Fire Performance Analysis for Buildings
Fire Performance Analysis for Buildings

Second Edition

Robert W. Fitzgerald and Brian J. Meacham

Worcester Polytechnic Institute, MA, USA
Contents

Preface xxiii
Acknowledgements xxv

1 Fire Performance and Buildings 1
1.1 The Dynamics of Building Fire Performance 1
1.2 The Anatomy of Building Fire Safety 1
1.3 Analysis and Design 2
1.4 Performance Analysis 3
1.5 Quantification 3
1.6 The Organization 4

Part I The Foundation 7

2 Preliminary Organization 9
2.1 Introduction 9
2.2 Overview of Evaluations 9

Part One: Organizational Concepts 12
2.3 The Diagnostic Fire 12
2.4 Anatomy of a Representative Fire 12
2.5 Fire Prevention 13
2.6 Fire Scenarios 13

Part Two: Barriers, Spaces, and Connectivity 15
2.7 Spaces and Barriers 15
2.8 Barriers and Fire 15
2.9 Barrier Performance 16
2.10 Space–Barrier Connectivity 16
2.11 Virtual Barriers 18
2.12 Virtual Barrier Applications 18
2.13 Space–Barrier Discussion 22

Part Three: Fire Defenses 23
2.14 Fire Defenses 23
2.15 Active Fire Defenses 24
2.15.1 Fire Detection and Alarm 24
2.15.2 The Automatic Sprinkler System 25
2.15.3 Fire Department Operations 25
2.15.4 Building Fire Brigade 26
2.15.5 Special Hazard Automatic Suppression Systems 26
2.15.6 Special Features 27
2.15.7 Occupant Activities 27
2.16 Passive Fire Defenses 28
2.16.1 Structural Fire Protection 28
2.16.2 Barriers 28
2.16.3 Opening Protectives 29
2.16.4 The Egress System 29
2.16.5 Area of Refuge 30
2.16.6 Fire Attack Route 30
2.17 Closure 30

3 Tools of Analysis 31
3.1 Introduction 31

Part One: The Logic 32
3.2 The Framework Logic 32
3.3 The Major Parts 32
3.4 Event Logic Diagrams 34
3.5 Event Logic Observations 38
3.6 Logic Networks 39
3.7 Decomposing Logic Networks 41
3.8 Network Diagram Observations 46
3.9 Single Value Networks 47
3.10 Time Relationships Using Event Trees 47
3.11 Continuous Value Networks 48
3.12 The IPI Chart 48
3.13 Coding 50

Part Two: Space–Barrier Connectivity 51
3.14 Introduction 51
3.15 Room Connectivity 51
3.16 Building Interconnectivity 53
3.17 Segmenting Buildings 54
3.18 Summary 54

Part Three: Additional Tools 55
3.19 Networks and Charts 55
3.20 Organizational Charts 55
3.21 Organizational Networks 56
3.22 Closure 57

4 An Introduction to the Interactive Performance Information Chart 59
4.1 Introduction 59
4.2 The Basic Template 59
6.22.1 Realm 1: Pre-burning 102
6.22.2 Realm 2: Initial burning 102
6.22.3 Realm 3: Vigorous Burning 104
6.22.4 Realm 4: Interactive Burning 106
6.22.5 Realm 5: Remote Burning 108
6.23 Flashover 108
6.24 $a^2$ Fires 111
6.25 Realm 6: Fully Developed Fire 112
6.26 Limits of Applicability 113
6.27 Large Rooms: Full Room Involvement 113
6.28 Fire Safety Engineering in the Information Age 114
6.29 Closure 118

7 The Room Fire: Qualitative Analysis 119
7.1 The Role of Qualitative Analysis 119
7.2 Qualitative Estimates for Room Fires 120

Part One: Bottom-up Estimates 121
7.3 Bottom-up Scenario Estimates 121
7.3.1 Realm 1: FFS to IG 121
7.3.2 Realm 2: IG to EB 121
7.3.3 Realm 3: EB to Enclosure Point (EP) 123
7.3.4 Realm 4: EP to Ceiling Point (CP) 124
7.3.5 Realm 5: CP to FO 126
7.4 Time and the Fire Growth Potential 126
7.5 FGP Adjustments 128
7.6 Estimating Spread-over Scenarios 131

