canadian and U.S.A. fire statistics for use in the risk-cost assessment model", IRC internal Report no. 637, National Research Council of Canada, Ottawa, Ontario (January, 1993).
- Gerald, C.F. and P.O. Wheatley, "Applied numerical analysis", 6th edition, Addison Wesley Longman, Inc., Don Mills, Ontario (1997), pp. 377-378.
- Government of Canada, "Canadian economy online", <http://canadianeconomy.gc.ca>, (2004).
- Hadjisophocleous, G. and N. Bénichou, "Performance criteria used in fire safety design", Automation in Construction, 8, pp. 489-501 (1999).
- Hall, J.R. Jr., "Calculating the total cost of fire in the United States", FIREJournal, pp. 69-72 (March/April, 1989).
- Hasofer, A.M. and M.A. Tat, "Optimal control of sprinklers in compartment fires", Quality and Reliability Engineering International, 13, pp. 209-216 (1997).

- Hixenbaugh, G.W., "Science, technology, and competitiveness", National Institute of Standards and Technology Special publication 837, Gaithersburg, Maryland, pp. 105-115 (1996).
- Hughes-Hallett, D., A.M. Gleason, D.E. Flath, S.P. Gordon, D.O. Lomen, D. Lovelock, W.G. McCallum, B.G. Osgood, A. Pasquale, J.B. Thrash, T.W. Tucker, D. Quinney and O.K. Bretscher, "Calculus: international edition", John Wiley and Sons Inc., Toronto, Ontario (1994), pp. 378-379.
- Hurley, M., "A Research Agenda for fire protection engineering", National Institute of Standards and Technology, NIST GCR 00-791, Gaithersburg, Maryland, (June, 2000).
- IBI Group and Larden Muniak Consulting Inc., "Impact of mandatory sprinklering of multi-unit residential buildings : final report", Canada Mortgage and Housing Corporation, Ottawa, ON (1993), p. 16.
- Johnston, R.E., "Fire prevention: are you up to the challenge?", MIS Week, p. 23, (May 7, 1990).
- Karter, M.J. Jr., "1996 U.S. fire loss", NFPA Journal, pp.77-83 (September/October 1997).
- Klopp, C., "Vulnerability awareness improves contingency planning", Computers and Security, 9, pp. 309-311 (June, 1990).
- Korzeniowski, P., "How to avoid disaster with a recovery plan", Software Magazine, pp. 46-55 (February, 1990).
- Kuffner, W., "Cost factors – Fire Protection systems", Presentation to the Society of Fire Protection Engineers, Ottawa Chapter, Ottawa, Canada (January 29, 2003a).
- Kuffner, W., "Personal correspondence", P.Eng., PMP, Leber-Rubes, 1725 St. Laurent Blvd., Ste. 225, Ottawa, Ontario (2003b).
- Lie, T.T., "Fire and buildings", Applied Science Publishers Limited, London, England (1972a), pp. 211-212, 215-216, 221, 223, 227, 228, 230-231, 238-239.
- Lie, T.T., "Optimum fire resistance of structures", Journal of the Structural Division Proceedings of the American Society of Civil Engineers, 98, ST 1, pp. 215-232 (January, 1972b).

- Lie, T.T., "Safety factors for fire loads", Canadian Journal of Civil Engineering, 6, pp. 617-628 (1979).
- Linder, K.W., "Water supply requirements for fire protection", Fire Protection Handbook, 17th edition, National Fire Protection Association, Quincy, Massachusetts (1981).
- Marvin, B.M., "Automatic sprinkler systems costs – Cost-benefit analysis", Professional Safety, 38, pp. 16-19 (July, 1993).
- Mauzerall, D.L., "Protecting the ozone layer: phasing out halon by 2000", FIREJournal, pp. 22-31 (September/October, 1990).
- McQueen, S., "Fire regulations – So you thought fire safety was about getting people out in time? Not any more. Retrofitting sprinkler system for you fire certificate could cost you a fortune – Depending on the outcome of a test case", Commercial Motor, 12-18, pp. 40-41 (July, 2001).
- Meade, W.P., "First pass at computing the cost of fire safety in a modern society", The Herndon Group Inc., NIST-GCR-91-592, Chapel Hill, North Carolina (1991).
- Melinek, S.J., "Effectiveness of sprinklers in reducing fire severity", Fire Safety Journal, 21, pp. 299-311 (1993).
- Merritt, F.S., "Standard handbook for civil engineers", 3rd edition, McGraw-Hill Book Company, Toronto, Ontario (1983), pp. 11-20 - 11-20.
- Miller, M.J., "Reliability of fire protection systems", Chemical Engineering Progress, 70, 4, pp. 62-67 (April, 1974).
- Minnesota department of public safety, "Construction types – Definitions", <http://www.dps.state.mn.us/fmarshal/mfirs/BuildingConstructionTypes.html>, (2004).
- Nakamura, H., "Investment model of fire protection equipment for office building", Fire Safety Science – Proceedings of the First International Symposium, Hemisphere Publishing Corporation, Washington, D.C. (1986).
- National Research Council of Canada, "National Building Code of Canada", National Research Council of Canada, Ottawa, Ontario (1995).

- Netherlands Arbeidsinspectie, "Methods for the determination of possible damage to people and objects resulting from release of hazardous materials", Den Haag: Arbeidsinspectie, Voorburg, Netherlands (1992), pp. 37, 42, 43.
- Pettersson, O., "Structural fire behaviour – Development trends", Fire Safety Science – Proceedings of the First International Symposium, Hemisphere Publishing Corporation, Washington, D.C. (1986).
- Plant Engineering, "Reader – Limit the chances of a fire sprinkler leak", Plant Engineering, 3, (March 1, 2001).
- Platt, D.G., D.G. Elms and A.H. Buchanan, "A probabilistic model of fire spread with time effects", Fire Safety Journal, 22, pp. 367-398 (1994).
- Quintiere, J.G., "Principles of fire behaviour", Delmar Publishers, Albany, New York (1997).
- Ramachandran, G., "Exponential model of fire growth", Fire Safety Science – Proceedings of the First International Symposium, Hemisphere Publishing Corporation, Washington, D.C. (1986).
- Ramachandran, G., "Early detection of fire and life risk", Fire Engineers Journal, 53, 171, pp. 33-37 (1993).
- Ramachandran, G., "The economics of fire protection", E and FN Spon, London, UK (1998) pp. 158-159.
- Richardson, L.R., "What fire statistics tell us about our fire and building codes for housing and small buildings and fire risk for occupants of those structures", Fire and Materials, 25, pp. 255-271 (2001).
- Riggs, J.L, D.B. Bedworth, S.U. Randhawa and A.M. Khan, "Engineering economics", 2nd edition, McGraw-Hill Ryerson Limited, pp. 84, 445 (1997).
- Rousseau, J., "Impact of mandatory sprinklering of multi-unit residential buildings", Research Highlights technical series, 96-232, Canada Mortgage and Housing Corporation, Ottawa, Ontario (1996).
- Royer, K., and W.N. Floyd, "Water for fire fighting – Rate-of-flow formula", Iowa State University Bulletin, Engineering Extension – Bulletin number 18, Iowa State University, Ames, Iowa.

- Särdqvist, S. and G. Holmstedt, "Correlation between firefighting operation and fire area: analysis of statistics", *Fire Technology*, 36, 2, pp. 109-130 (2000).
- Schaenman, P., J. Stern and R. Bush, "Total cost of fire in Canada: an initial estimate", TriData Corporation, Arlington, Virginia (December, 1994), pp. 2-5, 2-6, 2-7, 4-7, 4-8, 4-15, 4-16, 4-29, 7-5.
- Security Magazine, "Putting Smoke Damage to the test", *Security Magazine*, pp. 71-72, (September, 2000).
- Sherin, B., "Work station fire protection for a semiconductor facility", *Professional Safety*, pp. 16-21 (December, 1989).
- Silcock, A., "Protecting Buildings against fire: background to costs", *Architects' Journal Information Library*, 13, pp. 1515-1518 (December, 1967).
- Silcock, A., "Fire Protection of buildings – What does it cost?", *FIRE*, pp. 461-463 (February, 1968).
- Stephens, J., "Cost benefits of sprinkler protection", *Fire Prevention*, 277, pp. 20-21 (March, 1995).
- Tewarson, A., "SFPE Handbook of fire protection engineering", Chapter 3, National Fire Protection Association, Quincy, Massachusetts (1995), pp. 3-84, 3-91, 3-93, 3-95, 3-80, 3-96.
- Tewarson, A., "Characterization of the fire environment in central offices of the telecommunications industry", *Fire and Materials*, 27, pp. 131-149 (2003).
- Thomas, I.R., "Analysis of USA retail fires", FCRC Project 6, Fire Safety Systems for Low-Rise, Sprinklered Shopping Centres, Fire Code Reform Research Program, Technical Report FCRC-TR97-02, Mulgrave, Victoria, (February, 1997).
- Thomas, I.R., "The Development of CESARE risk: a fire-risk cost assessment program", *Fire Protection Engineering*, 19, pp. 24-27 (Summer, 2003).
- Water Damage, "Disaster advice: water damage", <http://www.disasteradvice.co.uk>, (2004).
- Watts, J.M. Jr., "Editorial – Nonthermal fire damage", *Fire Technology*, 37, pp. 107-108 (2001).

- Weber, S.F. and B.C. Lippiatt, "Alarm 1.0 decision support software for cost-effective compliance with fire safety codes" NISTIR 5554, National Fire Protection Association, Quincy, Massachusetts (December, 1994).
- Wigotsky, V., "Hot issues challenge flame-retardance industry", *Plastics Engineering*, pp. 25-30 (October, 1987).
- Wilmot, T., "National fire costs – A wasteful past but a better future", *Fire Safety Science – Proceedings of the First International Symposium*, Hemisphere Publishing Corporation, Washington, D.C. (1986).
- Wood Engineering Handbook, "Wood Engineering Handbook", 2nd edition, Forest Products Laboratory, Prentice Hall, Englewood Cliffs, New Jersey (1990), pp. 15-2 - 15-3.
- Woodford, J., "Microprocessor-based fire alarm systems", *Building Operating Management*, pp.82-85 (June, 1988).
- Woodward, C.D., "Counting the costs of fire", *Fire Prevention*, 224, pp. 18-19 (November, 1989).
- Vining, E.K., "New look in sprinklers answers fire demands", *National Safety and Health News*, pp. 35-39 (August, 1985).
- Young, J.F., S. Mindess, R.J. Gray and A. Bentur, "The Science and technology of civil engineering materials", Prentice Hall, Upper Saddle River, New Jersey (1998), pp. 242, 247.
- Yuill, J., "Loss lessons", Presentation to the Society of Fire Protection Engineers, Ottawa Chapter, Star Technical Risks Agency, Incorporated, Ottawa, Canada (March 17, 2004).
- Yung, D.T., N. Bénichou, C. Dutcher, W. Su and G. Soeharjono, "FiRECAM version 1.6.1 – FiRECAM manual appendices system model description, NRCC-45568, Institute for Research in Construction, National Research Council of Canada, Ottawa, Ontario (April 1, 2002).

Appendix A:

Outline of economic computer model

This appendix provides an outline of the economic computer model. The layout of the input and output files are shown for data not related to the smoke computer model. The files related to the smoke computer model are described in sections 7.0, 8.0 and 9.0. Figure A1 shows the various inputs and output files with corresponding numbers. The numbers that are shown in the figure correspond to the section of this appendix.

Figure A1: Input and output files for the economic computer model.

Input and output files of the economic computer model

- 1.0 Building construction components
- 2.0 Fire protection systems
- 3.0 Passive fire protection per compartment
- 4.0 Building contents
- 5.0 Threshold categories of contents and fire protection systems
- 6.0 General input data
- 7.0 Input of the smoke computer model
- 8.0 Output of smoke computer model (fire in each compartment)
- 9.0 Output of smoke computer model (fire in one compartment)
- 10.0 Probability of fire spread
- 11.0 Results of the economic computer model with fire spread and smoke spread

1.0 Building construction components

- 1.1 Site development
- 1.2 Substructure
- 1.3 Roof
- 1.4 Stairs
- 1.5 Services

2.0 Fire protection systems

- 2.1 Active fire protection systems
 - 2.1.1 Alarms systems
 - 2.1.1.1 Single stage
 - 2.1.1.2 Dual stage
 - 2.1.1.3 Other components

- 2.1.1.3.1 Manual pull bar stations
- 2.1.1.3.2 Voice communications
- 2.1.1.3.3 Emergency telephone system
- 2.1.1.3.4 Speaker or mini-horn/alarm bell
- 2.1.2 Detection systems
 - 2.1.2.1 Heat detectors
 - 2.1.2.1.1 Dual action
 - 2.1.2.1.2 Fixed temperature
 - 2.1.2.1.3 Line or strip type
 - 2.1.2.2 Smoke detectors
 - 2.1.2.2.1 Beam
 - 2.1.2.2.2 Photoelectric
 - 2.1.2.2.3 Ionization
- 2.1.3 Suppression Systems
 - 2.1.3.1 Manual extinguishers
 - 2.1.3.1.1 Type A
 - 2.1.3.1.2 Type B
 - 2.1.3.1.3 Type C
 - 2.1.3.1.4 Type ABC
 - 2.1.3.2 Fire hose standpipes
 - 2.1.3.3 Kitchen hood extinguishing systems
 - 2.1.3.4 Sprinklers
 - 2.1.3.4.1 Dry-pipe
 - 2.1.3.4.2 Wet-pipe
 - 2.1.3.4.3 Deluge
 - 2.1.3.4.4 Pre-action
 - 2.1.3.4.5 Other costs
 - 2.1.3.4.5.1 Supply
 - 2.1.3.4.5.2 Pressure tanks

2.1.3.4.5.3 Elevated gravity tanks

2.1.3.4.5.4 Fire pumps

2.1.4 Smoke control management systems

2.1.4.1 Smoke management systems

2.1.4.1.1 Atrium smoke exhaust

2.1.4.2 Smoke control systems

2.1.4.2.1 Elevator shaft pressurization

2.1.4.2.2 Zone pressurization

2.2 Passive fire safety systems

2.2.1 Egress routes

2.2.1.1 Additional exits

2.2.1.2 Additional stair shafts

2.3 Emergency systems

2.3.1 Emergency lighting

2.3.2 Exit signs

2.3.3 Posted emergency floor plans

3.0 Passive fire protection per compartment

3.1 Wall assemblies

3.1.1 East wall assembly

3.1.2 West wall assembly

3.1.3 North wall assembly

3.1.4 South wall assembly

3.2 Ceiling assembly

3.3 Floor assembly

3.4 Doors

3.5 Windows

4.0 Building contents

Building contents will vary from compartment to compartment. The contents listed below should be assigned to the compartments.

- 4.1 Books
- 4.2 Electronic equipment
- 4.3 Clothes
- 4.4 Food
- 4.5 Appliances
- 4.6 Upholstered furniture
- 4.7 Wood furniture
- 4.8 Plastics
- 4.9 Machinery
- 4.10 Interior linings/finishes
- 4.11 Lighting
- 4.12 User defined

5.0 Threshold categories of contents and fire protection systems (not including additional passive fire protection) for temperature, smoke and water

Contents and fire protection systems will have different sensitivities to temperature, smoke and water and therefore will be placed in one of the following categories:

- 5.1 Very high sensitivity
- 5.2 High sensitivity
- 5.3 Moderate sensitivity
- 5.4 Low sensitivity
- 5.5 No sensitivity

6.0 General input data

6.1 Economic factors

- 6.1.1 Inflation rate
- 6.1.2 Interest rate
- 6.1.3 Downtime cost per day
- 6.1.4 Rush construction factor
- 6.1.5 Reduction of downtime factor

6.2 Building characteristics

- 6.2.1 Building component calibration factor
- 6.2.2 Building life
- 6.2.3 Total floor area
- 6.2.4 Building construction calibration factor

6.3 Extinguishment

- 6.3.1 Efficiency of extinguishment
- 6.3.2 Specific heat capacity of water
- 6.3.3 Heat of vaporization of water
- 6.3.4 Temperature change
- 6.3.5 Extinguishment calibration factor

6.4 Basic costs

- 6.4.1 Wall assemblies (East, West, North, South)
- 6.4.2 Ceiling assembly
- 6.4.3 Floor assembly
- 6.4.4 Doors
- 6.4.5 Windows

7.0 Input for the smoke computer model

This file contains the floor dimensions and ambient temperature of each compartment, as well as the total simulation time.

8.0 Output from the smoke computer model (fire in each compartment)

This file contains temperature, smoke concentration, and heat release rates at each time interval assuming that there is a fire in each compartment.

9.0 Output from the smoke computer model (fire in one compartment)

This file contains temperature, smoke concentration, and heat release rates at each time interval assuming that there is a fire in only one compartment.

