

FOURTH EDITION



# MANUAL OF LOW-SLOPE ROOF SYSTEMS

- Specification and construction
- New technologies and materials
- Heat transfer and wind resistance
- Inspection and maintenance
- Standard prep guide for the Roofing Consultants Institute registration exams

---

# **Manual of Low-Slope Roof Systems**

**C. W. Griffin  
R. L. Fricklas**

**Fourth Edition**

**McGraw-Hill**

New York Chicago San Francisco Lisbon London Madrid  
Mexico City Milan New Delhi San Juan Seoul  
Singapore Sydney Toronto

CIP Data is on file with the Library of Congress

Copyright © 2006, 1996, 1982, 1970 by The McGraw-Hill Companies, Inc. All rights reserved. Printed in the United States of America. Except as permitted under the United States Copyright Act of 1976, no part of this publication may be reproduced or distributed in any form or by any means, or stored in a data base or retrieval system, without the prior written permission of the publisher.

2 3 4 5 6 7 8 9 0 DOC/DOC 0 1 2 1 0 9 8 7

ISBN 0-07-145828-X

*The sponsoring editor for this book was Cary Sullivan, the editing supervisor was Stephen M. Smith, and the production supervisor was Richard C. Ruzicka. It was set in Century Schoolbook by Kim Sheran of McGraw-Hill Professional's Hightstown, N.J., composition unit. The art director for the cover was Anthony Landi.*

*Printed and bound by RR Donnelley.*

McGraw-Hill books are available at special quantity discounts to use as premiums and sales promotions, or for use in corporate training programs. For more information, please write to the Director of Special Sales, McGraw-Hill Professional, Two Penn Plaza, New York, NY 10121-2298. Or contact your local bookstore.

Information contained in this work has been obtained by The McGraw-Hill Companies, Inc. ("McGraw-Hill") from sources believed to be reliable. However, neither McGraw-Hill nor its authors guarantee the accuracy or completeness of any information published herein, and neither McGraw-Hill nor its authors shall be responsible for any errors, omissions, or damages arising out of use of this information. This work is published with the understanding that McGraw-Hill and its authors are supplying information but are not attempting to render engineering or other professional services. If such services are required, the assistance of an appropriate professional should be sought.

---

# Preface

“It’s not rocket science.”

This oft-repeated cliché expresses our exasperation with any festering but simple problem not attacked with the required mental effort. Applied to the most challenging problem reported in this fourth edition of the *Manual of Low-Slope Roof Systems*, that of wind pressures, the old cliché would be grossly inaccurate. The approach to the aerodynamics of wind pressures promulgated by the recent SEI/ASCE Standard 7-02 brings this material close to rocket science—at least, many roof designers will find it so. Moreover, Standard 7-02 makes few concessions to the complexities of the subject, presenting readers with some of the hairiest mathematical formulas they will ever encounter.

Fortunately, a cottage industry of translations has simplified the esoteric problems tackled by 7-02. The best of these is RCIF Publication No. 01.02, “Wind Pressures on Low Slope Roofs,” which clearly abstracts the limited information essential to roof designers. They can ignore the more difficult problems of overall structural design—for example, distinguishing between flexible and rigid structures—tackled in 7-02. We used this RCIF document to good advantage.

An important innovation discussed in this new edition involves “cool” roofs, which are increasingly being utilized, especially in the Sun Belt, where U.S. population growth is concentrated. Huge, sprawling single-story buildings offer tremendous opportunities for energy conservation through use of light-colored single-ply membranes or metallic surfaces with high solar reflectance. In California, cool roofs capable of reducing peak roof-surface temperatures by 70°F under peak summer solar radiation have been made mandatory by a state energy code designed to alleviate the economic pain and disruption of rolling blackouts, such as those of 2000, when Enron and other corrupt power suppliers withheld electricity and sent consumers’ prices skyrocketing.