Part Two: Top-down Estimates 133
7.7 Qualitative Room Classifications 133
7.8 FGP Comparisons 133
7.9 Interior Design and Model Rooms 134
7.10 FGP Classification Groups 135
7.11 Selecting FGP Groups 137
7.11.1 Evaluation Guidelines 137
7.11.2 Classification Examples 139
7.12 Discussion 145
7.13 Closure 146

8 Beyond the Room of Origin 147
8.1 Introduction 147
8.2 The Inspection Plan 147

Part One: Barrier Effectiveness 149
8.3 Barrier Functions in Buildings 149
8.4 Barrier Fire Functions 149
8.5 Concepts for Barrier Evaluations 150
8.6 Barrier Failure Modes 152
8.7 Barrier Failures and Building Performance 158
Contents

Part Two: Barrier–Space Modules 159
8.8 Introduction 159
8.9 Barrier–Space Modules 159
8.10 Massive Barrier Failure (D̄) 159
8.11 Hot-spot Barrier Failure (T̄) 161
8.12 The Role of Interior Finish 161
8.13 Virtual Barriers 162
8.14 Qualitative Diagnostic Fire Analysis: Room Classifications 162
8.15 Qualitative Diagnostic Fire Analysis: Barrier Contributions 164
8.16 Qualitative Diagnostic Fire Analysis: Modules 164

Part Three: Qualitative Fire Analysis 165
8.17 Introduction 165
8.18 The Process 165
8.19 Discussion 172
8.20 Information Technology Enhancements 173

9 Smoke Analysis 175
9.1 Introduction 175
9.2 The Plan 176
9.3 Smoke 176
9.4 Buoyancy Forces 177
9.5 Natural Air Movement 178
9.6 Wind 180
9.7 Tenability Considerations 180
9.8 Smoke Movement Analysis 182
9.9 Smoke Movement Networks 183
9.10 Qualitative Smoke Movement Analysis 186
9.11 Quantitative Analysis 186
9.12 Discussion 188

10 The Diagnostic Fire 191
10.1 Diagnostic Fires 191
10.2 Interactive Performance Information (IPI) Chart and the Diagnostic Fire 191
10.3 Closure 192

11 Fire Detection 193
11.1 Introduction 193

Part One: Automatic Detection 194
11.2 Instrument Detection 194
11.3 Detection Instruments 194
11.3.1 Heat Detectors 195
11.3.2 Smoke Detectors 195
11.3.3 Flame Detectors 196
11.3.4 Operating Modes 196
11.4 Automatic Detection Analysis 197
11.5 Instrument Reliability 198
Part Two: Human Detection 200
11.6 Concepts in Human Fire Detection 200
11.7 Human Detection Analysis 200
11.8 Closure 202

12 Alarm: Actions After Detection 203
12.1 Introduction 203

Part One: Alert Occupants 205
12.2 Focus on Alert 205
12.3 Alerting Occupants 205
12.3.1 Audible Signals 206
12.3.2 Visual Signals 206
12.3.3 Human Alerting 207
12.3.4 Nuisance Alarms 207
12.3.5 Operating Modes 207
12.4 Summary 208

Part Two: Notify Local Fire Department 209
12.5 Introduction 209
12.6 Human Notification (MN) 209
12.6.1 Decide to Notify the Fire Department (dmn) 210
12.6.2 Send the Message (smn) 211
12.6.3 Message is Correctly Received (rmn) 211
12.7 Discussion 212
12.8 Automated Notification Services 213
12.8.1 Proprietary Supervising Station System 213
12.8.2 Central Station 214
12.8.3 Remote Station 214
12.8.4 Auxiliary Fire Alarm System 215
12.9 Discussion 216

Part Three: Building System Interfaces 217
12.10 Release Services 217

13 Fire Department Extinguishment: Arrival 219
13.1 Introduction 219
13.2 Organizing the Topic 219

Part One: Manual Extinguishment Overview 221
13.3 The Role of the Fire Department 221
13.4 Building Analysis Overview 221
13.5 Part A: Ignition to Notification 223
13.6 Part B: Notification to Arrival 223
13.7 Part C: Arrival to Extinguishment 224