10.0 Probability of fire spread

10.1 Compartment of fire origin

10.2 Probability of fire spread from the compartment of fire origin to the other compartments

11.0 Results of the economic computer model including fire spread and smoke spread

11.1 Overall results

11.1.1 Costs

11.1.1.1 Total cost of building construction, fire protection systems and contents

11.1.1.2 Total annual cost of fire protection systems

11.1.2 Damages

11.1.2.1 Total cost of direct damages

11.1.2.2 Total downtime days

11.1.2.3 Total cost of downtime (indirect damage)

11.1.2.4 Total cost of direct plus indirect damage

11.1.3 Ratio

11.1.3.1 Ratio of damage / Total cost of building construction, fire protection systems and contents

11.1.4 Percentage damages

11.1.4.1 Estimate of temperature damage as a percentage of the total damage to the building, its fire protection systems and its contents

11.1.4.2 Estimate of smoke damage as a percentage of the total damage to the building, its fire protection systems and its contents

11.1.4.3 Estimate of water damage as a percentage of the total damage to the building, its fire protection systems and its contents

11.1.5 Factors

11.1.5.1 Damage using a rush construction factor

11.1.5.2 Downtime using a downtime reduction factor

11.1.5.3 Total cost of damages

11.2 Detailed results

11.2.1 Costs

11.2.1.1 Building construction

- 11.2.1.1.1 Capital cost
- 11.2.1.2 Contents
 - 11.2.1.2.1 Capital cost
- 11.2.1.3 Fire Protection Systems
 - 11.2.1.3.1 Active fire Protection systems
 - 11.2.1.3.1.1 Capital cost
 - 11.2.1.3.1.2 Annual cost
 - 11.2.1.3.2 Passive fire protection systems
 - 11.2.1.3.2.1 Capital cost
 - 11.2.1.3.2.2 Annual cost
 - 11.2.1.3.3 Emergency fire protection systems
 - 11.2.1.3.3.1 Capital cost
 - 11.2.1.3.3.2 Annual cost
- 11.2.2 Damages
 - 11.2.2.1 Cost of damages to building construction and fire protection systems
 - 11.2.2.2 Cost of damages to building contents
- 11.2.3 Percentage damages
 - 11.2.3.1 Estimate of the temperature damage to all of the contents in the building as a percentage of the total damage to the contents in the building
 - 11.2.3.2 Estimate of the smoke damage to all of the contents in the building as a percentage of the total damage to the contents in the building
 - 11.2.3.3 Estimate of the temperature water to all of the contents in the building as a percentage of the total damage to the contents in the building

11.3 Results per compartment

11.3.1 Damage to building and fire protection systems

11.3.2 Cost of contents

11.3.3 Damage to contents

11.3.4 Total cost of damage

11.3.5 Estimate of the temperature damage to all of the contents in the compartment as a percentage of the total damage to the contents in the compartment

11.3.6 Estimate of the smoke damage to all of the contents in the compartment as a percentage of the total damage to the contents in the compartment

11.3.7 Estimate of the water damage to all of the contents in the compartment as a percentage of the total damage to the contents in the compartment

11.3.8 Amount of downtime

Appendix B:

Input estimates

1.0 INPUT ESTIMATES INTRODUCTION

Contractors and insurance companies use cost estimates following a fire to determine the cost of damages (Daley, 2004). In this section, costs for building components, fire protection and emergency systems, basic building construction (along with additional passive fire protection), and contents are discussed. Costs were determined by cost estimates, personal correspondence with a costing expert and engineering judgement. Input estimates for the economic computer model are given, with input costs based on the imperial system (most building construction in North America is performed in these units). The economic computer model converts the costs, based on area, from ($\$/\text{ft}^2$) to ($\$/\text{m}^2$) since the dimensions of the compartments obtained from the smoke computer model are in metres. Cost adjustment factors for different cities are included and were derived from cost estimates using Ottawa, Ontario as the baseline. To adjust the costs, the cost adjustment factor should be multiplied by the costs. The consumer price index, which is published each year by Statistics Canada, can be used to adjust the costs for subsequent years.

2.0 GENERAL INPUT DATA

The economic computer model requires some general input data. Table B1 shows the recommended values for the general input data. They are either known data or are judgement based. Basic costs will be discussed in section 5.0 (Basic building construction and additional passive fire protection).

Table B1: Recommended values for the general input data.

General data	Recommended value
Economic factors	
• Inflation rate	Market specific
• Interest rate	Market specific
• Downtime cost	Building specific
• Rush construction factor	2
• Reduction of downtime factor	0.5
Building characteristics	
• Building component calibration factor	1
• Building life	25 years
• Floor area	Building specific
• Building construction calibration factor	1
Extinguishment	
• Efficiency of extinguishment	0.1
• Specific heat capacity of water	4.182 (kJ/kg°C)
• Heat of vaporization of water	2,260 (kJ/kg)
• Temperature change	80°C (°C)
• Extinguishment calibration factor	1
Basic costs	
• Walls	Building specific
• Ceiling	Building specific
• Floor	Building specific
• Doors	Building specific
• Windows	Building specific

3.0 BUILDING COMPONENTS

The costs associated with building components were determined from cost estimates. Many costs appear to be the same for different types of construction and that is due to the fact that the building components, such as wall assemblies, floor assemblies, and ceiling assemblies, are not included in the cost of building components, but considered as basic building construction, with or without additional passive fire protection. Furthermore, the costs for building components do not include contingency fees, design fees, commissioning fees, or testing fees.

Design fees are generally between 20% and 30% of the capital cost and were determined from cost estimates. For contingency fees, a value of 5% of the capital cost is recommended but can be as high as 15% which was determined from judgement and Kuffner (2003a). The replacement time and downtime factors can vary greatly for various building components and therefore are user defined. The building components are split into five categories: site development, substructure, roof, stairs, and services which are described in Chapter 3 (Description of the economic computer model).

3.1 Costing for building components

Table B2 shows the cost adjustment factors for the building components. This factor is available for selected Canadian cities as shown in Table B2. The average of the cost adjustment factors for the selected Canadian cities in Table B2 is considered to be the Canadian average. Estimates for the cost of building components in Ottawa, Ontario are presented in Table B3. A cost adjustment factor should be multiplied by the costs in Table B3 to obtain a more accurate cost estimate. The cost of finishes, which is considered a content of the compartment, is included in Table B3 for clarity. Tables B2 and B3 were assembled using cost estimates.

Table B2: The cost adjustment factors for the cost of building components.

Cities	Factors
Calgary	0.98
Canadian average	0.96
Edmonton	0.99
Halifax	0.90
Montreal	0.95
Ottawa	1.00
Quebec	0.96
Regina	0.86
Toronto	1.04
Vancouver	1.01
Winnipeg	0.92

Table B3: Estimates for the costs of building components for the Ottawa, Ontario area.*

Structure description	Substructure (\$/ft ²)	Roof (\$/ft ²)	Stairs (\$/ft ²)	Services (\$/ft ²)	Finishes (\$/ft ²)
Apartment building (1-3 storey) – steel joists < 8,000 ft ²	9.62	3.67	1.27	50.62	11.99
Apartment building (1-3 storey) – steel joists < 36,000 ft ²	6.96	3.40	1.27	30.70	11.98
Apartment building (1-3 storey) – wood joists < 8,000 ft ²	9.62	2.74	0.55	50.62	12.56
Apartment building (1-3 storey) – wood joists < 36,000 ft ²	6.96	2.61	0.55	30.70	12.40
Convenience store – steel frame < 1,000 ft ²	37.04	11.93	-	22.70	8.67
Convenience store – steel frame < 15,000 ft ²	15.56	10.20	-	22.66	6.45
Convenience store – wood frame < 1,000 ft ²	37.04	7.33	-	22.70	6.31
Convenience store – wood frame < 15,000 ft ²	15.56	7.32	-	22.66	6.31
Department store (1 storey) – reinforced concrete < 50,000 ft ²	12.34	21.04	-	16.35	14.30
Department store (1 storey) – reinforced concrete < 170,000 ft ²	10.53	20.77	-	14.84	14.30

Table B3... Continued

Structure description	Substructure (\$/ft ²)	Roof (\$/ft ²)	Stairs (\$/ft ²)	Services (\$/ft ²)	Finishes (\$/ft ²)
Department store (1 storey) – steel frame < 50,000 ft ²	12.34	10.06	-	16.35	14.30
Department store (1 storey) – steel frame < 170,000 ft ²	10.53	9.79	-	14.84	14.30
Department store (3 storey) – reinforced concrete < 50,000 ft ²	5.75	6.24	17.70	23.59	1.59
Department store (3 storey) – reinforced concrete < 170,000 ft ²	4.55	6.09	17.16	21.85	0.47
Department store (1 storey) – steel frame < 50,000 ft ²	5.75	3.49	-	23.59	19.29
Department store (1 storey) – steel frame < 170,000 ft ²	4.55	3.34	-	21.85	17.63
Office building (1 storey) – steel roof deck < 2,000 ft ²	33.92	12.59	-	51.83	11.45
Office building (1 storey) – steel roof deck < 25,000 ft ²	14.76	9.86	-	33.54	11.43
Office building (1 storey) – wood trusses < 2,000 ft ²	33.92	27.26	-	49.85	11.45
Office building (1 storey) – wood trusses < 25,000 ft ²	14.76	27.26	-	33.38	11.43
Office building (2-4 storey) – reinforced concrete frame < 5,000 ft ²	14.45	6.20	2.00	48.60	11.76

Table B3... Continued

Structure description	Substructure (\$/ft ²)	Roof (\$/ft ²)	Stairs (\$/ft ²)	Services (\$/ft ²)	Finishes (\$/ft ²)
Office building (2-4 storey) – reinforced concrete frame < 80,000 ft ²	4.68	5.11	2.00	34.03	11.75
Office building (2-4 storey) – steel frame < 5,000 ft ²	14.45	4.40	2.00	48.60	11.76
Office building (2-4 storey) – steel frame < 80,000 ft ²	4.68	3.31	2.00	34.03	11.75
Office building (2-4 storey) – wood frame < 80,000 ft ²	4.68	2.46	1.04	34.03	11.75
Office building (5-10 storey) – reinforced concrete < 20,000 ft ²	6.57	2.12	1.22	41.36	11.24
Office building (5-10 storey) – reinforced concrete < 300,000 ft ²	2.40	1.88	1.22	34.75	11.24
Office building (5-10 storey) – steel frame < 20,000 ft ²	6.57	1.23	1.22	41.36	11.24
Office building (5-10 storey) – steel frame < 300,000 ft ²	2.40	0.98	1.22	34.75	11.24
Restaurant – steel joists < 2,000 ft ²	28.77	5.16	-	73.24	11.75
Restaurant – steel joists < 8,000 ft ²	18.70	4.56	-	59.61	11.74
Restaurant – wood joists < 2,000 ft ²	28.77	12.66	-	73.24	12.99

Table B3... Continued

Structure description	Substructure (\$/ft ²)	Roof (\$/ft ²)	Stairs (\$/ft ²)	Services (\$/ft ²)	Finishes (\$/ft ²)
Restaurant – wood joists < 8,000 ft ²	18.70	12.07	-	59.61	12.98
Retail – steel joists < 4,000 ft ²	23.04	9.47	-	28.96	9.02
Retail – steel joists < 220,000 ft ²	14.23	8.37	-	19.35	7.83
Supermarket – steel frame < 12,000 ft ²	16.69	11.29	-	21.92	9.37
Supermarket – steel frame < 60,000 ft ²	12.06	10.52	-	17.64	8.59

* – Finishes are not considered as building components but are considered contents of a compartment.

4.0 FIRE PROTECTION AND EMERGENCY SYSTEMS

The inputs for the fire protection and emergency systems are discussed in this section. The costs are based on cost estimates, personal correspondence with a costing expert and engineering judgement.

The costs for the alarm systems are very difficult to obtain because of the numerous options available, the complexity of installation, and the variations in building size (Kuffner, 2003b). Therefore, using judgement and information from Kuffner (2003a), a conservative estimate was determined for alarm systems. Engineering judgement was used for downtime factors while retrofit factors were estimated using a typical value of 20% (of the capital plus the labour cost) and the knowledge that retrofitting of sprinklers can cost 33% to 100% more if the installation had occurred during building construction (Dittman, 1988). If no estimate was available for a detector (for example), the costs and other fees were based on the cost of the closest known detector. If this is not possible, the field is left as a user input, and no value is provided. It is noted that conservative estimates were made for costs, fees, replacement time and downtime factors.

A commissioning and testing fee of 1.2% of the capital and labour cost is recommended which was determined by judgement and Kuffner (2003a). For contingency fees, a value of 5% of the capital cost plus labour cost is recommended,

but a value as high as 15% could be used as determined by judgement and Kuffner (2003a).

Where only the total cost is known, the labour cost is set to zero and the total cost is placed in the capital cost field with the fields for the fees set to zero. For yearly costs, it is recommended that 0.5% of the capital plus labour cost of a component be used for the maintenance cost, 0.5% be used for the replacement cost, and 0.5% be used for the annual inspection cost, which was based on judgement and the cost of testing and inspection reported by IBI Group and Larden Muniak Consulting Inc. (1993) in a study on sprinkler systems. Some typical maintenance costs can be seen in Table 25, Chapter 2 (Literature review) and can be used as an estimate.

Table B4 shows the cost adjustment factors for the cost of active fire protection systems, passive fire protection systems, and emergency systems as determined by cost estimates. These cost adjustment factors are available for selected Canadian cities, the average of the cost adjustment factors for the selected Canadian cities being considered the Canadian average. Table B5 shows the different costs of active fire protection systems, passive fire protection systems and emergency systems. A cost adjustment factor should be multiplied by the costs in Table B5 to obtain a more accurate cost estimate.

Table B4: The adjustment factors for the cost of active fire protection systems, passive fire protection systems and emergency systems.

Cities	Factors
Calgary	0.98
Canadian average	0.97
Edmonton	0.98
Halifax	0.93
Montreal	0.97
Ottawa	1.00
Quebec	0.98
Regina	0.87
Toronto	1.05
Vancouver	1.01
Winnipeg	0.91

Table B5 shows recommended values for the capital cost, labour cost, design and other fees, retrofit factor, downtime days, and downtime factor for active fire protection systems, passive fire protection systems, and emergency systems. The description of the nomenclature used in Table B5 is shown at the bottom of the table.

Table B5: Estimates for the costs of active, passive and emergency fire protection systems for the Ottawa, Ontario area.

Component	C_{CA} (\$)	L_C (\$)	DO (%)	f_R (%)	$Days$ (day)	f_{DT}	Notes
Active fire protection systems							
<i>Alarms systems</i>							
Single stage	206,400	-	25	20	14	0.1	Cost depends on features
Dual stage	206,400	-	25	20	14	0.1	Cost depends on features
Other components							
• Manual pull bar stations	70	37	22	10	0.15	0.1	
• Voice communications	1,825	300	16	20	1	0.1	Additional station, add 92.20 to C_{CA} , 40.30 to L_C and 0.15 to $Days$
• Emergency telephone system	860	231	23	20	0.77	0.1	Additional station, add 415 to C_{CA} , 188 to L_C and 0.63 to $Days$
• Speaker or mini-horn/alarm bell	133	56	22	20	0.20	0.1	Each
<i>Detection systems</i>							
Heat detectors							
• Dual action	38	50	22	10	0.15	0.1	
• Fixed temperature	32	50	22	10	0.15	0.1	
• Line or strip type	32	50	22	10	0.15	0.1	
Smoke detectors							
• Beam	84	65	22	10	0.15	0.1	

Table B5... Continued

Component	C_{CA} (\$)	L_C (\$)	DO (%)	f_R (%)	Days (day)	f_{DT}	Notes
• Photoelectric	105	48	22	10	0.17	0.1	Ceiling type
	350	93	19	20	0.30	0.1	Duct type
• Ionization	105	48	22	10	0.17	0.1	
<i>Suppression Systems</i>							
Manual extinguishers							
• Type A	39-126	-	10	0	0.01	0.1	2.5lb – 20lb
• Type B	39-126	-	10	0	0.01	0.1	2.5lb – 20lb
• Type C	39-126	-	10	0	0.01	0.1	2.5lb – 20lb
• Type ABC	39-119	-	10	0	0.01	0.1	2.5lb – 20lb
Fire hose/standpipes	714	117	20	20	0.5	0.1	Costs can vary
Kitchen hood extinguishing systems	32,800	535	11	20	2	0.1	Conservative
Sprinklers							
• Dry-pipe	4.81-6.70 (\$/ft ²)	3.63-4.56	20	33	A ^S	0.1	Ordinary – Extra hazard < 500 ft ²
	0.57-1.59 (\$/ft ²)	1.07-1.99	20	33	A ^S	0.1	Ordinary – Extra hazard < 50,000 ft ²
• Wet-pipe	1.19-3.59 (\$/ft ²)	1.85-3.06	20	33	A ^S	0.1	Ordinary – Extra hazard < 500 ft ²
	0.45-1.37 (\$/ft ²)	1.05-2.18	20	33	A ^S	0.1	Ordinary – Extra hazard < 50,000 ft ²
• Deluge	6.05-7.95 (\$/ft ²)	2.93-4.06	20	33	A ^S	0.1	Ordinary – Extra hazard < 500 ft ²
	0.62-1.56 (\$/ft ²)	1.07-2.03	20	33	A ^S	0.1	Ordinary – Extra hazard < 50,000 ft ²

Table B5... Continued

Component	C_{CA} (\$)	L_C (\$)	DO (%)	f_R (%)	Days (day)	f_{DT}	Notes
• Pre-action	4.94-6.85 (\$/ft ²)	2.90-4.03	20	33	A ^S	0.1	Ordinary – Extra hazard < 500 ft ²
	0.61-1.07 (\$/ft ²)	1.55-2.20	20	33	A ^S	0.1	Ordinary – Extra hazard < 50,000 ft ²
Other costs							
• Supply	910	245	22	20	1.25	0.1	
• Pressure tanks	501,500 - 712,500	-	-	-	6-17	0.1	500,000- 1,000,000 gallons
• Elevated gravity tanks	219,000- 1,071,500	-	-	-	6-17	0.1	50,000- 1,000,000 gallons
• Fire pumps	49,000- 1,045,00	1,575- 4,200	12	20	6.3- 16.6	0.1	Diesel 500 GPM – 3,500 GPM
	11,500- 18,400	1,425- 1,750	15	20	6-7	0.1	Electric 250 GPM -750 GPM
Smoke control management systems							
Smoke management systems	-	-	-	-	-	-	User input
• Atrium smoke exhaust	-	-	-	-	-	-	User input
Smoke control systems							
• Elevator shaft pressurization	-	-	-	-	-	-	User input
• Zone pressurization	-	-	-	-	-	-	User input
Passive fire protection systems							
Passive fire safety systems							
Egress routes							
• Additional exits	-	-	-	-	-	-	User input
• Additional stair shafts	-	-	-	-	-	-	User input

Table B5... Continued

Component	C_{CA} (\$)	L_C (\$)	DO (%)	f_R (%)	$Days$ (day)	f_{DT}	Notes
Emergency systems							
Emergency lighting	137	76	24	0	0.30	0.1	Lead battery
	630	76	13	0	0.30	0.1	Nickel battery
Exit signs	48-133	38-75	29	0	0.12-0.30	0.1	Incandescent single face – LED double face with battery
Posted emergency floor plans	20	-	9	0	0.01	0.1	Per sign

C_{CA} = Capital cost

L_C = Labour cost

DO = Design and other fees

f_R = Retrofit factor

$Days$ = Downtime days

f_{DT} = Downtime factor

A^S – Depends on size of installation, user input

GPM – Gallons per minute

LED – Light emitting diode

When determining the threshold categories for the fire protection systems, judgement should be used. For example, the activation temperature of a sprinkler head will be the value that should be used to determine when the sprinkler head will get damaged.

5.0 BASIC BUILDING CONSTRUCTION AND ADDITIONAL PASSIVE FIRE PROTECTION

Basic building construction and additional passive fire protection include: wall assemblies, floor assemblies, ceiling assemblies, doors and windows. For the basic cost of construction, the cheapest cost should be considered as the basic cost, while any additional cost will be considered additional passive fire protection. Care should be taken when assuming a basic cost for wall assemblies as the cost of exterior walls vary greatly from the cost of interior walls.

5.1 Costs

Default costs were determined by cost estimates and engineering judgement. The cost of walls, floors and ceilings is the cost of the whole assembly. Therefore, if a compartment shares a wall, floor or ceiling, the cost of the wall, floor or ceiling per compartment is divided by two. A weighted average can be taken for the cost and the Fire Resistance Rating (FRR) of a wall assembly if the wall has a portion which is an exterior wall and where the other portion of the same wall is an interior wall shared with another compartment. This weighted average results in a more representative value for both the cost and the FRR of the wall assembly. The exterior and interior walls should be considered separately but since the economic computer model assumes that each compartment only has four walls (i.e., East wall, West wall, North wall and South wall), the weighted average should be performed.