Part Two: Community Fire Departments 226
13.8 Fire Department Organizations 226
13.9 Fire Companies 226
13.9.1 Engine Company 227
13.9.2 Ladder Company 228
13.9.3 Specialized Companies 228
13.9.4 Emergency Services 229
13.9.5 Response Information 229
13.10 Building Fire Brigades 229

**Part Three: Community Fire Response** 231
13.11 Fire Department Response Time 231
13.12 Communications Centers 231
13.13 Alarm Handling Time 232
13.14 Turnout Time 233
13.15 Travel Time 234
13.16 Response Time Analysis 234

14 Fire Department Extinguishment: First Water (MA) 237
The Fire Fighter and the Engineer 237
14.1 Introduction 239

**Part One: An Overview of Manual Extinguishment Analysis** 241
14.2 The Process 241
14.3 Phase 1: Initial Water Application (MA) 242
14.3.1 Find the Fire 243
14.3.2 Establish a Water Supply 244
14.3.3 The Attack Launch Point 245
14.3.4 Interior Attack Lines 247
14.3.5 Critical Fire Conditions 247
14.3.6 Extinguishing the Fire 248
14.4 Summary 248

**Part Two: A Brief Look at Fire Fighting** 249
14.5 Initial Fire Ground Actions 249
14.6 Information 249
14.7 Pause for Discussion 251
14.8 Manual Fire Fighting 252
14.9 No Two Fires Are Alike 253
14.10 Summary 253

**Part Three: Supply Water Analysis** 254
14.11 Introduction 254
14.12 Scenario Analysis 254
14.13 Supply Water Analysis 258
14.14 Supply Water Discussion 260
14.15 Project Analysis 260
14.16 Task Modules 261
14.17 Time and Tasks 261
14.18 Variability 262
14.19 General Analysis 263
14.20 Work Breakdown Structure 263
## Part One: Sprinkler Systems 307
16.3 Sprinkler Extinguishment 307
16.4 The Sprinkler System 308
16.5 Types of Sprinkler Systems 309

## Part Two: Sprinkler Performance 312
16.6 Organization for Thinking 312
16.7 Agent Application (AA) 312
16.8 Agent Application Events 313
16.9 Operational Effectiveness Observations 314
16.10 Sprinkler Fusing (fac) 316
16.11 Water Discharge (dac) 317
16.12 Water Flow Continuity (cac) 319
16.13 Obstructions (wac) 320
16.14 Operational Effectiveness Guidelines 321
16.15 Analysis and the IPI Chart 322
16.16 Auxiliary Equipment and Other Conditions 322
16.17 Partially Sprinklered Buildings 322
16.18 Fire Department Mutual Aid 323
16.19 Automatic Suppression 323
16.20 Closure 324

### The Composite Fire 325
17.1 Introduction 325
17.2 The Fire Limit (L) 325
17.3 Composite Fire 327
17.4 Theoretical Completeness 327
17.5 Summary 328

### Materials, Codes, Standards, Practices, and Performance 331
18.1 Introduction 331

## Part One: Building Construction 333
18.2 The Structural Frame 333
18.3 Material Behavior in Fires 334
18.3.1 Structural Steel 334
18.3.2 Concrete 335
18.3.3 Concrete Masonry Units 335
18.3.4 Prestressed Concrete 336
18.3.5 Wood 336
18.3.6 Gypsum 336
18.3.7 Glass 337

## Part Two: Historical Perspective 338
18.4 The Built Environment Around World War I 338
18.5 Structural Practice Around World War I 338
18.6 A Century of Evolution 339
18.7 Fire Safety Around World War I 339
Contents

19.14.2 Continuous Flexural Members 381
19.15 Structures and Materials 384
19.16 Structural Engineering 384
19.17 Structural Engineering and Building Design 385

Part Four: Structural Analysis for Fire Conditions 387
19.18 Introduction 387
19.19 Outcomes 387
19.20 Pause for Discussion 388
19.21 The Process 389
19.22 Structural Mechanics 390
19.23 Protection Methods 392
19.24 Diagnostic Fire 392
19.25 Heat Transfer 393
19.26 Structural Performance 394
19.27 Reinforced Concrete 394
19.28 Mechanical Properties 395
19.29 Flexural Members in Reinforced Concrete 396
19.30 Concrete Members at Elevated Temperatures 398
19.31 Pause for Discussion 398
19.32 Other Materials 399
19.33 Summary 399