FRRs for different types of construction are shown in Table B6 and can be used to associate costs and FRRs. Definitions used for the types of construction are those used by the NFPA.

Table B6: Fire Resistance Ratings for different types of building construction (Egan, 1978).

Component	Type of construction			
	Fire resistive (h)	Noncombustible (h)	Protected combustible (h)	Wood frame (h)
Fire-resistive walls	4	4	4	4
Exterior load bearing walls	4	3	3	3
Exterior non load bearing walls	2	2	2	2
Interior load bearing walls	4	2	1	1
Stairs, elevator shafts, pipe shafts, duct shafts and corridors	2	2	2	1

5.2 Interior walls

Using the component additive method in the National Building Code of Canada (National Research Council of Canada, 1995), the FRR for the interior walls of a

building was determined. The FRRs were then associated with a cost from cost estimates. The cost is assumed to vary linearly with time, therefore, interpolation and/or extrapolation is used to find the costs associated with different FRR. Table B7 shows the cost adjustment factors for the interior walls of a building. The cost adjustment factors are available for selected Canadian cities. The average of the cost adjustment factors for the selected Canadian cities is considered the Canadian average. A cost adjustment factor should be multiplied by the costs in Table B8, which shows the different costs per squared foot (ft²) for the interior walls of a building, to obtain a more accurate cost estimate. Tables B7 and B8 were assembled using cost estimates.

Table B7: The cost adjustment factors for interior walls.

Cities	Factors
Calgary	0.94
Canadian average	0.95
Edmonton	0.94
Halifax	1.01
Montreal	0.97
Ottawa	1.00
Quebec	0.98
Regina	0.81
Toronto	1.00
Vancouver	0.97
Winnipeg	0.88

Table B8: Estimates for the costs of interior walls for the Ottawa, Ontario area.*

FRR (min)	Total cost ^A (\$/ft ²)	Total cost ^B (\$/ft ²)	Total cost ^C (\$/ft ²)	Total cost ^D (\$/ft ²)
30	1.27	2.65	8.92	4.62
45	3.01	3.46	9.19	6.46
60	4.75	4.27	9.46	8.29
75	6.49	5.08	9.74	10.13
90	8.22	5.89	10.01	11.97

* – Costs include a 5% contingency fee and a 20% profit markup.

^A – Walls drywall/wood stud framing

^B – Walls drywall/steel stud framing

^C – Walls plaster /wood framing

^D – Walls plaster /steel framing

5.3 Exterior walls

Costs for exterior walls were assembled using the lowest and highest cost available from cost estimates. Table B9 shows the cost adjustment factors for the interior walls of a building. The cost adjustment factors are available for selected Canadian cities. The average of the cost adjustment factors for the selected Canadian cities is considered the Canadian average. Table B10 shows the different costs for exterior walls. A cost adjustment factor should be multiplied by the costs in Table B10 to obtain a more accurate estimate. Tables B9 and B10 were assembled using cost estimates.

Table B9: The cost adjustment factors for exterior walls.

Cities	Factors
Calgary	0.97
Canadian average	0.96
Edmonton	0.97
Halifax	0.90
Montreal	0.95
Ottawa	1.00
Quebec	0.97
Regina	0.84
Toronto	1.08
Vancouver	1.04
Winnipeg	0.90

Table B10: Estimates for the costs of exterior walls for the Ottawa, Ontario area.*

Description	Low (\$/ft ²)	High (\$/ft ²)
Concrete block wall - regular weight		
• Hollow	6.83	10.45
• 75% solid	7.03	8.45
• Solid	7.86	10.51
Concrete block wall - light weight		
• Hollow	7.14	8.81
• 75% solid	6.94	8.81
• Solid	7.63	10.93

Table B10.... Continued

Description	Low (\$)	High (\$)
Reinforced concrete block wall - regular weight		
• Hollow	7.73	15.58
• 75% solid	8.68	12.29
• Solid	17.11	19.63
Reinforced concrete block wall - light weight		
• Hollow	8.38	14.06
• 75% solid	8.94	12.88
• Solid	17.75	22.88
Split ribbed block wall - regular weight		
• Hollow	9.91	19.50
• 75% solid	10.98	11.90
• Solid	12.00	13.19
Reinforced split ribbed block wall - regular weight		
• 75% solid	10.64	21.25
• Solid	14.25	18.13
Split face block wall - regular weight		
• Hollow	9.93	24.63
• 75% solid	10.98	22.44
• Solid	20.56	24.88
Reinforced split face block wall - regular weight		
• Hollow	17.75	22.00
• 75% solid	21.69	28.94
• Solid	26.69	34.38
Solid brick walls - single wythe	14.38	39.56
Solid brick walls - double wythe	19.19	48.25
Reinforced brick walls	17.15	45.31

Table B10.... Continued

Description	Low (\$)	High (\$)
Stone veneer	30.69	89.38
Brick veneer/wood stud backup	18.63	43.69
Brick veneer/metal stud backup	18.00	44.75
Glass block	24.88	67.50

* – Costs include a 5% contingency fee and a 20% profit markup.

It is recommended for exterior walls that the FRR be between one and four hours.

Table B11 shows different brick walls and associated Fire Resistance Ratings which can be related to costs in Table B10.

Table B11: Types of brick walls and corresponding Fire Resistance Ratings (Egan, 1978).

Brick wall type	Fire Resistance Rating ^A (h)
4 inch brick (75% solid)	1
4 inch solid brick with ½ inch type X gypsum board	2
4 inch solid brick with ½ inch plaster on both sides	2
6 inch solid brick	2
8 inch hollow brick	3
8 inch brick cavity (75% solid) with air space	3
8 inch hollow brick with perlite insulation	4
8 inch solid brick	4
10 inch brick cavity (75% solid) with air space	4

^A – If a wall assembly has combustible members framed into and has a two hour or greater Fire Resistance Rating, one hour should be subtracted from the Fire Resistance Ratings given above.

5.4 Floors/ceilings

Costs for floors/ceilings were determined by cost estimates using the lowest and highest cost available. It can be assumed that the floor of a compartment is the ceiling of another compartment. Table B12 shows the cost adjustment factors for the interior walls of a building. The cost adjustment factors are available for selected Canadian cities. The average of the cost adjustment factors for the selected Canadian cities is considered the Canadian average. Table B13 shows the cost of ceilings/floors which include a 5% contingency fee and a 20% profit. FRRs are user defined and should be between one and four hours. A cost adjustment factor should be multiplied by the costs in Table B13 to obtain a more accurate cost estimate. Tables B12 and B13 are assembled using cost estimates.

Table B12: The cost adjustment factors for floors/ceilings.

Cities	Factors
Calgary	1.03
Canadian average	0.98
Edmonton	1.05
Halifax	0.89
Montreal	0.98
Ottawa	1.00
Quebec	0.98
Regina	0.86
Toronto	1.03
Vancouver	1.02
Winnipeg	0.96

Table B13: Estimates for the costs of floor/ceilings for the Ottawa, Ontario area.*

Description	Low (\$/ft ²)	High (\$/ft ²)
Light gauge steel floor systems	4.48	9.98
Cast in place slabs one way	10.55	23.25
Cast in place beam and slab, two way	15.58	23.06
Cast in place flat plate	12.40	15.19
Cast in place multi-span joist slab	15.50	19.13
Steel joists, beams and slab on columns ^A	10.24	22.55
Deck and joists on bearing walls ^A	10.93	16.99
Wood and beam joist	11.64	40.94
Metal deck concrete fill	4.58	6.14

* – Costs include a 5% contingency fee and a 20% profit markup.

^A – Includes a 5/8 inch layer of gypsum board. For other floor assemblies add \$2.54 per ft².

5.5 Doors

The costs of doors were determined using cost estimates. If the fire rating of a given door is not provided with the cost estimates then the fire rating is taken from Table B14. Low and high cost estimates are given and include a 5% contingency fee and a 20% profit. The price of the door can be adjusted to include the price of the door frame, but the door frame can also be considered as a content of the compartment. If a door is shared with another compartment, the cost of the door should be halved.

Table B14: Types of doors and corresponding Fire Resistance Ratings (1 ¾ inch thick) (Egan, 1978).

Type of door	Fire Resistance Rating (min)
Wood hollow – core flush	NR ^A
Wood hollow core with louvers	NR ^A
Wood panel	30
Wood solid – core flush	30
Protected wood panel	30
Wood solid – core flush with insulating core	90
Hollow metal – louvered	90
Hollow metal with steel stiffeners, polystyrene or honeycomb core	180
Steel composite construction with mineral board or glass fiberboard core	180

^A – No Fire Resistance Rating given, assumed to be 20 minutes.

Table B15 shows the cost adjustment factors for the interior walls of a building. The cost adjustment factors are available for selected Canadian cities. The average of the cost adjustment factors for the selected Canadian cities is considered the Canadian average. A cost adjustment factor should be multiplied by the costs in Table B16 to obtain a more accurate cost estimate. Tables B15 and B16 were assembled using cost estimates.

Table B15: The cost adjustment factors for doors/windows and door frames.

Cities	Door/window factors	Door frame factors
Calgary	0.97	0.98
Canadian average	0.96	0.95
Edmonton	0.97	0.98
Halifax	0.86	0.80
Montreal	0.97	0.99
Ottawa	1.00	0.95
Quebec	0.99	0.99
Regina	0.87	0.85
Toronto	1.02	1.02
Vancouver	1.02	1.02
Winnipeg	0.94	0.95

Table B16 shows the costs of different types of doors and frames along with the fire rating of the doors.

Table B16: Estimates for the costs of door and frames for the Ottawa, Ontario area.*

Description	FRR (min)	Low (\$)	High (\$)
Exterior doors (steel)	90	246	733
Exterior doors (wood, birch)	30	1,814	1,853
Fire doors steel	90	242	364
Fire doors wood	60	300	616
Fire doors wood	90	243	565
Frames – steel ^A		235	1,202
Frames – wood ^A		6	21
Insulated steel doors	180	1,795	2,120
Paneled doors	20	83	92
Single leaf doors – hollow	20	539	683
Single leaf doors – solid core	30	620	1,814
Steel - hollow	90	206	453

* – Costs include a 5% contingency fee and a 20% profit markup.

^A – Per linear foot

5.6 Windows

The cost for windows was determined by cost estimates. Windows are assumed to have a 20 minute fire rating. If a zero is placed in the fire rating field, the window is assumed to be 100% damaged when the temperature in the compartment reaches 100°C (this a conservative estimate). Costs are per window unless otherwise indicated. A cost adjustment factor from Table B16 should be multiplied by the costs in Table B17 to obtain a more accurate cost estimate. Table B17 was assembled using cost estimates.

Table B17: Estimates for the costs of windows for the Ottawa, Ontario area.*

Description	Low (\$)	High (\$)
Wood	382	3669
Steel	403	3025
Aluminum	273	1581
Curtain wall panels ^A	16	71

* – Costs include a 5% contingency fee and a 20% profit markup.

^A – Per square foot

5.7 Downtime for building construction and downtime factors

No estimates for downtime and downtime factor for building construction (i.e., basic building construction and additional passive fire resistance) are included. These values will be user defined.

6.0 CONTENTS

If a fire is confined to a small area, smoke will affect the contents of compartments a couple of floors above the compartment of fire origin, while additional water used to suppress a fire moves down the building and will affect compartments a couple of floors below the compartment of fire origin (Daley, 2004). When a small fire occurs, anything within or in contact with the fire compartment is usually replaced, especially so if the property is insured (Daley, 2004). As was seen from a real life case, in a room where the temperature was below 300°C, there was not much damage aside from the melting of plastics, but everything in the room had to be replaced because of smoke damage (Daley, 2004). Also if there is a small fire (in some cases), the smoke layer does not drop low enough to affect contents (Daley, 2004), therefore, the economic computer model makes a conservative estimate when it comes to small fires. The largest damage is usually from smoke damage as smoke has the ability to migrate and spread quickly (Daley, 2004). After the fire has been extinguished, moisture and humidity will have a great affect (Daley, 2004). Dehumidifiers and ventilators are placed at the fire scene 24 to 48 hours (48 hours is considered a long time) after the fire has occurred to remove humidity and odours (Daley, 2004). If there is a small fire, the insurance company will attempt to clean and restore contents if items are irreplaceable (Daley, 2004).

Typical categories of contents in a commercial setting which have the same thresholds to temperature, smoke and water can be seen in Table 38 of Chapter 3 (Description of the economic computer model). Finishes are considered a content category, where contents will include the finishes to the floor, ceilings and walls. An estimate of the cost of finishes is shown in Table B3.

Table B18 shows the cost adjustment factors for the interior walls of a building. The cost adjustment factors are available for selected Canadian cities. The average of the cost adjustment factors for the selected Canadian cities is considered the Canadian average. Table B18 was assembled using cost estimates.

Downtime days and the downtime factors will be a user input. The costs of contents will also vary and will be considered a user input as well.

Table B18: The cost adjustment factors for finishes of a compartment.

Cities	Factors
Calgary	0.98
Canadian average	0.96
Edmonton	0.99
Halifax	0.90
Montreal	0.95
Ottawa	1.00
Quebec	0.96
Regina	0.86
Toronto	1.04
Vancouver	1.01
Winnipeg	0.92

Table B19 shows the sensitivity categories that the contents in each category should be placed in with respect to their sensitivity towards temperature, smoke and water determined qualitatively from personal correspondence with Daley (2004). A dash in Table B19 indicates that smoke and water have a much greater effect than temperature.

Table B19: The sensitivity of contents to temperature, smoke and water (Daley, 2004).

Content Category	Temperature	Smoke	Water
Books	–	High sensitivity	High sensitivity
Electronic equipment	High sensitivity	High or moderate sensitivity	High sensitivity
Clothes	–	High sensitivity	Low sensitivity
Food	High sensitivity	Very high sensitivity	High sensitivity
Appliances	Varies	High or moderate sensitivity	Moderate sensitivity
Upholstered furniture	High sensitivity	High sensitivity	Low sensitivity
Wood furniture	–	Low sensitivity	Low sensitivity
Plastics	High sensitivity	Low sensitivity	Low sensitivity
Machinery	Varies	High or moderate sensitivity	High sensitivity
Interior linings and finishes	Varies	Varies	Varies
Lighting	Normally in ceiling, first to be attacked	High or moderate sensitivity	High sensitivity

Temperature has more of a direct effect on the structure than on the contents. By the time the temperature has damaged the contents, the contents are already damaged because of smoke (Daley, 2004). Water that is used to extinguish a fire is usually not clean (i.e., it is full of contaminants, smoke residue, etc.), therefore, the contents made of textiles that get wet are usually replaced. If drywall or insulation gets wet, it will also be replaced (Daley, 2004).

Special notes about some contents (Daley, 2004):

- If books are not valuable and they are in a fire, they will be replaced
- Electronic equipment will be replaced in some cases because smoke can cause the equipment to short and it will be cheaper to replace the equipment rather than clean the equipment
- Upholstered furniture is harder to clean than wood furniture which can be wiped down, if there is a small fire, but it depends on the finish of the wood
- Upholstered furniture and clothes tend to absorb odours
- Metal surfaces can be wiped down if there is a small fire and soot does not attach to metal surfaces when temperature is above 370°C
- Food will be destroyed (even in a small fire) as ordered by the health department
- Paints soften at 200°C, discolor at 300°C, blister at 420°C and burn off at 500°C

7.0 THRESHOLDS VALUES

Threshold values are used to calculate the damage to contents and fire protection systems (not including additional passive fire protection). Different categories were developed for damages due to temperature, smoke and water. The temperature ranges are based on the melting points of materials (Table 9, Chapter 2, Literature review) and damages to materials (Table 8, Chapter 2, Literature review) with engineering judgement being used for the composition of the categories. Smoke categories were based on the value of smoke density from Table 12, in Chapter 2 (Literature review). The values of smoke density were changed to a concentration, as shown in Table B20 by assuming that the density of air remains constant with temperature rise (this is not true but is only used as an estimate). Equation (B1) was used to change smoke density to parts per million (ppm) on a mass basis. In Table B20 the hydrochloric acid (HCl) concentration and the possible damages is also shown.

Table B20: Concentration of smoke and possibility of damages.

Smoke Density (kg/m ³)	Smoke Concentration (ppm) ^A	HCl Concentration (ppm) ^A	Possibility of damages
0.02	15,267	–	Can have shorting of equipment
0.04	30,075	100	Smoke damage to equipment, equipment can be restored
0.06	44,444	220	Equipment will be severely damaged

^A – Calculated using a mass basis.

$$\begin{aligned}
 ppm &= \left(\frac{\text{mass of component}}{\text{mass of solution}} \right) \times 10^6 \\
 &= \left(\frac{\text{smoke density} \cdot 1\text{m}^3}{\text{air density} \cdot 1\text{m}^3 + \text{smoke density} \cdot 1\text{m}^3} \right) \times 10^6
 \end{aligned}
 \tag{B1}$$

It is assumed that the smoke values (Table B20) were obtained from burning polyvinyl chloride (PVC) cables. The cables are usually insulated but there are no correlations taking into account both PVC and the insulation to determine the yields of the products of combustion. A discussion on how the value of smoke in Table B20 is changed to a value for soot, as needed in the economic computer model, is shown next.

In a well ventilated PVC fire, the yields of carbon dioxide, carbon monoxide, hydrocarbons and soot are as follows (Tewarson, 1995):

$$Y_{CO_2, \infty} = 0.46 \text{ (g/g)}$$

$$Y_{CO, \infty} = 0.063 \text{ (g/g)}$$

$$Y_{hc, \infty} = 0.023 \text{ (g/g)}$$

$$Y_s, \infty = 0.172 \text{ (g/g)}$$

$$Y_{CO_2, \infty} = \text{Yield of carbon dioxide in well ventilated conditions (g/g)}$$

$$Y_{CO, \infty} = \text{Yield of carbon monoxide in well ventilated conditions (g/g)}$$

$$Y_{hc, \infty} = \text{Yield of hydrocarbons in well ventilated conditions (g/g)}$$

$$Y_s, \infty = \text{Yield of soot in well ventilated conditions (g/g)}$$

Equations (B2-B5) represent the correction for the yields when different amounts of air are available. These correlations are for PVC and were determined in the Fire Research Institute's (FRI) flammability apparatus in a 0.022 m³ enclosure in Tokyo, Japan (Tewarson, 1995).

$$Y_{CO_2} = Y_{CO_2, \infty} \left[1 - \frac{0.30}{\exp(\Phi / 0.53)^{-11.0}} \right] \quad (\text{B2})$$

$$Y_{CO} = Y_{CO, \infty} \left[1 + \frac{6.5}{\exp(\Phi / 0.42)^{-8.0}} \right] \quad (\text{B3})$$

$$Y_{hc} = Y_{hc,\infty} \left[1 + \frac{0.38}{\exp(\Phi / 0.42)^{-8.0}} \right] \quad (B4)$$

$$Y_s = Y_{s,\infty} \left[1 + \frac{2.8}{\exp(\Phi / 2.02)^{-1.3}} \right] \quad (B5)$$

Y_{CO_2} = Adjusted yield of carbon dioxide (g/g)

$Y_{CO_2,\infty}$ = Yield of carbon dioxide in well ventilated conditions (g/g)

Φ = Equivalence ratio as defined in equation (B6)

Y_{CO} = Adjusted yield of carbon monoxide (g/g)

$Y_{CO,\infty}$ = Yield of carbon monoxide in well ventilated conditions (g/g)

Y_{hc} = Adjusted yield of hydrocarbons (g/g)

$Y_{hc,\infty}$ = Yield of hydrocarbons in well ventilated conditions (g/g)

Y_s = Adjusted yield of soot (g/g)

$Y_{s,\infty}$ = Yield of soot in well ventilated conditions (g/g)

$$\Phi = \frac{S m'' A}{m_{air}} \quad (B6)$$

Φ = Equivalence ratio

S = Stoichiometric mass air to fuel ratio (g/g)

m'' = Mass loss rate (g/m²s)

A = Exposed area of burning material (m²)

m_{air} = Mass flow rate of air (g/s)

It is noted that in PVC fires, there is a great amount of HCl produced which is due to pyrolysis (see Glossary) and not combustion. Taking the most severe conditions of HCl from Table 12, in Chapter 2 (Literature review), it is determined that HCl comprises only 0.5% of the smoke concentration $\left(\left(\frac{220 ppm}{44,444 ppm} \right) \times 100 \right)$ which might indicate that the smoke generated was due to the burning of many different materials, not just PVC. However, an assumption has to be made in order to proceed. An equivalence ratio of 3.5 is assumed (which is based on the assumption of restricted air supply). The results of using equations (B2-B5) are shown below.

$$Y_{CO_2} = 0.322 \text{ (g/g)}$$

$$Y_{CO} = 0.473 \text{ (g/g)}$$

$$Y_{hc} = 0.032 \text{ (g/g)}$$

$$Y_s = 0.468 \text{ (g/g)}$$

$$Y_{CO_2} = \text{Adjusted yield of carbon dioxide (g/g)}$$

$$Y_{CO} = \text{Adjusted yield of carbon monoxide (g/g)}$$

$$Y_{hc} = \text{Adjusted yield of hydrocarbons (g/g)}$$

Y_s = Adjusted yield of soot (g/g)

The amount of HCl in the smoke is subtracted to obtain $44,444 - 220 = 44,224 \text{ ppm}$ and the yields are expressed as a percentage assuming that carbon dioxide (24.9%), carbon monoxide (36.5%), hydrocarbons (2.5%) and soot (36.1%) comprise the rest of the smoke (this is usually not the case as other corrosive gases could be present). A concentration of soot is obtained to be $15,965 \text{ ppm} \left(44,224 \times \frac{36.1}{100} \right)$.

It is known that electronic equipment is moderately or highly sensitive to smoke damage. Therefore, the other ranges in the categories were determined with the use of this knowledge and the possibility of damages from Table B20. The smoke computer model provides the concentration of soot which will be assumed to be the concentration of the smoke. The user will decide in which category the content or fire protection system fits in. The water threshold was solely based on engineering judgement.

Table B21 shows different sensitivities ranges that the contents and fire protection systems might have to temperature, smoke and water.

Table B21: Threshold values with respect to temperature, smoke and water.

Category	Temperature (°C)		Smoke (ppm) ^A		Water (L/m ²)	
	Low	High	Low	High	Low	High
Very sensitive	20.0	50.0	2,500	5,000	0.1	0.3
Sensitive	50.0	80.0	5,000	10,000	0.3	1.0
Moderate	80.0	110.0	10,000	15,000	1.0	2.5
Low	110.0	150.0	15,000	25,000	2.5	5.0
No sensitivity	150.0	230.0	25,000	35,000	5.0	10.0

^A – Calculated using a mass basis, based on soot.

8.0 PROBABILITY OF FIRE SPREAD

Since the fire spread computer model has not yet been developed for the fire hazard and fire risk analysis computer model at Carleton University, the probability of fire spread must be estimated. These estimates are not only based on judgement but by knowing the layout of the building and the probability of damage to the compartment's assemblies which the economic computer model calculates to determine the cost of damage (i.e., the probabilities that are obtained from the economic computer model are the probabilities of damage assuming that there is a fire in every compartment which is calculated using the method in section 5.2.1 of Chapter 5 (Methodology)).

Figure B1 shows five fictional compartments only drawn to show the probability of fire spread to each of the compartments. Each wall (North, East, South, and West) will have a probability of damage which will be used as the probability of fire spread.

Figure B1: An illustration of a floor plan consisting of five compartments where the third compartment is the compartment of fire origin.

Probabilities of fire spread from the compartment of fire origin are show below in equations (B7-B8).

$$P_{FS}(3,1) = P_{DEast}(2) \cdot P_{DWest}(2) \quad (B7)$$

$$P_{FS}(3,5) = [P_{DWest}(4) \cdot P_{DSouth}(4) + P_{DNorth}(5)] - [P_{DWest}(4) \cdot P_{DSouth}(4) \cdot P_{DNorth}(5)] \quad (B8)$$

P_{FS} = Probability of fire spread from compartment of fire origin to compartment i

P_{DEast} = Probability of damage to a compartment's East wall

P_{DWest} = Probability of damage to a compartment's West wall

P_{DSouth} = Probability of damage to a compartment's South wall

P_{DNorth} = Probability of damage to a compartment's North wall

Where the layout of the building is complicated, assumptions will have to be made in order to obtain the probability of fire spread. In the case where the sprinklers activate in a building, it is assumed that the probability of fire spread to any compartment is zero.

Appendix C:

Input files for case study

```

'-----'
'Building_Components file description'
'-----'
'
'This file contains the input values for the building components,
'and does not include basic building construction.
'
'Format of the text cannot be changed, only fields that are
'described can be changed and fields must be separated by a comma.
'
'First entry: Capital and labour costs, if applicable ($)
'Second entry: Design and other fees (%)
'Third entry: Contingency fees (%)
'Fourth entry: Commissioning and testing fees (%)
'Fifth entry: Retrofit factor (%)
'Sixth entry: Replacement time (total days)
'Seventh entry: Downtime factor (number)
'-----
Building components

Site development
10.00, 20, 5, 0, 0, 0, 0

Substructure
7.80, 20, 5, 1.2, 0, 30, 1

Roof
5.46, 20, 5, 1.2, 0, 15, 1

Stairs
2.00, 20, 5, 1.2, 0, 15, 1

Services
38.69, 20, 5, 1.2, 0, 30, 1

'-----'
'FP_Systems_Cost file description'
'-----'
'
'This file contains the input values for the fire protection systems,
'not including additional passive fire protection.
'
'Format of the text cannot be changed, only fields that are
'described can be changed and fields must be separated by a comma.
'
'First entry: Number of components of ft^2 (number)
'Second entry: Capital costs ($/component) or ($/ft^2)
'Third entry: Commissioning and testing fees (%)
'Fourth entry: Contingency fees (%)
'Fifth entry: Design and other fees (%)
'Sixth entry: Retrofit factor (%)
'Seventh entry: Yearly maintenance fees ($ total)
'Eighth entry: Yearly inspection fees ($ total)
'Ninth entry: Yearly replacement fees ($ total)
'Tenth entry: Replacement time (total days)
'Eleventh entry: Downtime factor (number)
'Twelfth entry: Sensitivity category for temperature (two capital letters)
'Thirteenth entry: Sensitivity category for smoke (two capital letters)
'Fourteenth entry: Sensitivity category for water (two capital letters)
'
'Sensitivity categories:
'
'VS - Very high sensitivity

```

'HS - High sensitivity
 'MO - Moderate sensitivity
 'LO - Low sensitivity
 'NS - No sensitivity

Active FP- Alarm systems - Single stage

0, 206400, 0, 1.2, 5, 25, 20, 1000, 1000, 1000, 14, 0.1, LO,LO,LO

Active FP- Alarm systems - Dual stage

1, 206400, 0, 1.2, 5, 25, 0, 1000, 1000, 1000, 14, 0.1, LO,LO,LO

Active FP- Alarm systems - Other components- Manual pull bar station

12, 70, 37, 1.2, 5, 20, 0, 50, 50, 50, 1.8, 0.1, LO,LO,LO

Active FP- Alarm systems - Other components- Voice communication

0, 1825, 300, 1.2, 5, 16, 20, 110, 110, 110, 1, 0.1, MO,MO,MO

Active FP- Alarm systems - Other components- Emergency telephone system

0, 860, 231, 1.2, 5, 23, 20, 54, 54, 54, 0.77, 0.1, MO,MO,MO

Active FP- Alarm systems - Other components- Speaker or mini-horn/alarm bell

12, 133, 56, 1.2, 5, 22, 0, 115, 115, 115, 2.4, 0.1, MO,MO,MO

Active FP- Detection - Heat detectors - Dual action - Location -> Compartment

0, 38, 50, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Dual action - Location -> Corridor

0, 38, 50, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Dual action - Location -> Stairshaft

0, 38, 50, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Dual action - Location -> HVAC

0, 38, 50, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Dual action - Location -> Service shaft

0, 38, 50, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Dual action - Location -> Elevator shaft

0, 38, 50, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Dual action - Location -> Garbage chute

0, 38, 50, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Fixed temperature - Location -> Compartment

0, 32, 50, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Fixed temperature - Location -> Corridor

0, 32, 50, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Fixed temperature - Location -> Stairshaft

0, 32, 50, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Fixed temperature - Location -> HVAC

0, 32, 50, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Fixed temperature - Location -> Service shaft

0, 32, 50, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Fixed temperature - Location -> Elevator shaft

0, 32, 50, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Fixed temperature - Location -> Garbage chute

0, 32, 50, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Line or strip - Location -> Compartment
0, 32, 50, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Line or strip - Location -> Corridor
0, 32, 50, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Line or strip - Location -> Stairshaft
0, 32, 50, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Line or strip - Location -> HVAC
0, 32, 50, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Line or strip - Location -> Service shaft
0, 32, 50, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Line or strip - Location -> Elevator shaft
0, 32, 50, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Line or strip - Location -> Garbage chute
0, 32, 50, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Smoke detectors - Beam - Location -> Compartment
0, 84, 65, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Smoke detectors - Beam - Location -> Corridor
0, 84, 65, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Smoke detectors - Beam - Location -> Stairshaft
0, 84, 65, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Smoke detectors - Beam - Location -> HVAC
0, 84, 65, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Smoke detectors - Beam - Location -> Service shaft
0, 84, 65, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Smoke detectors - Beam - Location -> Elevator shaft
0, 84, 65, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Smoke detectors - Beam - Location -> Garbage chute
0, 84, 65, 1.2, 5, 22, 10, 0, 0, 0, 0.15, 0.1, LO,LO,HS

Active FP- Detection - Smoke detectors - Photoelectric - Location -> Compartment
20, 105, 48, 1.2, 5, 22, 0, 360, 360, 360, 3.4, 0.1, LO,LO,HS

Active FP- Detection - Smoke detectors - Photoelectric - Location -> Corridor
4, 105, 48, 1.2, 5, 22, 0, 72, 72, 72, 0.68, 0.1, LO,LO,HS

Active FP- Detection - Smoke detectors - Photoelectric - Location -> Stairshaft
4, 105, 48, 1.2, 5, 22, 0, 72, 72, 72, 2.72, 0.1, LO,LO,HS

Active FP- Detection - Smoke detectors - Photoelectric - Location -> HVAC
2, 350, 93, 1.2, 5, 19, 0, 72, 72, 72, 0.6, 0.1, LO,LO,HS

Active FP- Detection - Smoke detectors - Photoelectric - Location -> Service shaft
0, 105, 48, 1.2, 5, 22, 0, 0, 0, 0, 0.17, 0.1, LO,LO,HS

Active FP- Detection - Smoke detectors - Photoelectric - Location -> Elevator shaft
0, 105, 48, 1.2, 5, 22, 0, 0, 0, 0, 0.17, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Photoelectric - Location -> Garbage chute
0, 105, 48, 1.2, 5, 22, 0, 0, 0, 0, 0.17, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Ionization - Location -> Compartment
0, 105, 48, 1.2, 5, 22, 0, 0, 0, 0, 0.17, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Ionization - Location -> Corridor
0, 105, 48, 1.2, 5, 22, 0, 0, 0, 0, 0.17, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Ionization - Location -> Stairshaft
0, 105, 48, 1.2, 5, 22, 0, 0, 0, 0, 0.17, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Ionization - Location -> HVAC
0, 105, 48, 1.2, 5, 22, 0, 0, 0, 0, 0.17, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Ionization - Location -> Service shaft
0, 105, 48, 1.2, 5, 22, 0, 0, 0, 0, 0.17, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Ionization - Location -> Elevator shaft
0, 105, 48, 1.2, 5, 22, 0, 0, 0, 0, 0.17, 0.1, LO,LO,HS

Active FP- Detection - Heat detectors - Ionization - Location -> Garbage chute
0, 105, 48, 1.2, 5, 22, 0, 0, 0, 0, 0.17, 0.1, LO,LO,HS

Active FP- Suppression systems - Manual extinguishers - Type A
0, 52, 0, 1.2, 5, 10, 0, 0, 0, 0, 0.01, 0.1, NS,NS,NS

Active FP- Suppression systems - Manual extinguishers - Type B
0, 52, 0, 1.2, 5, 10, 0, 0, 0, 0, 0.01, 0.1, NS,NS,NS

Active FP- Suppression systems - Manual extinguishers - Type C
0, 52, 0, 1.2, 5, 10, 0, 0, 0, 0, 0.01, 0.1, NS,NS,NS

Active FP- Suppression systems - Manual extinguishers - Type ABC
32, 52, 0, 1.2, 5, 10, 0, 175, 175, 175, 0.32, 0.1, NS,NS,NS

Active FP- Suppression systems - Fire hose /standpipe
4, 714, 117, 1.2, 5, 20, 0, 175, 175, 175, 0.32, 0.1, LO,NS,NS

Active FP- Suppression systems - Kitchen hood extinguishing system
0, 32800, 535, 1.2, 5, 11, 0, 560, 560, 560, 2, 0.1, LO,LO,LO

Active FP- Suppression systems - Sprinklers - Dry pipe
0, 0, 0, 1.2, 5, 20, 33, 0, 0, 0, 0, 0.1, HS,NS,NS

Active FP- Suppression systems - Sprinklers - Wet pipe
56400, 1.37, 2.18, 1.2, 5, 20, 0, 550, 550, 550, 7, 0.1, HS,NS,NS

Active FP- Suppression systems - Sprinklers - Pre-action
0, 0, 0, 1.2, 5, 20, 33, 0, 0, 0, 0, 0.1, HS,NS,NS

Active FP- Suppression systems - Sprinklers - Deluge
0, 0, 0, 1.2, 5, 20, 33, 0, 0, 0, 0, 0.1, HS,NS,NS

Active FP- Suppression systems - Sprinklers - Other costs - Supply
1, 910, 245, 1.2, 5, 22, 0, 150, 150, 0, 1.25, 0.1, NS,NS,NS

Active FP- Suppression systems - Sprinklers - Other costs - Pressure tanks
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, NS,NS,NS

Active FP- Suppression systems - Sprinklers - Other costs - Elevated gravity tanks
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, NS,NS,NS

Active FP- Suppression systems - Sprinklers - Other costs - Fire pumps
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, NS,NS,NS

Active FP- Smoke control and management - Smoke management system
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, NS,NS,NS

Active FP- Smoke control and management - SC - Elevator shaft pressurization
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, NS,NS,NS

Active FP- Smoke control and management - SC -Stairshaft pressurization
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, NS,NS,NS

Active FP- Smoke control and management - Zone pressurization
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, NS,NS,NS

Passive FR - Egress routes - Additional exits
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, NS,NS,NS

Passive FR - Egress routes - Additional stairshafts
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, NS,NS,NS

Passive ES - Emergency lighting
20, 630, 76, 1.2, 5, 13, 0, 200, 200, 200, 6, 0.1, NS,NS,NS

Passive ES - Exit signs
20, 133, 75, 1.2, 5, 29, 0, 100, 100, 100, 6, 0.1, NS,NS,NS

Passive ES - Posted emergency floor plans
4, 20, 0, 1.2, 5, 9, 0, 0, 0, 0.04, 0.1, NS,NS,NS

```

'-----'
'Passive_FR Input file description'
'-----'
'
'This file contains the input for the components of a compartment.
'Entries must be made right below the dotted line and must be separated by a comma.
'Format of text above the dotted line cannot be changed.
'In brackets, the needed data type is described.
'
'Data is as follows:
'Below title of "Number of compartments" (integer) enter integer for number of
compartments
'Next is line "Compartment ID number".
'Compartment ID number (integer).
'Description or number of components (description are for walls, ceilings, floors).
'Number of doors and windows is needed (Doors are after ceiling, followed by windows).
'
'Entries
'
'First entry: Description or number (E = East, W=West, N=North, S=South)
'Second entry: Cost per ft^2 or per unit
'Third entry: Fire Resistance Rating or fire rating (min)
'Fourth entry: Downtime days (number)
'Fifth entry: Downtime factor (number)
'-----
Number of compartments
48
Compartment ID number
1
EWall, 48.00, 120, 0.6, 0.7
WWall, 48.00, 120, 0.6, 0.7
NWall, 2.14, 60, 0.5, 0.7
SWall, 48.00, 120, 0.5, 0.7
Ceiling, 16.40, 120, 3.4, 0.7
Floor, 16.40, 120, 3.4, 0.7
2, 165.00, 90, 0.25, 0.1
0, 0, 0, 0, 0
Compartment ID number
2
EWall, 48.00, 120, 0.4, 0.7
WWall, 2.14, 60, 0.4, 0.7
NWall, 48.00, 120, 0.3, 0.7

```



```

SWall, 9.78, 70, 0.3, 0.7
Ceiling, 16.40, 120, 1.4, 0.7
Floor, 16.40, 120, 1.4, 0.7
1, 165.00, 90, 0.25, 0.1
0, 0, 0, 0, 0