20 Target Spaces and Smoke 401
20.1 Introduction 401
20.2 Orientation 401
20.3 Tenability Measures for Humans 403
20.4 Visibility in Smoke 404
20.5 Equipment and Data Storage 405
20.6 Overview of Target Space Analysis 406
20.7 Target Rooms 407
20.8 Barrier Effectiveness 407
20.9 Mechanical Pressurization 408
20.10 Fire Department Ventilation 409
20.11 Summary 409

21 Life Safety 411
21.1 Introduction 411
21.2 Human Reaction to Products of Combustion 412
21.3 Tenability 414
21.4 Fire Fighter Safety 414

22 Risk Characterizations 417
22.1 Introduction 417
22.2 The Exposed 417

Part One: Human Safety 419
22.3 Life Safety 419
22.4 Overview of Life Safety Alternatives 419
22.5 Prescriptive Code Egress 421
22.6 Plans Approval for Prescriptive Code Egress 422
22.7 Overview of Egress Risk Characterizations 423
22.8 Discussion 423
22.9 Pre-evacuation Activities 424
22.10 Pre-evacuation Evaluations 426
22.11 Travel Times 426
22.12 Defend in Place 428
22.13 Areas of Refuge 428
22.14 Fire Department Rescue I 428
22.15 Risk Characterizations for Life Safety 429

Part Two: Other Risks 431
22.16 Property Protection 431
22.17 Continuity of Operations 431
22.18 Threat to Neighboring Exposures 432
22.19 Threat to Environment 432
22.20 Closure 432

23 Fire Prevention 435
23.1 Introduction 435

Part One: Prevent Established Burning 436
23.2 Prevent EB 436
23.2.1 Ignition Potential 436
23.2.2 Initial Fire Growth 437
23.3 Occupant Extinguishment 437
23.4 Portable Fire Extinguishers 438
23.5 Evaluating Extinguisher Effectiveness 439
23.6 Discussion 440

Part Two: Automatic Special Hazard Suppression 442
23.7 Introduction 442
23.8 Carbon Dioxide Systems 443
23.9 Clean Agent Systems 443
23.10 Dry Chemical Extinguishing Systems 444
23.11 Water-spray Extinguishing Systems 445
23.12 Fine Water Mist Extinguishing Systems 445
23.13 Foam Extinguishing Systems 445
23.14 Explosion Suppression Systems 446
23.15 Building Evaluations for Special Hazard Installations 446
23.16 Closure 447

Part III The Analysis 449

24 Fire Performance: Framework for Analysis 451
24.1 Organizational Concepts 451
24.2 Performance Evaluations 451
24.3 Analytical Framework 452
24.4 Fire, Risk, and Buildings 454

25 The Diagnostic Fire 455
25.1 Introduction 455
25.2 Top-down Estimates 456
25.3 Modular Estimates 456
25.4 Bottom-up Scenario Analysis 458
25.5 Network Estimates 458
25.6 Scenario Applications 461
25.7 Interactive Performance Information (IPI) Chart Applications 462

26 Fire Detection 463
26.1 Introduction 463

Part One: Automatic Detection 464
26.2 Detection Analysis 464
26.3 Detection Example 466
26.4 Detection Estimate 469
26.5 Detector Reliability 469

Part Two: Human Detection 471
26.6 Concepts in Human Detection Analysis 471
26.7 Human Detection Analysis 471
26.8 Closure 473

27 Fire Department Notification 475
27.1 Introduction 475
27.2 The Human Link in Notification 475
27.3 Human Notification Analysis 476
27.3.1 The Role of Detection 478
27.3.2 Initial Scenario Analysis 478
27.3.3 Information Augmentation 479
27.4 Human Notification 479
27.5 Automated Notification Analysis 480
27.6 Closure 481