```

Compartment ID number

3

```

EWall, 48.00, 120, 0.3, 0.7
WWall, 48.00, 120, 0.3, 0.7
NWall, 48.00, 120, 0.4, 0.7
SWall, 2.14, 60, 0.4, 0.7
Ceiling, 16.40, 120, 1.3, 0.7
Floor, 16.40, 120, 1.3, 0.7
1, 165.00, 90, 0.25, 0.1
0, 0, 0, 0, 0

```

Compartment ID number

4

```

EWall, 2.14, 60, 0.2, 0.7
WWall, 48.00, 120, 0.2, 0.7
NWall, 48.00, 120, 0.2, 0.7
SWall, 13.61, 75, 0.2, 0.7
Ceiling, 16.40, 120, 0.5, 0.7
Floor, 16.40, 120, 0.5, 0.7
1, 165.00, 90, 0.25, 0.1
0, 0, 0, 0, 0

```

Compartment ID number

5

```

EWall, 0, 0, 0, 0
WWall, 0, 0, 0, 0
NWall, 4.27, 60, 0.3, 0.7
SWall, 2.14, 60, 0.3, 0.7
Ceiling, 16.40, 120, 0.3, 0.7
Floor, 16.40, 120, 0.3, 0.7
1, 165.00, 90, 0.25, 0.1
0, 0, 0, 0, 0

```

Compartment ID number

6

```

EWall, 2.14, 60, 0.03, 0.7
WWall, 2.14, 60, 0.03, 0.7
NWall, 2.14, 60, 0.3, 0.7
SWall, 4.27, 60, 0.3, 0.7
Ceiling, 16.40, 120, 0.1, 0.7
Floor, 16.40, 120, 0.1, 0.7
1, 165.00, 90, 0.25, 0.1
0, 0, 0, 0, 0

```

Compartment ID number

7

```

EWall, 2.14, 60, 0.03, 0.7
WWall, 2.14, 60, 0.03, 0.7
NWall, 2.14, 60, 0.3, 0.7
SWall, 2.14, 60, 0.3, 0.7
Ceiling, 16.40, 120, 0.1, 0.7
Floor, 16.40, 120, 0.1, 0.7
1, 165.00, 90, 0.25, 0.1
0, 0, 0, 0, 0

```

Compartment ID number

8

```

EWall, 0, 0, 0, 0
WWall, 48.00, 120, 0.5, 0.7
NWall, 2.14, 60, 0.6, 0.7
SWall, 8.00, 70, 0.6, 0.7
Ceiling, 16.40, 120, 0.2, 0.7
Floor, 16.40, 120, 0.2, 0.7
1, 165.00, 90, 0.25, 0.1
0, 0, 0, 0, 0

```

Compartment ID number

9
 EWall, 2.14, 60, 0.2, 0.7
 WWall, 48.00, 120, 0.2, 0.7
 NWall, 2.14, 60, 0.7, 0.7
 SWall, 38.80, 100, 0.7, 0.7
 Ceiling, 16.40, 120, 0.3, 0.7
 Floor, 16.40, 120, 0.3, 0.7
 2, 335.00, 90, 0.25, 0.1
 0, 0, 0, 0, 0

Compartment ID number

10
 EWall, 48.00, 120, 0.6, 0.7
 WWall, 48.00, 120, 0.6, 0.7
 NWall, 2.90, 60, 0.9, 0.7
 SWall, 38.80, 100, 0.9, 0.7
 Ceiling, 16.40, 120, 5.0, 0.7
 Floor, 16.40, 120, 5.0, 0.7
 2, 165.00, 90, 0.25, 0.1
 0, 0, 0, 0, 0

Compartment ID number

11
 EWall, 48.00, 120, 0.3, 0.7
 WWall, 2.14, 60, 0.3, 0.7
 NWall, 12.70, 70, 0.4, 0.7
 SWall, 12.70, 70, 0.4, 0.7
 Ceiling, 16.40, 120, 1.2, 0.7
 Floor, 16.40, 120, 1.2, 0.7
 1, 165.00, 90, 0.25, 0.1
 0, 0, 0, 0, 0

Compartment ID number

12
 EWall, 48.00, 120, 0.5, 0.7
 WWall, 2.14, 60, 0.5, 0.7
 NWall, 48.00, 120, 0.3, 0.7
 SWall, 2.14, 60, 0.3, 0.7
 Ceiling, 16.40, 120, 1.4, 0.7
 Floor, 16.40, 120, 1.4, 0.7
 1, 165.00, 90, 0.25, 0.1
 0, 0, 0, 0, 0

Compartment ID number

13
 EWall, 10.48, 70, 0.3, 0.7
 WWall, 10.48, 70, 0.3, 0.7
 NWall, 48.00, 120, 0.4, 0.7
 SWall, 2.14, 60, 0.4, 0.7
 Ceiling, 16.40, 120, 1.2, 0.7
 Floor, 16.40, 120, 1.2, 0.7
 1, 165.00, 90, 0.25, 0.1
 0, 0, 0, 0, 0

Compartment ID number

14
 EWall, 2.14, 60, 0.3, 0.7
 WWall, 48.00, 120, 0.3, 0.7
 NWall, 48.00, 120, 0.4, 0.7
 SWall, 11.97, 70, 0.4, 0.7
 Ceiling, 16.40, 120, 1.1, 0.7
 Floor, 16.40, 120, 1.1, 0.7
 1, 165.00, 90, 0.25, 0.1
 0, 0, 0, 0, 0

Compartment ID number

15
 EWall, 2.14, 60, 0.4, 0.7
 WWall, 48.00, 120, 0.4, 0.7
 NWall, 2.14, 60, 0.3, 0.7
 SWall, 15.20, 75, 0.3, 0.7
 Ceiling, 16.40, 120, 0.9, 0.7

```

Floor, 16.40, 120, 0.9, 0.7
1, 165.00, 90, 0.25, 0.1
1, 1715.00, 20, 0.25, 0.1
Compartment ID number
16
EWall, 0, 0, 0, 0
WWall, 0, 0, 0, 0
NWall, 4.27, 60, 0.3, 0.7
SWall, 2.14, 60, 0.3, 0.7
Ceiling, 16.40, 120, 0.3, 0.7
Floor, 16.40, 120, 0.3, 0.7
0, 0, 0, 0
0, 0, 0, 0
Compartment ID number
17
EWall, 2.14, 60, 0.04, 0.7
WWall, 2.14, 60, 0.04, 0.7
NWall, 2.14, 60, 0.3, 0.7
SWall, 4.27, 60, 0.3, 0.7
Ceiling, 16.40, 120, 0.1, 0.7
Floor, 16.40, 120, 0.1, 0.7
1, 165.00, 90, 0.25, 0.1
0, 0, 0, 0
Compartment ID number
18
EWall, 2.14, 60, 0.04, 0.7
WWall, 2.14, 60, 0.04, 0.7
NWall, 2.14, 60, 0.3, 0.7
SWall, 2.14, 60, 0.3, 0.7
Ceiling, 16.40, 120, 0.1, 0.7
Floor, 16.40, 120, 0.1, 0.7
1, 165.00, 90, 0.25, 0.1
0, 0, 0, 0
Compartment ID number
19
EWall, 40.36, 110, 0.6, 0.7
WWall, 48.00, 120, 0.6, 0.7
NWall, 2.14, 60, 0.5, 0.7
SWall, 48.00, 120, 0.5, 0.7
Ceiling, 16.40, 120, 3.6, 0.7
Floor, 16.40, 120, 3.6, 0.7
2, 165.00, 90, 0.25, 0.1
0, 0, 0, 0
Compartment ID number
20
EWall, 48.00, 120, 0.5, 0.7
WWall, 2.14, 60, 0.5, 0.7
NWall, 4.27, 60, 0.3, 0.7
SWall, 48.00, 120, 0.3, 0.7
Ceiling, 16.40, 120, 2.3, 0.7
Floor, 16.40, 120, 2.3, 0.7
1, 165.00, 90, 0.25, 0.1
0, 0, 0, 0
Compartment ID number
21
EWall, 4.27, 60, 0.3, 0.7
WWall, 1.32, 95, 0.3, 0.7
NWall, 48.00, 120, 0.2, 0.7
SWall, 2.14, 60, 0.2, 0.7
Ceiling, 16.40, 120, 0.9, 0.7
Floor, 16.40, 120, 0.9, 0.7
1, 165.00, 90, 0.25, 0.1
0, 0, 0, 0
Compartment ID number
22
EWall, 2.17, 60, 0.6, 0.7

```

```

Wwall, 48.00, 120, 0.6, 0.7
NWall, 48.00, 120, 0.3, 0.7
SWall, 35.51, 100, 0.3, 0.7
Ceiling, 16.40, 120, 2.1, 0.7
Floor, 16.40, 120, 2.1, 0.7
1, 165.00, 90, 0.25, 0.1
0, 0, 0, 0, 0
Compartment ID number
23
EWall, 0, 0, 0, 0
Wwall, 0, 0, 0, 0
NWall, 4.27, 60, 0.3, 0.7
SWall, 2.14, 60, 0.3, 0.7
Ceiling, 16.40, 120, 0.3, 0.7
Floor, 16.40, 120, 0.3, 0.7
0, 0, 0, 0, 0
0, 0, 0, 0, 0
Compartment ID number
24
EWall, 0, 0, 0, 0
Wwall, 0, 0, 0, 0
NWall, 4.27, 60, 0.3, 0.7
SWall, 2.14, 60, 0.3, 0.7
Ceiling, 16.40, 120, 0.3, 0.7
Floor, 16.40, 120, 0.3, 0.7
0, 0, 0, 0, 0
0, 0, 0, 0, 0
Compartment ID number
25
EWall, 2.14, 60, 0.03, 0.7
Wwall, 2.14, 60, 0.03, 0.7
NWall, 2.14, 60, 0.3, 0.7
SWall, 4.27, 60, 0.3, 0.7
Ceiling, 16.40, 120, 0.1, 0.7
Floor, 16.40, 120, 0.1, 0.7
1, 165.00, 90, 0.25, 0.1
0, 0, 0, 0, 0
Compartment ID number
26
EWall, 2.14, 60, 0.6, 0.7
Wwall, 48.00, 120, 0.6, 0.7
NWall, 2.14, 60, 0.4, 0.7
SWall, 48.00, 120, 0.4, 0.7
Ceiling, 16.40, 120, 2.6, 0.7
Floor, 16.40, 120, 2.6, 0.7
2, 165.00, 90, 0.25, 0.1
0, 0, 0, 0, 0
Compartment ID number
27
EWall, 48.00, 120, 0.6, 0.7
Wwall, 2.14, 60, 0.6, 0.7
NWall, 2.14, 60, 0.4, 0.7
SWall, 48.00, 120, 0.4, 0.7
Ceiling, 16.40, 120, 3.0, 0.7
Floor, 16.40, 120, 3.0, 0.7
2, 335.00, 90, 0.25, 0.1
0, 0, 0, 0, 0
Compartment ID number
28
EWall, 48.00, 120, 0.4, 0.7
Wwall, 2.14, 60, 0.4, 0.7
NWall, 2.14, 60, 0.3, 0.7
SWall, 2.14, 60, 0.3, 0.7
Ceiling, 16.40, 120, 2.0, 0.7
Floor, 16.40, 120, 2.0, 0.7
1, 165.00, 90, 0.25, 0.1

```

```

0,      0,  0,      0,      0
Compartment ID number
29
EWall,  2.14, 60,    0.4,    0.7
WWall,  48.00, 120,   0.4,    0.7
NWall,  48.00, 120,   0.3,    0.7
SWall,   4.27, 60,    0.3,    0.7
Ceiling, 16.40, 120,   1.3,    0.7
Floor,   16.40, 120,   1.3,    0.7
1,      165.00, 90,    0.25,   0.1
0,      0,  0,      0,      0
Compartment ID number
30
EWall,   0,  0,      0,      0
WWall,   0,  0,      0,      0
NWall,   4.27, 60,    0.3,    0.7
SWall,   2.14, 60,    0.3,    0.7
Ceiling, 16.40, 120,   0.3,    0.7
Floor,   16.40, 120,   0.3,    0.7
1,      165.00, 90,    0.25,   0.1
0,      0,  0,      0,      0
Compartment ID number
31
EWall,   2.14, 60,    0.03,   0.7
WWall,   2.14, 60,    0.03,   0.7
NWall,   2.14, 60,    0.3,    0.7
SWall,   4.27, 60,    0.3,    0.7
Ceiling, 16.40, 120,   0.1,    0.7
Floor,   16.40, 120,   0.1,    0.7
1,      165.00, 90,    0.25,   0.1
0,      0,  0,      0,      0
Compartment ID number
32
EWall,   2.14, 60,    0.03,   0.7
WWall,   2.14, 60,    0.03,   0.7
NWall,   2.14, 60,    0.3,    0.7
SWall,   2.14, 60,    0.3,    0.7
Ceiling, 16.40, 120,   0.1,    0.7
Floor,   16.40, 120,   0.1,    0.7
1,      165.00, 90,    0.25,   0.1
0,      0,  0,      0,      0
Compartment ID number
33
EWall,   2.14, 60,    0.03,   0.7
WWall,  48.00, 120,   0.03,   0.7
NWall,   2.14, 60,    0.3,    0.7
SWall,   2.14, 60,    0.3,    0.7
Ceiling, 16.40, 120,   0.1,    0.7
Floor,   16.40, 120,   0.1,    0.7
1,      500.00, 90,    0.25,   0.1
0,      0,  0,      0,      0
Compartment ID number
34
EWall,   2.14, 60,    0.03,   0.7
WWall,  48.00, 120,   0.03,   0.7
NWall,  10.74, 70,    0.6,    0.7
SWall,   2.14, 60,    0.6,    0.7
Ceiling, 16.40, 120,   0.2,    0.7
Floor,   16.40, 120,   0.2,    0.7
2,      335.00, 90,    0.25,   0.1
0,      0,  0,      0,      0
Compartment ID number
35
EWall,   3.28, 60,    0.3,    0.7
WWall,   1.42, 60,    0.3,    0.7
NWall,   2.14, 60,    0.1,    0.7

```

```

SWall, 2.14, 60, 0.1, 0.7
Ceiling, 16.40, 120, 0.3, 0.7
Floor, 16.40, 120, 0.3, 0.7
0, 0, 0, 0, 0
0, 0, 0, 0, 0

```

Compartment ID number

36

```

EWall, 1.75, 60, 0.5, 0.7
WWall, 1.78, 60, 0.5, 0.7
NWall, 2.14, 60, 0.1, 0.7
SWall, 2.14, 60, 0.1, 0.7
Ceiling, 16.40, 120, 0.5, 0.7
Floor, 16.40, 120, 0.5, 0.7
4, 165.00, 90, 0.25, 0.1
0, 0, 0, 0, 0

```

Compartment ID number

37

```

EWall, 2.63, 60, 0.6, 0.7
WWall, 1.28, 60, 0.6, 0.7
NWall, 2.14, 60, 0.1, 0.7
SWall, 2.14, 60, 0.1, 0.7
Ceiling, 16.40, 120, 0.5, 0.7
Floor, 16.40, 120, 0.5, 0.7
4, 165.00, 90, 0.25, 0.1
0, 0, 0, 0, 0

```

Compartment ID number

38

```

EWall, 2.14, 60, 0.6, 0.7
WWall, 2.63, 60, 0.6, 0.7
NWall, 2.14, 60, 0.1, 0.7
SWall, 2.14, 60, 0.1, 0.7
Ceiling, 16.40, 120, 0.5, 0.7
Floor, 16.40, 120, 0.5, 0.7
5, 165.00, 90, 0.25, 0.1
0, 0, 0, 0, 0

```

Compartment ID number

39

```

EWall, 0, 0, 0, 0
WWall, 0, 0, 0, 0
NWall, 4.27, 60, 0.3, 0.7
SWall, 2.14, 60, 0.3, 0.7
Ceiling, 16.40, 120, 0.3, 0.7
Floor, 16.40, 120, 0.3, 0.7
0, 0, 0, 0, 0
0, 0, 0, 0, 0

```

Compartment ID number

40

```

EWall, 2.63, 60, 0.5, 0.7
WWall, 1.58, 60, 0.5, 0.7
NWall, 2.14, 60, 0.1, 0.7
SWall, 2.14, 60, 0.1, 0.7
Ceiling, 16.40, 120, 0.5, 0.7
Floor, 16.40, 120, 0.5, 0.7
3, 165.00, 90, 0.25, 0.1
0, 0, 0, 0, 0

```

Compartment ID number

41

```

EWall, 2.48, 60, 0.5, 0.7
WWall, 2.63, 60, 0.5, 0.7
NWall, 2.14, 60, 0.1, 0.7
SWall, 2.14, 60, 0.1, 0.7
Ceiling, 16.40, 120, 0.5, 0.7
Floor, 16.40, 120, 0.5, 0.7
3, 165.00, 90, 0.25, 0.1
0, 0, 0, 0, 0

```

Compartment ID number

```

42
EWall,      0,  0,      0,      0
WWall,      0,  0,      0,      0
NWall,      4.27, 60,    0.3,    0.7
SWall,      2.14, 60,    0.3,    0.7
Ceiling,    16.40,120,   0.3,    0.7
Floor,      16.40,120,   0.3,    0.7
1,          165.00, 90,   0.25,   0.1
0,          0,  0,      0,      0
Compartment ID number
43
EWall,      3.30, 60,    0.1,    0.7
WWall,      4.27, 60,    0.1,    0.7
NWall,      2.14, 60,    0.3,    0.7
SWall,      2.14, 60,    0.3,    0.7
Ceiling,    16.40,120,   0.3,    0.7
Floor,      16.40,120,   0.3,    0.7
4,          165.00, 90,   0.25,   0.1
0,          0,  0,      0,      0
Compartment ID number
44
EWall,      3.30, 60,    0.5,    0.7
WWall,      1.80, 60,    0.5,    0.7
NWall,      2.14, 60,    0.1,    0.7
SWall,      2.14, 60,    0.1,    0.7
Ceiling,    16.40,120,   0.5,    0.7
Floor,      16.40,120,   0.5,    0.7
2,          165.00, 90,   0.25,   0.1
0,          0,  0,      0,      0
Compartment ID number
45
EWall,      48.00,120,   0.3,    0.7
WWall,      2.14, 60,    0.3,    0.7
NWall,      48.00,120,   0.8,    0.7
SWall,      2.14, 60,    0.8,    0.7
Ceiling,    16.40,120,   3.4,    0.7
Floor,      16.40,120,   3.4,    0.7
2,          165.00, 90,   0.25,   0.1
0,          0,  0,      0,      0
Compartment ID number
46
EWall,      48.00,120,   0.1,    0.7
WWall,      0,  0,      0,    0.7
NWall,      0,  0,      0,    0.7
SWall,      48.00,120,   0.1,    0.7
Ceiling,    16.40,120,   0.1,    0.7
Floor,      16.40,120,   0.1,    0.7
1,          500.00, 90,   0.25,   0.1
0,          0,  0,      0,      0
Compartment ID number
47
EWall,      48.00,120,   0.1,    0.7
WWall,      0,  0,      0,    0.7
NWall,      0,  0,      0,    0.7
SWall,      48.00,120,   0.2,    0.7
Ceiling,    16.40,120,   0.1,    0.7
Floor,      16.40,120,   0.1,    0.7
1,          500.00, 90,   0.25,   0.1
0,          0,  0,      0,      0
Compartment ID number
48
EWall,      48.00,120,   0.1,    0.7
WWall,      0,  0,      0,      0
NWall,      2.14, 60,    0.4,    0.7
SWall,      2.14, 60,    0.4,    0.7
Ceiling,    16.40,120,   0.4,    0.7