28 Fire Department Extinguishment 483
28.1 Introduction 483
28.2 Framework for Analysis 483
28.3 Notification to Arrival 483
28.4 Fire Department Response 485
28.5 Arrival to Extinguishment 488
28.6 Phase 1 Analysis 489
28.7 Phase 2 Analysis 489
28.8 Phase 3 Analysis 490
28.9 Putting It Together 492
28.10 Discussion 498
28.11 Closure 499
29 Automatic Sprinkler Suppression 501
29.1 Introduction 501
29.2 Agent Application (AA) 502
29.3 Design Effectiveness (AC) 504
29.3.1 First Sprinkler Fusing (fac) 504
29.3.2 Multiple Sprinkler Fusing (fac) 504
29.3.3 Discharge Density (dac) 505
29.3.4 Water Continuity (cac) 505
29.3.5 Obstructions (wac) 506
29.4 Automatic Sprinkler Suppression (A) 507
29.5 Automatic Sprinkler System Analysis 507
29.5.1 Role of Performance Analysis 509
29.5.2 Organizing Performance Analysis 509
29.5.3 Performance Evaluation 513
29.6 Sprinkler Reliability 514
29.7 Closure 514

30 The Composite Fire 517
30.1 Introduction 517
30.2 Event Logic Description 517
30.3 Network Description 519
30.4 Summary 520

31 Structural Performance 521
31.1 Introduction 521
31.2 Interactive Performance Information (IPI) Documentation 521
31.3 IPI Numerical Estimates 523
31.4 Summary 524

32 Target Space Smoke Analysis 525
32.1 Introduction 525
32.2 Success or Failure? 526
32.3 Target Room Performance Bounds 527

33 Life Safety Analysis 531
33.1 Introduction 531
33.2 The Exposed 531
33.3 The Exposure 532
33.4 The Window of Time 532
33.5 Pre-movement Time for Egress 533
33.5.1 Fire Detection (OD) 534
33.5.2 Alert Occupants (OA) 535
33.5.3 Occupants Start Egress (OT) 535
33.6 Occupant Life Safety (LS) 536
33.7 Discussion 536
33.8 Defend in Place 538
33.9 Closure 538
## Contents

### Part One: Established Burning Prevention 544

34.1 Introduction 541

34.2 Ignition Potential 544

34.3 Established Burning Evaluation 544

34.3.1 Fire Self-termination 545

34.3.2 Occupant Extinguishment 546

34.4 Scenario Selection 546

34.5 Prevent EB: Discussion 546

### Part Two: Special Hazards Protection 550

34.6 The Role of Special Hazards Suppression 550

34.7 Framework for Analysis 550

34.8 Special Hazards Analysis 551

34.9 Protection Combinations 551

34.10 Closure 554

### Part IV Managing Uncertainty 555

35 Understanding Uncertainty 557

35.1 Introduction 557

35.2 Window of Uncertainty 557

35.3 Calibrating Uncertainty 558

35.4 Degree-of-Belief Estimations 559

35.5 The Role of the Analytical Framework 560

35.6 Sprinkler Analysis Networks 560

35.7 Sprinkler Control (AC) 561

35.8 Pause to Organize Thoughts 562

35.9 Calculating Single Value Outcomes 563

35.10 Graphing Results 564

35.11 Cumulative Evaluations 568

35.12 Sprinkler Reliability (AA) 572

35.13 Sprinkler System Performance (A) 573

35.14 Control and Extinguishment 574

35.15 Sprinkler Performance for a Building 576

35.16 Visual Thinking 577

35.17 The IPI Chart 578

35.18 The Narrative 578

35.19 Sprinklers and the Fire Department 578

35.20 Other Components 579

35.21 Summary 579

### 36 Visual Thinking 581

36.1 Introduction 581

36.2 A Case Study 581

36.3 A Way of Thinking 584
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>36.4</td>
<td>The Interactive Performance Information (IPI) Chart Relation</td>
<td>584</td>
</tr>
<tr>
<td>36.5</td>
<td>Performance Evaluators</td>
<td>585</td>
</tr>
<tr>
<td>36.6</td>
<td>Reading Performance Curves</td>
<td>586</td>
</tr>
<tr>
<td>36.6.1</td>
<td>Detection</td>
<td>586</td>
</tr>
<tr>
<td>36.6.2</td>
<td>Fire Department Notification</td>
<td>588</td>
</tr>
<tr>
<td>36.6.3</td>
<td>Sprinkler Control</td>
<td>589</td>
</tr>
<tr>
<td>36.6.4</td>
<td>Fire Extinguishment</td>
<td>590</td>
</tr>
<tr>
<td>36.7</td>
<td>The L Curve</td>
<td>591</td>
</tr>
<tr>
<td>36.8</td>
<td>L Curve Illustration</td>
<td>594</td>
</tr>
<tr>
<td>36.9</td>
<td>Variability and Reliability</td>
<td>594</td>
</tr>
<tr>
<td>36.10</td>
<td>Summary</td>
<td>595</td>
</tr>
<tr>
<td>37</td>
<td>Introduction to Risk Management</td>
<td>597</td>
</tr>
<tr>
<td>37.1</td>
<td>Introduction</td>
<td>597</td>
</tr>
<tr>
<td>37.2</td>
<td>Audience</td>
<td>598</td>
</tr>
<tr>
<td>37.3</td>
<td>Fire Safety Management</td>
<td>598</td>
</tr>
<tr>
<td>37.4</td>
<td>Decisions and Uncertainty</td>
<td>600</td>
</tr>
<tr>
<td>37.5</td>
<td>Management Applications</td>
<td>600</td>
</tr>
<tr>
<td>37.6</td>
<td>Comparisons</td>
<td>601</td>
</tr>
<tr>
<td>37.7</td>
<td>Process Overview</td>
<td>601</td>
</tr>
<tr>
<td>37.8</td>
<td>Part Two: Information Acquisition</td>
<td>604</td>
</tr>
<tr>
<td>37.9</td>
<td>Introduction</td>
<td>604</td>
</tr>
<tr>
<td>37.10</td>
<td>Understand the Problem</td>
<td>604</td>
</tr>
<tr>
<td>37.11</td>
<td>Describe the Building</td>
<td>605</td>
</tr>
<tr>
<td>37.12</td>
<td>Evaluate Performance</td>
<td>605</td>
</tr>
<tr>
<td>37.13</td>
<td>Characterize Risk</td>
<td>605</td>
</tr>
<tr>
<td>37.14</td>
<td>Part Three: Develop a Risk Management Program</td>
<td>608</td>
</tr>
<tr>
<td>37.15</td>
<td>Structure a Risk Management Program</td>
<td>608</td>
</tr>
<tr>
<td>37.16</td>
<td>Evaluate “Prevent EB”</td>
<td>608</td>
</tr>
<tr>
<td>37.17</td>
<td>Evaluate Special Hazards Protection</td>
<td>609</td>
</tr>
<tr>
<td>37.18</td>
<td>Emergency Preparedness</td>
<td>609</td>
</tr>
<tr>
<td>37.19</td>
<td>Decision Analysis</td>
<td>611</td>
</tr>
<tr>
<td>38</td>
<td>Analytical Foundations</td>
<td>615</td>
</tr>
<tr>
<td>38.1</td>
<td>Historical Origins</td>
<td>615</td>
</tr>
<tr>
<td>38.2</td>
<td>Part One: Logic Diagrams and Networks</td>
<td>617</td>
</tr>
<tr>
<td>38.3</td>
<td>Event Trees</td>
<td>617</td>
</tr>
<tr>
<td>38.4</td>
<td>Fault and Success Trees</td>
<td>618</td>
</tr>
<tr>
<td>38.5</td>
<td>Fault and Success Tree Calculations</td>
<td>619</td>
</tr>
<tr>
<td>38.6</td>
<td>Fault and Success Trees Beyond the Room of Origin</td>
<td>620</td>
</tr>
<tr>
<td></td>
<td>Network Organization</td>
<td>621</td>
</tr>
</tbody>
</table>
38.7 Network Calculations 621
38.8 Sequential Path Analysis 623
38.9 Rooms Beyond the Room of Origin 624
38.10 Modular Analysis 624
38.11 Closure 626

Part Two: Probability 628
38.12 Meanings of Probability 628
38.13 Fire Safety Applications 629
38.14 Degree of Belief 629
38.15 Mathematics of Probability 630
38.16 Assessment Quality 630