```

```
Floor, 16.40, 120, 0.4, 0.7
1, 165.00, 90, 0.25, 0.1
0, 0, 0, 0, 0
```

```
'-----'
'Contents file description'
'-----'
```

```
'
'This file contains the input values for the contents of each compartment.
'Entries must be made right below the dotted line and must be separated by a comma.
'Format of the text above the dotted line cannot be changed.
'In brackets, the needed data type is described.
'
```

```
'First entry: Compartment number (integer)
'Second entry: Title of contents (text)
'Third entry: Sensitivity category for temperature (two capital letters)
'Fourth entry: Sensitivity category for smoke (two capital letters)
'Fifth entry: Sensitivity category for water (two capital letters)
'Sixth entry: Replacement time (number)
'Seventh entry: Downtime factor (number)
'
```

```
'Sensitivity categories:
```

```
'
'VS - Very high sensitivity
'HS - High sensitivity
'MO - Moderate sensitivity
'LO - Low sensitivity
'NS - No sensitivity
'
```

```
'Do not remove line ,,,,,,-----END-----,,,,,
'Must be last line right after last entry.
'-----'
```

```
1, Books, 15000, HS, HS, HS, 10, 0.01
1, Electronic, 24000, HS, MO, HS, 10, 0.05
1, Furniture(upholstered), 15000, HS, HS, LO, 10, 0.01
1, Furniture(wood), 15000, LO, LO, LO, 10, 0.01
1, Linings/finishes, 48125, LO, LO, LO, 10, 0.01
1, Lighting, 36000, LO, VS, LO, 10, 0.05
1, Partitions, 7050, LO, LO, LO, 10, 0.01
2, Books, 6200, HS, HS, HS, 10, 0.01
2, Electronic, 9900, HS, MO, HS, 10, 0.05
2, Furniture(upholstered), 6200, HS, HS, LO, 10, 0.01
2, Furniture(wood), 6200, LO, LO, LO, 10, 0.01
2, Linings/finishes, 19725, LO, LO, LO, 10, 0.01
2, Lighting, 14800, LO, VS, LO, 10, 0.05
2, Partitions, 1570, LO, LO, LO, 10, 0.01
3, Books, 6000, VS, VS, VS, 10, 0.01
3, Electronic, 9600, VS, VS, VS, 10, 0.05
3, Furniture(upholstered), 6000, VS, VS, VS, 10, 0.01
3, Furniture(wood), 6000, VS, VS, VS, 10, 0.01
3, Linings/finishes, 19020, VS, VS, VS, 10, 0.01
3, Lighting, 1440, VS, VS, VS, 10, 0.05
3, Partitions, 1130, VS, VS, VS, 10, 0.01
4, Books, 2300, HS, HS, HS, 10, 0.01
4, Food, 3000, VS, VS, VS, 10, 0.01
4, Electronic, 3600, HS, MO, HS, 10, 0.05
4, Furniture(upholstered), 2300, HS, HS, LO, 10, 0.01
4, Furniture(wood), 2300, LO, LO, LO, 10, 0.01
4, Plastics, 2300, HS, LO, LO, 10, 0.01
4, Machinery, 2000, MO, MO, HS, 10, 0.01
4, Linings/finishes, 7035, LO, LO, LO, 10, 0.01
4, Lighting, 36000, LO, VS, LO, 10, 0.05
4, Drugs, 20000, VS, VS, VS, 10, 0.01
```


5,	Linings/finishes,	5505,	LO, LO, LO, 10, 0.01
6,	Linings/finishes,	1695,	LO, LO, LO, 10, 0.01
7,	Linings/finishes,	1225,	LO, LO, LO, 10, 0.01
8,	Linings/finishes,	3765,	LO, LO, LO, 10, 0.01
9,	Linings/finishes,	3885,	LO, LO, LO, 10, 0.01
10,	Books,	22200,	HS, HS, HS, 10, 0.01
10,	Electronic,	35550,	HS, MO, HS, 10, 0.05
10,	Furniture(upholstered),	22200,	HS, HS, LO, 10, 0.01
10,	Furniture(wood),	22200,	LO, LO, LO, 10, 0.01
10,	Linings/finishes,	71410,	LO, LO, LO, 10, 0.01
10,	Lighting,	54000,	LO, VS, LO, 10, 0.05
10,	Partitions,	13390,	LO, LO, LO, 10, 0.01
11,	Books,	5300,	HS, HS, HS, 10, 0.01
11,	Electronic,	8500,	HS, MO, HS, 10, 0.05
11,	Furniture(upholstered),	5300,	HS, HS, LO, 10, 0.01
11,	Furniture(wood),	5300,	LO, LO, LO, 10, 0.01
11,	Linings/finishes,	20570,	LO, LO, LO, 10, 0.01
11,	Lighting,	12600,	LO, VS, LO, 10, 0.05
12,	Books,	6450,	HS, HS, HS, 10, 0.01
12,	Electronic,	10320,	HS, MO, HS, 10, 0.05
12,	Furniture(upholstered),	6450,	HS, HS, LO, 10, 0.01
12,	Furniture(wood),	6450,	LO, LO, LO, 10, 0.01
12,	Linings/finishes,	20570,	LO, LO, LO, 10, 0.01
12,	Lighting,	15480,	LO, VS, LO, 10, 0.05
13,	Books,	5100,	HS, HS, HS, 10, 0.01
13,	Electronic,	8160,	HS, MO, HS, 10, 0.05
13,	Furniture(upholstered),	5100,	HS, HS, LO, 10, 0.01
13,	Furniture(wood),	5100,	LO, LO, LO, 10, 0.01
13,	Linings/finishes,	16515,	LO, LO, LO, 10, 0.01
13,	Lighting,	12240,	LO, VS, LO, 10, 0.05
13,	Partitions,	1435,	LO, LO, LO, 10, 0.01
13,	Dental_Stuff,	50000,	LO, MO, HS, 10, 0.05
14,	Books,	5100,	HS, HS, HS, 10, 0.01
14,	Electronic,	8160,	HS, MO, HS, 10, 0.05
14,	Furniture(upholstered),	5100,	HS, HS, LO, 10, 0.01
14,	Furniture(wood),	5100,	LO, LO, LO, 10, 0.01
14,	Linings/finishes,	16230,	LO, LO, LO, 10, 0.01
14,	Lighting,	12240,	LO, VS, LO, 10, 0.05
14,	Partitions,	5740,	LO, LO, LO, 10, 0.01
14,	Dental_Stuff,	50000,	LO, MO, HS, 10, 0.05
15,	Food,	5000,	VS, VS, VS, 10, 0.01
15,	Electronic,	6000,	HS, MO, HS, 10, 0.05
15,	Furniture(upholstered),	5000,	HS, HS, LO, 10, 0.01
15,	Furniture(wood),	5000,	LO, LO, LO, 10, 0.01
15,	Linings/finishes,	11925,	LO, LO, LO, 10, 0.01
15,	Lighting,	9000,	LO, VS, LO, 10, 0.05
15,	Machinery,	50000,	LO, LO, LO, 10, 0.05
16,	Linings/finishes,	4235,	LO, LO, LO, 10, 0.01
17,	Linings/finishes,	1695,	LO, LO, LO, 10, 0.01
18,	Linings/finishes,	1695,	LO, LO, LO, 10, 0.01
19,	Books,	15750,	HS, HS, HS, 10, 0.01
19,	Electronic,	25200,	HS, MO, HS, 10, 0.05
19,	Furniture(upholstered),	15750,	HS, HS, LO, 10, 0.01
19,	Furniture(wood),	15750,	LO, LO, LO, 10, 0.01
19,	Linings/finishes,	50310,	LO, LO, LO, 10, 0.01
19,	Lighting,	37800,	LO, VS, LO, 10, 0.05
19,	Partitions,	6525,	LO, LO, LO, 10, 0.01
20,	Books,	10350,	HS, HS, HS, 10, 0.01
20,	Electronic,	16560,	HS, MO, HS, 10, 0.05
20,	Furniture(upholstered),	10350,	HS, HS, LO, 10, 0.01
20,	Furniture(wood),	10350,	LO, LO, LO, 10, 0.01
20,	Linings/finishes,	33375,	LO, LO, LO, 10, 0.01
20,	Lighting,	24840,	LO, VS, LO, 10, 0.05
20,	Partitions,	3915,	LO, LO, LO, 10, 0.01
21,	Books,	3900,	HS, HS, HS, 10, 0.01
21,	Furniture(upholstered),	4000,	HS, HS, LO, 10, 0.01

21,	Furniture(wood),	4000,	LO, LO, LO, 10, 0.01
21,	Linings/finishes,	12705,	LO, LO, LO, 10, 0.01
21,	Lighting,	9360,	LO, VS, LO, 10, 0.05
21,	Partitions,	870,	LO, LO, LO, 10, 0.01
22,	Books,	9150,	HS, HS, HS, 10, 0.01
22,	Electronic,	14640,	HS, MO, HS, 10, 0.05
22,	Furniture(upholstered),	9150,	HS, HS, LO, 10, 0.01
22,	Furniture(wood),	9150,	LO, LO, LO, 10, 0.01
22,	Linings/finishes,	29215,	LO, LO, LO, 10, 0.01
22,	Lighting,	21960,	LO, VS, LO, 10, 0.05
22,	Partitions,	3915,	LO, LO, LO, 10, 0.01
23,	Linings/finishes,	4235,	LO, LO, LO, 10, 0.01
24,	Linings/finishes,	1695,	LO, LO, LO, 10, 0.01
25,	Linings/finishes,	1695,	LO, LO, LO, 10, 0.01
26,	Books,	11700,	HS, HS, HS, 10, 0.01
26,	Electronic,	18720,	HS, MO, HS, 10, 0.05
26,	Furniture(upholstered),	11700,	HS, HS, LO, 10, 0.01
26,	Furniture(wood),	11700,	LO, LO, LO, 10, 0.01
26,	Linings/finishes,	37330,	LO, LO, LO, 10, 0.01
26,	Lighting,	28080,	LO, VS, LO, 10, 0.05
27,	Books,	13200,	HS, HS, HS, 10, 0.01
27,	Electronic,	21120,	HS, MO, HS, 10, 0.05
27,	Furniture(upholstered),	13200,	HS, HS, LO, 10, 0.01
27,	Furniture(wood),	13220,	LO, LO, LO, 10, 0.01
27,	Linings/finishes,	42195,	LO, LO, LO, 10, 0.01
27,	Lighting,	31680,	LO, VS, LO, 10, 0.05
27,	Partitions,	6086,	LO, LO, LO, 10, 0.01
28,	Books,	5850,	HS, HS, HS, 10, 0.01
28,	Electronic,	9360,	HS, MO, HS, 10, 0.05
28,	Furniture(upholstered),	5850,	HS, HS, LO, 10, 0.01
28,	Furniture(wood),	5850,	LO, LO, LO, 10, 0.01
28,	Linings/finishes,	18820,	LO, LO, LO, 10, 0.01
28,	Lighting,	14040,	LO, VS, LO, 10, 0.05
29,	Books,	6000,	HS, HS, HS, 10, 0.01
29,	Electronic,	9600,	HS, MO, HS, 10, 0.05
29,	Furniture(upholstered),	6000,	HS, HS, LO, 10, 0.01
29,	Furniture(wood),	6000,	LO, LO, LO, 10, 0.01
29,	Linings/finishes,	19020,	LO, LO, LO, 10, 0.01
29,	Lighting,	14400,	LO, VS, LO, 10, 0.05
29,	Partitions,	2610,	LO, LO, LO, 10, 0.01
30,	Linings/finishes,	4235,	LO, LO, LO, 10, 0.01
31,	Linings/finishes,	1695,	LO, LO, LO, 10, 0.01
32,	Linings/finishes,	1695,	LO, LO, LO, 10, 0.01
33,	Linings/finishes,	1835,	LO, LO, LO, 10, 0.01
34,	Linings/finishes,	3250,	LO, LO, LO, 10, 0.01
35,	Linings/finishes,	4590,	LO, LO, LO, 10, 0.01
36,	Linings/finishes,	6940,	LO, LO, LO, 10, 0.01
37,	Linings/finishes,	7295,	LO, LO, LO, 10, 0.01
38,	Linings/finishes,	7295,	LO, LO, LO, 10, 0.01
39,	Linings/finishes,	4235,	LO, LO, LO, 10, 0.01
40,	Linings/finishes,	7295,	LO, LO, LO, 10, 0.01
41,	Linings/finishes,	7295,	LO, LO, LO, 10, 0.01
42,	Linings/finishes,	4235,	LO, LO, LO, 10, 0.01
43,	Linings/finishes,	7295,	LO, LO, LO, 10, 0.01
44,	Linings/finishes,	7295,	LO, LO, LO, 10, 0.01
45,	Books,	15000,	HS, HS, HS, 10, 0.01
45,	Electronic,	24000,	HS, MO, HS, 10, 0.05
45,	Furniture(upholstered),	15000,	HS, HS, LO, 10, 0.01
45,	Furniture(wood),	15000,	LO, LO, LO, 10, 0.01
45,	Linings/finishes,	48040,	LO, LO, LO, 10, 0.01
45,	Lighting,	36000,	LO, VS, LO, 10, 0.05
46,	Linings/finishes,	2353,	LO, LO, LO, 10, 0.01
47,	Linings/finishes,	2353,	LO, LO, LO, 10, 0.01
48,	Linings/finishes,	5765,	LO, LO, LO, 10, 0.01

////////-----END-----////////

```

'-----'
'Thresholds file description'
'-----'
'
'This file contains the input values for the threshold categories.
'Format and spacing of the data cannot be changed, only the threshold
'values.
'
'Naming conventions:
'
'L - Represents the lower threshold
'U - Represents the upper threshold
'
'Units:
'
'Temperature - (degrees C)
'Smoke - (ppm) (mass basis)
'Water - (L/m^2)
'
'Sensitivity categories:
'
'VS - Very high sensitivity
'HS - High sensitivity
'MO - Moderate sensitivity
'LO - Low sensitivity
'NS - No sensitivity

```

Category	Temperature		Smoke		Water	
	L	H	L	H	L	H
VS,	20.0,	50.0,	2500,	5000,	0.1,	0.3
HS,	50.0,	80.0,	5000,	10000,	0.3,	1.0
MO,	80.0,	110.0,	10000,	15000,	1.0,	2.5
LO,	110.0,	150.0,	15000,	25000,	2.5,	5.0
NS,	150.0,	230.0,	25000,	35000,	5.0,	10.0

```

'-----'
'General Input file description'
'-----'
'
'This file contains general input data.
'Structure of the file cannot be changed, only numbers.
'

```

Economic Factors

```

-Inflation rate (%)
3.00
-Interest rate (%)
7.00
-Downtime cost (/day)
15000
-Rush construction factor
2
-Reduction of downtime factor
0.5

```

Building characteristics

```

-Building component calibration factor
1
-Building life (years)
50
Total floor area (m^2)

```

5240
-Building construction calibration factor
1

Extinguishment

-Efficiency of extinguishment
0.1
-Specific heat capacity of water (kJ/kg C)
4.182
-Heat of vaporization of water (kJ/kg)
2260
-Temperature change (i.e. from 20 C to 100 C)
80
-Extinguishment calibration factor
1

Basic costs

-West wall (\$/ft^2)
24.88
-East wall (\$/ft^2)
24.88
-North wall (\$/ft^2)
24.88
-South wall (\$/ft^2)
24.88
-Ceiling (\$/ft^2)
10.24
-Floor (\$/ft^2)
10.24
-Doors (\$/door)
165
-Windows (\$/window)
1715

Results from the Economic Model using smoke and fire spread

Number of compartments analyzed: 48

Overall results

-----Costs-----

-Total cost of building, fire protection systems and contents
\$10,251,348.82
-Total annual cost
\$14,295.00

-----Damages-----

Total cost of direct damages
\$82,372.20
Total downtime days
2.0
Total cost of downtime
\$30,000.00
Total damages (indirect plus direct)
\$112,372.20

-----Ratio-----

Ratio of direct damage/building cost
0.008

-----% Damages-----

Estimate of temperature damage as a percentage of total damage
to the building, its FP systems and contents
81.8%

Estimate of smoke damage as a percentage of total damage
to the building, its FP systems and contents
6.1%

Estimate of water damage as a percentage of total damage
to the building, its FP systems and contents
12.1%

-----Factors-----

Damages using rush construction factor
\$164,744.40
Downtime, using downtime reduction factor
\$15,000.00
Total damages using adjustment factors
\$179,744.40

Detailed results

Costs

Building construction

---Capital cost
\$6,409,388.44

Contents

----Capital cost
\$2,085,767.00

Fire Protection Systems

Active fire Protection systems

---Capital cost
\$542,212.95
---Annual cost
\$13,395.00

Passive fire protection systems

---Capital cost
\$1,191,432.90
---Annual cost
\$0.00

Emergency fire protection systems

---Capital cost
\$22,547.52
---Annual cost
\$900.00

Damages

---Damages to building construction and fire protection systems
\$31,878.87

---Damages to building contents
\$50,493.33

---% Damages

Estimate of the temperature damage to all of the contents in the building as a percentage of the total damage to the contents in the building
85.2%

Estimate of the smoke damage to all of the contents in the building as a percentage of the total damage to the contents in the building
7.4%

Estimate of the water damage to all of the contents in the building as a percentage of the total damage to the contents in the building
7.4%