Part Three: The Role of Judgment 632
38.17 Introduction 632
38.18 Building Decisions 632
38.19 Judgment in Engineering 632
38.20 Language and Culture 633
38.21 Uncertainty and Performance 633
38.22 Summary 634

Appendix A Organizational Structure 637
A.1 The Organizational Framework 637
A.2 Basic Organization 637
A.3 The Composite Fire 637
A.4 The Diagnostic Fire (I) 639
A.5 Fire Department Manual Extinguishment 640
A.6 Detection 640
A.7 Notification 642
A.8 Notification to Arrival 643
A.9 Arrival to Extinguishment 645
A.10 Automatic Sprinkler System 646
A.11 Building Response: Structural Behavior 647
A.12 Building Response: Space Tenability 648
A.13 Risk Characterizations 648
A.14 Occupant Movement 650
A.15 Other Risks 651
A.16 Prevent Established Burning (EB): Occupant Extinguishment 651
A.17 Prevent EB: Special Hazards Protection 653
A.18 Closure 653

Appendix B Model Building 655
Description 655
Plans 655

Index 661
This book describes a framework to analyze the fire performance for any building – in any location, under any regulatory system, and constructed in any regulatory era.

The book is intended for any individual who wants to understand the fire performance of buildings. The approach allows one to examine the performance of specific components in isolation or to integrate them to describe holistic behavior.

It is anticipated that readers will have varied backgrounds and levels of knowledge in the subject. The book enables a reader to obtain specific information in isolation. For example, an individual may wish to increase their knowledge of fire behavior or the operational details of a specific fire defense. When such background knowledge is already known, the reader may go directly to the analytical techniques. Although a reader may move through specific topics in isolation, the content is structured in a logical progression.

Unit One describes the foundation on which the analytical framework is organized. Theory and practice are based on well-established techniques. Because fire performance in buildings is dynamic, the Interactive Performance Integration (IPI) chart is given special attention. This chart is an essential tool to relate the fire and the phasing in and phasing out of fire defenses and risk characterizations.

Unit Two explains each part of the system of fire and buildings. Fire department operations are of particular interest in building analysis. The procedures are described for fire safety professionals with no experience in fire ground operations. Techniques relate the fire size to the time of water application and to damage estimates at eventual extinguishment.

Modern structural analysis and design for fire conditions is another important part of fire performance in which many fire safety professionals have little knowledge. Chapter 18 describes the evolution of structural requirements while Chapter 19 makes the transition from traditional regulations to modern calculation methods. The information enables a fire safety professional to work with a structural engineer to establish performance understanding of the building’s structural system.

Unit Three identifies the analytical framework for each component and for holistic performance. The organization is based on the framework of Unit One and the component behavior of Unit Two. The IPI chart is an essential tool for ordering the time-related phases of fire and fire defenses.

Fire safety engineering is an evolving discipline. Although some components are now reaching early maturity, others are making a transition from infancy into adolescence. Uncertainty is inherent to all analysis and design. Unit Four describes ways to manage uncertainty and communicate credible knowledge to other individuals who are involved in the built environment.
Harold E. (Bud) Nelson created the foundation of performance analysis and design nearly half a century ago. This book represents the current status of the “Nelson Method.”

The acknowledgements in the first edition identified many of the pioneers who contributed significantly to the maturation of this structure for fire safety performance. Although their names are not repeated in this edition, their contributions should not be forgotten. Nevertheless, the names of Rexford Wilson and Rolf Jensen are again recognized because of their significance to the development of these procedures and to the history of performance based fire safety engineering.

The first edition attempted to describe performance analysis for unique, site-specific buildings. Unfortunately, recognition of the analytical framework was obscured by emphasis of probabilistic performance descriptors that were used to sort out complicated interactions. This second edition emphasizes state-of-the-art deterministic fire science and engineering in performance quantification. The role of the Interactive Performance Information (IPI) chart has been expanded to describe dynamic interactions.

The role and depiction of the framework and quantitative measures have been reorganized in this edition. Techniques for evaluating a building design for fire department extinguishment and analyzing structural performance have been upgraded. Essentially, this second edition is an entirely new book that is based on concepts of the first edition.

One of the important new techniques involves building analysis for fire department suppression. James F. Callery, District Chief (ret) Worcester (MA) Fire Department, Clifford S. Harvey, Assistant Chief (ret), Boulder (CO) Fire Department, Peter V. Mulvihill, Nevada State Fire Marshal, and Matthew T. Braley, District Chief, Worcester (MA) Fire Department have made valuable contributions. Professor Guillermo F. Salazar (WPI) provided support for BIM drawings and construction management procedures.

The state of the art of structural design for fire conditions has progressed significantly in recent years. The fire safety engineer and the structural engineer have interactive roles in understanding structural performance for fire conditions. Professor Leonard D. Albano (WPI) and Roger Wildt, P.E., gave valuable support for the structural engineering documentation.

The Society of Fire Protection Engineers (SFPE) provided important support for this edition. Professor Tahar El Korchi of the WPI FPE Department funded students to test practices, develop numerical examples, draw figures, and format the product. Professor Roberto Pietroforte guided the architectural interface. Professor Robert C. Till (John Jay)
used early drafts of the text to provide useful feedback. We are very grateful for the support of SFPE, WPI, and the following students: Ian Jutras, Drew Martin, Yu Liu, Yecheng Lyu, Young-Geun You, Milad Zabeti Targhi, and Camille Levy.

A book of this type requires an enormous amount of time to organize, discuss, and prepare. We appreciate the tolerance and sacrifice given by our wives, Margaret and Sharon. Their support has been important to the completion of this project.

Robert W. Fitzgerald
Brian J. Meacham
1

Fire Performance and Buildings

1.1 The Dynamics of Building Fire Performance

A building fire is dynamic because hostile fire characteristics change minute by minute. The dynamic fire produces products of combustion that affect the building and its fire defenses. The continually changing building environment influences time relationships for risk characterizations involving occupants and building functions. These actions occur in a variety of sequences and ways for different buildings.

During a fire, some components complete their roles and become inactive before other components become operational. Additionally, actions of some parts of the system depend on the status and sequential phasing of other components. Performance evaluations analyze interactions that combine time-dependent changes in the fire, building fire defenses, and people.

The goal of this book is to organize the complicated process into an analytical framework with which an engineer can evaluate fire performance. A performance evaluation enables one to understand specific component behavior as a part of holistic building performance.

*Time* is the common factor that links all of the important events.

1.2 The Anatomy of Building Fire Safety

Figure 1.1 shows the major parts of the complete system of fire performance for buildings. Initially, the system is organized into three major groups:

1) The *composite fire* combines a diagnostic fire and the active extinguishment actions provided by local fire department manual extinguishment and automatic sprinkler suppression, if present.

2) The *building response* is based on the flame-heat and smoke-gas products of combustion produced by the composite fire and their movement through the building. The process continues from ignition to extinguishment.

3) The *risk characterizations* for exposed people, property, and functions are based on the building’s response.

Figure 1.1 is a static representation of the major parts. At each minute into the fire, the status of each part changes.
The analytical framework decomposes each part into components that can be evaluated separately. The components are recombined to incorporate the influences of time, fire conditions, and other components within the system. This allows each component to be evaluated as an independent unit and the effects combined to describe holistic performance.

1.3 Analysis and Design

Analysis and design are two sides of the same coin. In its most basic form, all design involves trial and error. For example, a design process starts by gathering information about a building’s function, the design objectives, hazards to which the building will be subjected, the dimensional, material, economic and site constraints, and regulatory expectations. An initial trial design is formulated and then analyzed to evaluate the extent to which function, economics, and safety are acceptable. The design is then updated by changing parts of the trial design that did not perform in an acceptable manner. The iterative process of design–analyze–redesign continues until an updated design produces acceptable conditions for function, safety, and economy.

This book does not address building design, nor does it use any specific code or design standard. Rather, it describes how to analyze a building for a hostile fire. The results of the fire analysis provide a basis to characterize risk for people, property, and function. The goal is to describe a way to understand fire performance and risk characterizations for any existing building or proposed new building design. Although the book does not describe conventional procedures to accomplish design objectives, a performance analysis will give an insight into effective ways to achieve stated objectives.