Results per compartment

ID	Damage(building and FP systems) (\$)	Contents cost (\$)	Damage contents (\$)	Total Damage (\$)	Contents			Downtime /comp (days)
					Damage Temp (%)	Damage Smoke (%)	Damage Water (%)	
001	00,000,352	00,160,175	00,000,000	00,000,352	000.0%	000.0%	000.0%	0.0
002	00,000,155	00,064,595	00,000,000	00,000,155	000.0%	000.0%	000.0%	0.0
003	00,024,335	00,049,190	00,049,190	00,073,525	033.3%	033.3%	033.3%	1.9
004	00,000,014	00,080,835	00,000,920	00,000,934	100.0%	000.0%	000.0%	0.0
005	00,001,365	00,005,505	00,000,000	00,001,365	000.0%	000.0%	000.0%	0.0
006	00,000,000	00,001,695	00,000,000	00,000,000	000.0%	000.0%	000.0%	0.0
007	00,000,007	00,001,225	00,000,000	00,000,007	000.0%	000.0%	000.0%	0.0
008	00,000,131	00,003,765	00,000,000	00,000,131	000.0%	000.0%	000.0%	0.0
009	00,000,056	00,003,885	00,000,000	00,000,056	000.0%	000.0%	000.0%	0.0
010	00,000,127	00,240,950	00,000,000	00,000,127	000.0%	000.0%	000.0%	0.0
011	00,000,029	00,057,570	00,000,000	00,000,029	000.0%	000.0%	000.0%	0.0
012	00,000,033	00,065,720	00,000,000	00,000,033	000.0%	000.0%	000.0%	0.0
013	00,000,028	00,103,650	00,000,000	00,000,028	000.0%	000.0%	000.0%	0.0
014	00,000,059	00,107,670	00,000,000	00,000,059	000.0%	000.0%	000.0%	0.0
015	00,000,052	00,091,925	00,000,383	00,000,435	100.0%	000.0%	000.0%	0.0
016	00,000,027	00,004,235	00,000,000	00,000,027	000.0%	000.0%	000.0%	0.0
017	00,000,010	00,001,695	00,000,000	00,000,010	000.0%	000.0%	000.0%	0.0
018	00,000,010	00,001,695	00,000,000	00,000,010	000.0%	000.0%	000.0%	0.0
019	00,000,166	00,167,085	00,000,000	00,000,166	000.0%	000.0%	000.0%	0.0
020	00,000,055	00,109,740	00,000,000	00,000,055	000.0%	000.0%	000.0%	0.0
021	00,000,033	00,034,835	00,000,000	00,000,033	000.0%	000.0%	000.0%	0.0
022	00,000,113	00,097,180	00,000,000	00,000,113	000.0%	000.0%	000.0%	0.0
023	00,000,028	00,004,235	00,000,000	00,000,028	000.0%	000.0%	000.0%	0.0
024	00,000,015	00,001,695	00,000,000	00,000,015	000.0%	000.0%	000.0%	0.0
025	00,000,011	00,001,695	00,000,000	00,000,011	000.0%	000.0%	000.0%	0.0
026	00,000,006	00,119,230	00,000,000	00,000,006	000.0%	000.0%	000.0%	0.0
027	00,000,007	00,140,701	00,000,000	00,000,007	000.0%	000.0%	000.0%	0.0
028	00,000,011	00,059,770	00,000,000	00,000,011	000.0%	000.0%	000.0%	0.0
029	00,000,002	00,063,630	00,000,000	00,000,002	000.0%	000.0%	000.0%	0.0
030	00,000,008	00,004,235	00,000,000	00,000,008	000.0%	000.0%	000.0%	0.0
031	00,000,012	00,001,695	00,000,000	00,000,012	000.0%	000.0%	000.0%	0.0

032	00,000,006	00,001,695	00,000,000	00,000,006	000.0%	000.0%	000.0%	0.0
033	00,000,000	00,001,835	00,000,000	00,000,000	000.0%	000.0%	000.0%	0.0
034	00,000,026	00,003,250	00,000,000	00,000,026	000.0%	000.0%	000.0%	0.0
035	00,000,548	00,004,590	00,000,000	00,000,548	000.0%	000.0%	000.0%	0.0
036	00,003,564	00,006,940	00,000,000	00,003,564	000.0%	000.0%	000.0%	0.1
037	00,000,066	00,007,295	00,000,000	00,000,066	000.0%	000.0%	000.0%	0.0
038	00,000,041	00,007,295	00,000,000	00,000,041	000.0%	000.0%	000.0%	0.0
039	00,000,027	00,004,235	00,000,000	00,000,027	000.0%	000.0%	000.0%	0.0
040	00,000,076	00,007,295	00,000,000	00,000,076	000.0%	000.0%	000.0%	0.0
041	00,000,041	00,007,295	00,000,000	00,000,041	000.0%	000.0%	000.0%	0.0
042	00,000,028	00,004,235	00,000,000	00,000,028	000.0%	000.0%	000.0%	0.0
043	00,000,009	00,007,295	00,000,000	00,000,009	000.0%	000.0%	000.0%	0.0
044	00,000,020	00,007,295	00,000,000	00,000,020	000.0%	000.0%	000.0%	0.0
045	00,000,003	00,153,040	00,000,000	00,000,003	000.0%	000.0%	000.0%	0.0
046	00,000,117	00,002,353	00,000,000	00,000,117	000.0%	000.0%	000.0%	0.0
047	00,000,040	00,002,353	00,000,000	00,000,040	000.0%	000.0%	000.0%	0.0
048	00,000,010	00,005,765	00,000,000	00,000,010	000.0%	000.0%	000.0%	0.0

Appendix D:

Comparison data

1.0 INTRODUCTION

This appendix presents fire loss data collected or analyzed from different sources. The purpose of this appendix is to demonstrate that there is great discrepancy among data sets.

With respect to data availability, insurance companies are not always a good source of fire loss data since many losses either go unreported or were never insured. Making generalized assumptions from fire loss data from insurance companies can prove to be difficult since most payments are dependent on the type of coverage that is present in a given situation. Usually estimates from insurance companies are more accurate than estimates from firefighters since firefighters tend to underestimate losses (Schaenman et al., 1994). Schaenman et al. (1994) suggests that a combination of both insurance data and firefighter data should be utilized when considering fire loss data. Presently, no set method exists for the collection or examination of fire loss data. Since many fires go unreported to the fire department but are reported to the insurance companies or vice versa, this may result in the skewing of fire loss data (Schaenman et al., 1994). The analysis of the Ontario Fire Marshall's office data from 1995-2002, offers insight as to why fire statistics may be difficult to use.

2.0 ONTARIO FIRE MARSHALL'S DATA ANALYSIS

Raw fire data was obtained from the Ontario Fire Marshal's office for the years 1995-2002. The average, standard deviation, median, high and low values were calculated. From the high and low values, it can be seen that there is a large discrepancy of loss estimates throughout the data. Where there is a large sample size, it is noted that the standard deviation is quite high and the distributions tend to be those of a log normal distribution. Therefore, using the average loss for a fire is not really applicable, nor is the corresponding standard deviation. It should be noted that the data is not adjusted for inflation.

The following descriptive data can be limiting: the floor area of the building, the degree of fire spread, the degree of smoke spread, construction era of the building, type of floor construction, type of interior construction, type of ceiling construction and type of roof construction. It should be noted that this data is only collected for fires that involve fatalities.

Tables D1-D17 are selected from the analysis of the Ontario Fire Marshal's office data between 1995-2002. What is similar in all these tables are the high standard deviations, however, major differences include the low and high values for losses. Residential structures comprise the majority of the structures analysed. Other structures are grouped into the same category because of the lack of data.

Table D1: Average, median, high and low direct damage costs for structure fires in Ontario from 1995-2002.*

Type of structure	Number of fires	Average loss (\$)	Standard deviation	Median (\$)	High (\$)	Low (\$)
Residential	59,217	23,066	106,774	2,000	20,000,000	0
Assembly occupancies	4,706	26,810	147,987	1,000	3,500,000	0
Institutional Occupancies	1,268	12,604	205,530	300	7,000,000	0
Business/personal services	1,829	34,249	151,079	1,000	3,800,000	0
Mercantile	2,858	42,873	178,936	1,500	5,000,000	0
Industrial Occupancies	6,829	67,168	438,082	5,000	19,600,000	0
Miscellaneous Structures	5,103	32,523	102,044	2,000	2,500,000	0

* – Total number of fires analyzed was 81,810.

Table D2: Average, median, high and low direct damage costs in residential building fires in relation to floor area in Ontario from 1995-2002.*

Floor area of building (m ²)	Number of fires	Average loss (\$)	Standard deviation	Median (\$)	High (\$)	Low (\$)
<100	393	64,160	68,584	50,000	800,000	0
100 - 600	365	128,292	199,759	95,000	3,000,000	0
601 - 2,000	45	95,763	187,444	30,000	1,000,000	0
2001 - 4,500	13	37,077	52,770	20,000	200,000	500
4,501 - 10,000	6	46,167	63,547	23,500	175,000	10,000
10,001 - 50,000	8	434,188	943,568	62,500	2,750,000	500

* – Total number of fires analyzed was 830.

Table D3: Average, median, high and low direct damage costs in residential building fires in relation to fire spread in Ontario from 1995-2002.*

Fire spread	Number of fires	Average loss (\$)	Standard deviation	Median (\$)	High (\$)	Low (\$)
A	60	10,010	24,614	1,250	150,000	0
B	189	36,710	58,974	25,000	530,000	0
C	63	87,622	165,758	40,000	1,050,000	1
D	98	85,646	61,462	75,000	350,000	0
E	34	99,744	93,438	80,000	450,000	1,000
F	2	1,635,000	1,576,848	1,635,000	2,750,000	520,000
G	118	135,153	154,821	100,000	1,250,000	1
H	221	136,753	220,016	100,000	3,000,000	1
I	22	96,959	119,030	60,000	440,000	600

* – Total number of fires analyzed was 807.

A – Fire spread confined to object of fire origin

B – Fire spread to portion of room of fire origin

C – Fire spread to entire room of fire origin

D – Fire spread beyond room of fire origin

E – Fire beyond room of fire origin, same floor, outside unit

F – Fire beyond room of fire origin, same floor, separate unit

G – Fire beyond floor of fire origin, different floor

H – Fire spread throughout entire structure

I – Multiple points of fire origin or fire spread not reported

Table D4: Average, median, high and low direct damage costs in residential building fires in relation to smoke spread in Ontario from 1995-2002.*

Smoke spread	Number of fires	Average loss (\$)	Standard deviation	Median (\$)	High (\$)	Low (\$)
A	17	12,413	36,745	600	150,000	0
B	46	13,296	37,775	1,000	240,000	0
C	40	39,639	54,571	25,000	250,000	0
D	127	82,976	204,937	40,000	2,000,000	100
E	12	80,083	95,103	50,000	350,000	1,000
F	3	60,000	20,000	60,000	80,000	40,000
G	135	131,080	262,931	86,000	2,750,000	0
H	246	120,503	208,001	80,000	3,000,000	0
I	1	120,000	N/A	120,000	120,000	120,000

* – Total number of fires analyzed was 627.

A – Smoke spread confined to object of fire origin

B – Smoke spread to portion of room of fire origin

C – Smoke spread to entire room of fire origin

D – Smoke spread beyond room of fire origin

E – Smoke beyond room of fire origin, same floor, outside unit

F – Smoke beyond room of fire origin, same floor, separate unit

G – Smoke beyond floor of fire origin, different floor

H – Smoke spread throughout entire structure

I – Multiple points of fire origin or smoke spread not reported

Table D5: Average, median, high and low direct damage costs in residential building fires in relation to building construction era in Ontario from 1995-2002.*

Building era	Number of fires	Average loss (\$)	Standard deviation	Median (\$)	High (\$)	Low (\$)
A	190	107,172	134,279	80,000	1,250,000	0
B	364	80,961	175,001	50,000	2,750,000	0
C	206	101,646	223,926	60,000	3,000,000	0
D	72	98,850	79,397	80,000	400,000	0

* – Total number of fires analyzed was 832.

A – Building constructed prior to 1945

B – Building constructed between 1945 and 1975

C – Building constructed after 1975

D – Building renovated after 1975

Table D6: Average, median, high and low direct damage costs in residential building fires in relation to floor construction in Ontario from 1995-2002.*

Floor type	Number of fires	Average loss (\$)	Standard deviation	Median (\$)	High (\$)	Low (\$)
A	642	102,770	162,004	75,000	3,000,000	0
B	145	76,812	248,197	25,000	2,750,000	0

* – Total number of fires analyzed was 787.

A – Combustible

B – Non-combustible

Table D7: Average, median, high and low direct damage costs in residential building fires in relation to interior construction in Ontario from 1995-2002.*

Interior type	Number of fires	Average loss (\$)	Standard deviation	Median (\$)	High (\$)	Low (\$)
A	38	38,616	64,261	20,000	375,000	0
B	135	96,924	136,000	70,000	1,250,000	26
C	217	94,538	216,749	50,000	3,000,000	0
D	20	78,155	46,285	82,500	181,050	8,000
E	60	72,443	73,074	59,500	500,000	0
F	12	25,634	31,938	16,000	98,000	1
G	4	117,500	96,134	92,500	250,000	35,000
H	215	124,833	229,725	80,000	2,750,000	0

* – Total number of fires analyzed was 701.

A – Masonry or concrete

B – Lath and plaster/gypsum

C – Gypsum board on studs

D – Wood finish on studs greater than ½ inch

E – Wood finish on studs less than ½ inch

F – Exposed wood studs

G – Exposed metal studs

H – Other

Table D8: Average, median, high and low direct damage costs in residential building fires in relation to ceiling construction in Ontario from 1995-2002.*

Ceiling type	Number of fires	Average loss (\$)	Standard deviation	Median (\$)	High (\$)	Low (\$)
A	64	88,005	362,594	20,000	2,750,000	0
B	93	101,900	118,235	70,000	555,000	30
C	203	98,523	222,678	55,000	3,000,000	0
D	18	107,028	125,097	70,000	500,000	500
E	56	75,244	48,275	75,000	240,000	100
F	2	35,000	14,142	35,000	45,000	25,000
G	25	58,344	55,067	35,000	170,000	1
H	3	82,333	38,031	70,000	125,000	52,000
I	23	76,396	83,343	60,000	350,000	0
J	98	132,564	221,777	85,500	2,000,000	0

* - Total number of fires analyzed was 585.

A - Concrete

B - Lath and plaster

C - Gypsum board

D - Suspended "T" bar

E - Fibre tile

F - Mineral Tile

G - Exposed wood joists

H - Exposed metal joists

I - Wood finish

J - Other (includes combination)

Table D9: Average, median, high and low direct damage costs in residential building fires in relation to roof construction in Ontario from 1995-2002.*

Roof type	Number of fires	Average loss (\$)	Standard deviation	Median (\$)	High (\$)	Low (\$)
A	706	99,173	156,642	70,000	3,000,000	0
B	104	83,502	288,999	26,000	2,750,000	0

* – Total number of fires analyzed was 810.

A – Combustible

B – Non-combustible

Table D10: Average, median, high and low direct damage costs in other structure fires in relation to floor area in Ontario from 1995-2002.*

Floor area of building (m ²)	Number of fires	Average loss (\$)	Standard deviation	Median (\$)	High (\$)	Low (\$)
<100	19	63,924	91,965	25,000	350,000	1
100 - 600	57	206,907	334,412	110,000	2,100,000	500
601 - 2,000	11	40,646	53,006	10,000	150,000	1
2001 - 4,500	8	259,481	683,377	15,000	1,950,000	1
4,501 - 10,000	2	1,525	742	1,525	2,050	1,000
10,001 - 50,000	2	1,250,075	1,767,661	1,250,075	2,500,000	150

* – Total number of fires analyzed was 99.

Table D11: Average, median, high and low direct damage costs in other structure fires in relation to fire spread in Ontario from 1995-2002.*

Fire spread	Number of fires	Average loss (\$)	Standard deviation	Median (\$)	High (\$)	Low (\$)
A	16	8,505	14,599	2,025	45,000	1
B	37	144,023	434,461	25,000	2,500,000	1
C	8	92,688	434,461	25,000	2,500,000	1
D	9	372,333	619,467	150,000	2,000,000	51,000
E	6	755,917	1,493,783	142,750	3,800,000	50,000
F	0	N/A	N/A	N/A	N/A	N/A
G	9	181,111	100,926	200,000	350,000	20,000
H	33	416,777	548,855	240,000	2,500,000	150
I	7	39,214	51,249	25,000	150,000	3,500

* – Total number of fires analyzed was 125.

A – Fire spread confined to object of fire origin

B – Fire spread to portion of room of fire origin

C – Fire spread to entire room of fire origin

D – Fire spread beyond room of fire origin

E – Fire beyond room of fire origin, same floor, outside unit

F – Fire beyond room of fire origin, same floor, separate unit

G – Fire beyond floor of fire origin, different floor

H – Fire spread throughout entire structure

I – Multiple points of fire origin or fire spread not reported

Table D12: Average, median, high and low direct damage costs in other structure fires in relation to smoke spread in Ontario from 1995-2002.*

Smoke spread	Number of fires	Average loss (\$)	Standard deviation	Median (\$)	High (\$)	Low (\$)
A	4	2,138	2,080	1,750	5,000	50
B	11	18,139	33,574	2,050	110,000	1
C	5	21,730	25,867	5,000	50,000	150
D	10	283,200	780,085	25,000	2,500,000	6,000
E	0	N/A	N/A	N/A	N/A	N/A
F	0	N/A	N/A	N/A	N/A	N/A
G	7	52,286	30,385	60,000	100,000	1,000
H	23	257,357	459,700	100,000	1,950,000	1
I	0	N/A	N/A	N/A	N/A	N/A

* – Total number of fires analyzed was 60.

A – Smoke spread confined to object of fire origin

B – Smoke spread to portion of room of fire origin

C – Smoke spread to entire room of fire origin

D – Smoke spread beyond room of fire origin

E – Smoke beyond room of fire origin, same floor, outside unit

F – Smoke beyond room of fire origin, same floor, separate unit

G – Smoke beyond floor of fire origin, different floor

H – Smoke spread throughout entire structure

I – Multiple points of fire origin or smoke spread not reported

Table D13: Average, median, high and low direct damage costs in other structure fires in relation to building construction era in Ontario from 1995-2002.*

Building era	Number of fires	Average loss (\$)	Standard deviation	Median (\$)	High (\$)	Low (\$)
A	22	410,386	658,878	200,000	2,500,000	1
B	40	232,363	449,334	60,000	2,000,000	1
C	49	258,413	654,255	60,000	3,800,000	1
D	14	55,411	59,732	45,500	200,000	100

* – Total number of fires analyzed was 125.

A – Building constructed prior to 1945

B – Building constructed between 1945 and 1975

C – Building constructed after 1975

D – Building renovated after 1975

Table D14: Average, median, high and low direct damage costs in other structure fires in relation to floor construction in Ontario from 1995-2002.*

Floor type	Number of fires	Average loss (\$)	Standard deviation	Median (\$)	High (\$)	Low (\$)
A	39	416,366	804,522	130,000	3,800,000	1
B	44	169,449	488,015	25,050	2,500,000	1

* – Total number of fires analyzed was 83.

A – Combustible

B – Non-combustible

Table D15: Average, median, high and low direct damage costs in other structure fires in relation to interior construction in Ontario from 1995-2002.*

Interior type	Number of fires	Average loss (\$)	Standard deviation	Median (\$)	High (\$)	Low (\$)
A	19	186,532	484,723	6,000	1,950,000	1
B	4	165,125	145,539	150,000	350,000	10,500
C	16	70,509	98,956	35,000	325,000	1
D	2	518,250	681,297	518,250	1,000,000	36,500
E	2	325,000	35,355	325,000	350,000	300,000
F	3	60,000	70,711	60,000	110,000	10,000
G	1	2,500,000	N/A	2,500,000	2,500,000	2,500,000
H	37	296,085	525,174	100,000	2,500,000	1

* – Total number of fires analyzed was 84.

A – Masonry or concrete

B – Lath and plaster/gypsum

C – Gypsum board on studs

D – Wood finish on studs greater than ½ inch

E – Wood finish on studs less than ½ inch

F – Exposed wood studs

G – Exposed metal studs

H – Other

Table D16: Average, median, high and low direct damage costs in other structure fires in relation to ceiling construction in Ontario from 1995-2002.*

Ceiling type	Number of fires	Average loss (\$)	Standard deviation	Median (\$)	High (\$)	Low (\$)
A	7	14,164	16,764	6,000	45,000	150
B	0	N/A	N/A	N/A	N/A	N/A
C	11	26,286	46,033	5,000	150,000	1
D	4	276,700	482,830	53,000	1,000,000	800
E	1	250,000	N/A	250,000	250,000	250,000
F	0	N/A	N/A	N/A	N/A	N/A
G	4	346,275	445,572	180,000	1,000,000	25,100
H	2	212,500	159,099	212,500	325,000	100,000
I	2	105,000	63,640	105,000	150,000	60,000
J	20	170,410	550,838	40,750	2,500,000	1

* – Total number of fires analyzed was 51.

A – Concrete

B – Lath and plaster

C – Gypsum board

D – Suspended "T" bar

E – Fibre tile

F – Mineral Tile

G – Exposed wood joists

H – Exposed metal joists

I – Wood finish

J – Other (includes combination)

Table D17: Average, median, high and low direct damage costs in other structure fires in relation to roof construction in Ontario from 1995-2002.*

Roof type	Number of fires	Average loss (\$)	Standard deviation	Median (\$)	High (\$)	Low (\$)
A	82	260,895	509,953	100,000	2,500,000	1
B	26	110,164	389,179	13,000	2,000,000	1

* – Total number of fires analyzed was 108.

A – Combustible

B – Non-combustible

3.0 OTHER COMPARISON DATA

This section includes data from other sources including Factory Mutual Research Corporation (FMRC), the National Fire Protection Association (NFPA), the Canadian Wood Council and USA fire retail data. NFPA data will be limited to retail establishments and is not adjusted for inflation. NFPA data does not include estimates that are taken by private fire departments (Meade, 1991).

Care must be taken when using this data as it may be similar to the data presented in the previous section (Ontario Fire Marshall's data). From the analysis of the Ontario Fire Marshall's data for structure fires between the years 1995-2002, the particular trend is a log-normal distribution which makes the analysis of the average and standard deviations not very useful. The USA fire retail data contains more data than Canadian data due to the US's greater population. This data is useful because of the similar construction methods and materials used. However, there remains a suspicion that the data follows a similar trend to that of the Ontario Fire Marshall's data which may nullify the average values used.

Table D18 shows the average losses with and without sprinklers as determined by the Factory Mutual Research Corporation.

Table D18: Average losses for fires with and without sprinklers as determined by Factory Mutual Research Corporation (Dowling et al., 1993).

Year	Number of fires	Losses with sprinklers (\$)	Number of fires	Losses without sprinklers (\$)
1980	575	68,500	523	362,100
1981	388	73,500	423	431,200
1982	248	108,900	329	644,700
1983	206	74,900	341	280,700
1984	196	199,700	265	523,300
1985	145	355,400	226	1,046,700
1986	141	184,900	240	843,500
1987	161	208,900	189	666,900
1988	127	146,100	206	962,700
1989	136	340,800	165	994,700
Total	2,323	140,200	2,907	600,600

Table D19 describes the average losses with and without sprinklers as determined by NFPA statistics. Table D19 clearly demonstrates that sprinklers reduce fire losses.

**Table D19: Average losses per fire from NFPA data for the years 1980-1990
(Dowling et al., 1993).**

Occupancy type	Loss without sprinklers (\$)	Loss with sprinklers (\$)
Public assembly	15,300	5,700
Educational	11,500	2,900
Health care and correctional	2,400	1,000
Stores and offices	17,400	9,800
Manufacturing	26,300	12,100

Table D20 shows the average losses in commercial buildings in the USA from the years 1989-1998 as given by the Canadian Wood Council (2002).

Table D20: Average losses in commercial buildings in the USA between the years 1989-1998 (Canadian Wood Council, 2002).

Type of construction	Average losses without sprinklers (\$)	Average losses with sprinklers (\$)
Fire resistive	9,870	7,600
Heavy timber	30,000	22,000
Protected noncombustible	11,400	6,550
Unprotected noncombustible	35,000	30,300
Protected ordinary	10,400	7,610
Unprotected ordinary	16,000	12,100
Protected wood frame	12,700	7,360
Unprotected wood frame	12,600	12,900

Tables D21 to D24 are from the analysis of USA retail fires in low-rise shopping centres. Table D21 shows that the average loss increases as flame spreads which is as expected.

Table D21: Extent of flame damage from USA retail fires between the years 1983-1993 (Thomas, 1997).

Extent of flame damage	Number of fires	Average losses (\$)
A	32,580	5,601
B	13,460	10,681
C	8,679	17,006
D	579	54,504
E	1,499	52,337
F	10,829	108,412
G	2,325	152,615
H	8,045	9,993

A – Flame damage confined to object of fire origin
 B – Flame damage confined to part of room of fire origin
 C – Flame damage confined to room of fire origin
 D – Flame damage confined to fire-rated compartment of fire origin
 E – Flame damage confined to floor of fire origin
 F – Flame damage confined to the structure of fire origin
 G – Flame damage is beyond structure of fire origin
 H – Unknown

Table D22: Flame damage with and without sprinklers from USA retail fires between the years 1983-1993 (Thomas, 1997).

Extent of flame damage	No sprinklers		Sprinklers		Sprinklers and operated		Sprinklers and did not operate	
	Fires	Avg. losses	Fires	Avg. losses	Fires	Avg. losses	Fires	Avg. losses
	(#)	(\$)	(#)	(\$)	(#)	(\$)	(#)	(\$)
A	17,404	2,580	6,107	5,600	1,065	7,187	5,042	5,291
B	8,799	8,890	2,899	15,900	1,421	29,379	1,478	2,895
C	2,021	22,800	654	32,000	453	39,390	201	15,511
D	417	50,000	86	66,000	46	85,360	40	44,467
E	881	51,000	115	66,000	77	84,169	38	30,477
F	7,472	84,900	310	270,000	177	127,194	133	459,316
G	1,428	158,000	60	109,000	30	150,087	30	67,091

A – Flame damage confined to object of fire origin

B – Flame damage confined to part of room of fire origin

C – Flame damage confined to room of fire origin

D – Flame damage confined to fire-rated compartment of fire origin

E – Flame damage confined to floor of fire origin

F – Flame damage confined to the structure of fire origin

G – Flame damage is beyond structure of fire origin

Table D23: Smoke damage with and without sprinklers from USA retail fires between the years 1983-1993 (Thomas, 1997).

Extent of smoke damage	No sprinklers		Sprinklers		Sprinklers and operated		Sprinklers and did not operate	
	Fires	Avg. losses	Fires	Avg. losses	Fires	Avg. losses	Fires	Avg. losses
	(#)	(\$)	(#)	(\$)	(#)	(\$)	(#)	(\$)
A	6,078	3,560	1,680	9,970	245	2,900	1,435	11,182
B	4,656	1,720	1,932	5,920	456	10,000	1,476	4,657
C	4,255	4,290	1,547	3,580	563	7,000	984	1,615
D	463	10,400	241	6,670	106	12,000	135	2,479
E	1,609	23,100	887	10,600	399	19,100	488	3,548
F	12,751	48,100	2,167	45,300	1,151	59,000	1,016	29,742
G	3,230	118,000	308	84,300	171	106,200	137	57,036
H	7,245	4,210	1,839	19,600	215	2,051	1,624	21,950

- A – Smoke damage confined to object of fire origin
 B – Smoke damage confined to part of room of fire origin
 C – Smoke damage confined to room of fire origin
 D – Smoke damage confined to fire-rated compartment of fire origin
 E – Smoke damage confined to floor of fire origin
 F – Smoke damage confined to the structure of fire origin
 G – Smoke damage is beyond structure of fire origin

Care must be taken when using statistical data. For example, Tables D22 and D23 show that in some cases the damages without sprinklers are less than the damages with sprinklers.

Table D24: Flame damage and the time it takes the fire department to arrive from USA retail fires between the years 1983-1993 (Thomas, 1997).

Extent of flame damage	Arrival of fire department					
	0-4 min		5-9 min		10-14 min	
	Number of fires	Average losses (\$)	Number of fires	Average losses (\$)	Number of fires	Average losses (\$)
A	12,254	3,297	3,563	2,395	278	2,583
B	5,723	9,781	1,680	12,948	122	8,526
C	1,742	25,685	547	34,173	56	31,908
D	257	54,764	74	85,071	6	2,783
E	501	56,757	132	56,144	11	21,032
F	2,640	101,806	1,191	96,389	180	69,234
G	727	154,421	243	104,206	48	220,858

- A – Flame damage confined to object of fire origin
 B – Flame damage confined to part of room of fire origin
 C – Flame damage confined to room of fire origin
 D – Flame damage confined to fire-rated compartment of fire origin
 E – Flame damage confined to floor of fire origin
 F – Flame damage confined to the structure of fire origin
 G – Flame damage is beyond structure of fire origin

In general, Table D24 shows that the faster the fire department arrives at the scene of a fire, the less damage will result. Tables D25-D27 are for structure fires in selected occupancies relating the type of construction, flame damage, smoke damage with losses from 1980-1998 NFPA annual averages (Ahrens, 2003).

**Table D25: Type of construction and losses from NFPA data from 1980-1998
(Ahrens, 2003).**

Type of construction	Eating and drinking establishments		Stores and Mercantile properties		Business and other office properties	
	Fires (#)	Avg. losses (\$)	Fires (#)	Avg. losses (\$)	Fires (#)	Avg. losses (\$)
Fire resistive	1,440	7,100	3,070	14,000	1,640	13,400
Heavy timber	250	21,900	480	32,200	140	19,100
Protected noncombustible	920	7,200	1,970	15,000	880	12,300
Unprotected noncombustible	740	12,400	2,720	26,500	560	22,700
Protected ordinary	3,110	8,400	4,480	16,400	13,80	13,600
Unprotected ordinary	3,280	14,500	5,800	24,000	13,50	38,300
Protected wood frame	20,240	11,700	2,020	17100	800	19,000
Unprotected wood frame	2,900	14,400	4,230	18,200	1,120	20,100
Unclassified	110	14,900	380	20,100	80	71,300

Table D26: Extent of flame damage and losses from NFPA data from 1980-1998 (Ahrens, 2003).

Extent of flame damage	Eating and drinking establishments		Stores and Mercantile properties		Business and other office properties	
	Fires	Average losses	Fires	Average losses	Fires	Average losses
	(#)	(\$)	(#)	(\$)	(#)	(\$)
A	7,810	900	11,010	2,500	4,010	1,300
B	2,520	4,200	4,760	6,300	1,310	4,800
C	1,840	7,700	3,230	11,000	1,140	10,200
D	110	23,900	220	33,700	70	38,000
E	340	29,300	640	32,500	280	76,800
F	1,950	55,900	4,350	66,000	970	91,600
G	230	83,600	940	88,800	170	152,300

A – Flame damage confined to object of fire origin

B – Flame damage confined to part of room of fire origin

C – Flame damage confined to room of origin

D – Flame damage confined to fire-rated compartment of fire origin

E – Flame damage confined to floor of fire origin

F – Flame damage confined to the structure of fire origin

G – Flame damage is beyond structure of fire origin

Table D27: Extent of smoke damage and losses from NFPA data from 1980-1998 (Ahrens, 2003).

Extent of smoke damage	Eating and drinking establishments		Stores and mercantile properties		Business and other office properties	
	Fires	Avg. losses	Fires	Avg. losses	Fires	Avg. losses
	(#)	(\$)	(#)	(\$)	(#)	(\$)
A	2690	900	3960	3800	1,440	1,000
B	1760	1200	2730	1700	850	1,500
C	2220	1800	3460	3300	1,140	3,200
D	130	5100	260	9800	110	6,400
E	850	7400	1360	10600	790	11,000
F	4010	28900	7610	38500	2,100	51,600
G	640	56400	1850	71900	350	103,800
H	2530	2000	3900	4300	1,180	1,800

- A – Smoke damage confined to object of fire origin
 B – Smoke damage confined to part of room of fire origin
 C – Smoke damage confined to room of origin
 D – Smoke damage confined to fire-rated compartment of fire origin
 E – Smoke damage confined to floor of fire origin
 F – Smoke damage confined to the structure of fire origin
 G – Smoke damage is beyond structure of fire origin
 H – No smoke damage

GLOSSARY

<i>Active fire protection</i>	Systems that are involved in the detection, the control and the suppression of a fire.
<i>ASTM</i>	American Society for Testing and Materials.
<i>Cable vapour concentration</i>	The concentration of vapour from the burning of electrical cables derived from measuring the mass loss of a cable tray and the volume of the enclosure (Tewarson, 2003).
<i>Calcination</i>	The process in which a solid is heated up causing the solid to breakdown.
<i>Cladding</i>	The outside protective or insulating layer of a building.
<i>Class 1</i>	Plant particle count in a Class 1 wafer fabrication is not greater than 3000 particles/m ³ and largest particle in any sample cannot be greater than 5µ (Clean Room, 2004).
<i>Compartmentation</i>	The division of a building into discrete fire zones with the purpose of limiting the damages that can occur in a fire.
<i>Continuous compounding of interest</i>	The process of calculating interest on a sum at infinitely short time intervals.
<i>Cost-effective design</i>	A cost-effective design is an acceptable, safe design with the lowest cost.
<i>CTTC</i>	Carleton Technology and Training Centre.
<i>Direct losses</i>	Losses due to the damage to the building and its contents due to fire.
<i>Downtime</i>	The amount of time that a business is not operational.
<i>Effectiveness</i>	Operation of the system in that the system will complete its intended task (i.e. sprinklers will control a fire if activated).
<i>Fire rating</i>	The amount of time that a door or window can withstand a standard fire.

<i>Fire Resistance Rating</i>	The amount of time that an assembly can withstand a standard fire.
<i>Fire resistive construction</i>	Noncombustible construction is used, with any metal members being "fire proofed". Collapse and fire spread will be minimized using this type of construction (Firewise, 2004).
<i>Fire severity</i>	Measure of the potential damage that a fire may cause.
<i>Flashover</i>	The event in which all combustible materials in a compartment ignite. Flashover usually occurs when the upper layer temperature is approximately 600°C or when the radiant heat flux at the floor level reaches 20 kW/m ² . (Hadjisophocleous and Bénichou, 1999).
<i>FMRC</i>	Factory Mutual Research Corporation.
<i>GDP</i>	Gross domestic product. The measurement of the value of the goods and services within a country.
<i>GNP</i>	Gross national product. The measurement of the value of goods and services that are produced by a country.
<i>Halon</i>	Halocarbon used to extinguish a fire.
<i>Hand line</i>	A hose that firefighters use to directly apply water onto a fire inside a burning building.
<i>Heavy timber construction</i>	Walls are masonry, columns are 8 inch (203 mm) wood, floors are 3 inch (76 mm) plank, roof decks are 2 inch (51 mm) plank, beams and girders are 6 inch (152 mm) wide and 10 inch (254 mm) high. Planks are tongue and groove construction (Firewise, 2004).
<i>Indirect losses</i>	Indirect losses can include the following: businesses interruption, loss of market share, temporary housing, legal fees etc.
<i>NFPA</i>	National Fire Protection Association.

<i>Noncombustible construction</i>	Structural members are made of non-combustible materials that do not fit into the fire resistive construction category (Firewise, 2004).
<i>Ordinary construction</i>	Walls are made from noncombustible material (i.e. masonry) and other structural members are made from combustible materials such as wood (could be partially be made of wood) (Firewise, 2004).
<i>Passive fire protection</i>	Protection which is primarily intended to help keep the stability of the structure during fire and reduce fire spread.
<i>Performance based codes</i>	Objectives are stated and must be fulfilled by the designer (a comparison of prescriptive based codes versus performance based codes is shown in Hadjisophocleous and Bénichou, 1999).
<i>ppm</i>	Parts per million, $ppm = \left(\frac{\text{mass of component}}{\text{mass of solution}} \right) \times 100$
<i>Prescriptive based codes</i>	Intent of codes is not described but if the cods are followed, requirements for the acceptable levels of safety will be achieved.
<i>Protected noncombustible construction</i>	Exterior walls, structure, floor, ceiling and roof all have a one hour fire resistance rating (Minnesota department of public safety, 2004).
<i>Protected ordinary construction</i>	Structure, floor, ceiling and roof all have a one hour fire resistance rating while exterior walls have a two hour fire resistance rating (Minnesota department of public safety, 2004).
<i>Protected wood frame construction</i>	Exterior walls, structure, floor, ceiling and roof all have a one hour fire resistance rating (Minnesota department of public safety, 2004).
<i>PVC</i>	Polyvinyl chloride.
<i>pyrolysis</i>	Decomposition of a compound caused by heating the compound.

<i>Reliability</i>	The ability of the system to operate as intended (i.e., sprinklers will activate if there is a fire)
<i>Spalling</i>	The process in which concrete crumbles.
<i>Soot</i>	Black particles found in smoke (mostly carbon) as a result of the incomplete combustion of a compound.
<i>Switch rack</i>	A piece of equipment that provides communication between other systems.
<i>t-squared</i>	A design fire for which the heat release rate is proportional to the time squared.
<i>Trapezoidal rule</i>	Integration technique characterized by trapezoids.
<i>Two-zone model</i>	A fire model which divides a room into a hot upper zone and a cold lower zone.
<i>ULC</i>	Underwriters' Laboratories of Canada.
<i>Wood frame construction</i>	Structural members are made from wood (could be partially made of wood) or another combustible material and does not fall into the ordinary construction category (Firewise, 2004).