More mundane changes have affected every one of the manual’s 21 chapters. Within the past decade, from an insignificant part of the thermoplastic single-ply market, TPO membrane has surpassed PVC as the dominant material,

propelled by relatively low cost, durability, and easy field weldability. Some changes stem less from inherent desirability than from environmental and safety concerns. The hot-mopping and torching of modified-bituminous membranes have yielded to self-adhering seals, which require greater field control to produce dependable joint integrity.

Despite the slow advance of laboratory tests for evaluating roof components, field experience still reveals unanticipated flaws. During the past decade, phenolic foam insulation proved to be a destructive agent through water-based chemical reactions that corroded metal fasteners, decks, and accessories. The travails of this insulation follow those of another unsuitable insulation, extruded polystyrene, an excellent material for PMRs but a disaster in conventional BUR systems. Four decades ago, the hopes for two-ply, coated-felt BUR membranes, a presumed labor-saving answer to ridging and several other common failure modes, culminated in an epidemic of split or blistered membranes. A switch to glass-fiber felts ultimately solved these and other traditional problems with conventional BUR systems. Since this manual's last edition, published in 1996, the replacement of thin, unreinforced thermoplastic single-ply membranes with thicker, reinforced sheets has ensured lengthened durability at minimal cost.

These and other additions to new and updated standards and practices mark the progress of the roofing industry toward more science, less art. There's still a long way to go, but a comparison of this fourth edition with the first (1970) edition indicates a journey of several thousand technological miles.

*C. W. Griffin  
Dick Fricklas*

---

# Acknowledgments

Each of the four editions of this manual has been made possible by the contributions of many of our industry's top professionals, who provided expert review, up-to-date information, and illustrations.

Special credit for help with this fourth edition must go to the following people: Justin Henshell, FAIA, who provided major portions of text including material on vegetated roofs; Wayne Tobiasson, formerly with CRREL, who was of great assistance with air barriers and moisture considerations; Jerry Teitsma of RCI, whose clarification and proofing of the revisions to ASCE-7 were greatly needed; Stanley Graveline of Sarnafil, whose experience with PVC, KEE, EVA, and TPO was invaluable; Dr. Walter Rossiter of NIST, whose overview of roofing research and programs on EPDM tape greatly advanced the single-ply industry; Patricia Wood-Shields of RICOWI, whose insight into building codes was badly needed; Larry Spielvogel of L.G. Spielvogel, Inc., who tried to keep us current with the ever-changing drafts of ASHRAE 90.1; and Bill Kirn, who helped us understand the impact of cool roofs, test procedures for field measurements, and the solar reflectance index.

Many other individuals and organizations contributed materials, data, and illustrations to the updating that occurred in this new edition and to improve the quality of some of the photographs that we found rather disappointing in the third edition. With digital editing, we hope the new or reworked materials are clear and understandable.

Contributors worthy of mention are (and we apologize to anybody we overlooked) Jim Anderson, Foam Enterprises; Bob Backstrom, Underwriters Laboratories; Jerry Beall, Seaman Corp.; Larry Brown, Tectum Inc.; Jim Carlson, Building Envelope Technology and Research; Bruce Cotton, AFC Ltd.; Gerry Curtis, GBC Consultants; Hugh Dudley, Constructive Consulting, Inc.; Mark Graham, Associate Executive Director, Technical Services, NRCA; Rob Haddock, Metal Roof Advisory Group; Helene Hardy-Pierce, GAF; Riaz Hasan, ITW Buildex; Joe Hobson, ARMA; Mark James, RetroSpec Consultants; Jim Jannasch, Firestone; Linda King, SPRI; Mason Knowles, SPFA; Dr. Ted Michelsen, Michelsen Technologies; Luther Mock, Foursquare Solutions Inc.;

Roger Morrison, North Carolina Foam Industries; Frank Nestle, BASF Corp.; Dr. Ralph M. Paroli, National Research Council of Canada; Greg Pender, APOC; Steve Phillips, Hendrick, Phillips, Schemm & Saltzman, PC; Don Portfolio, PRI; Doug Robbins, Horizon Group of New England; Dave Roodvoets, DLR Consultants; Bruce Schenke, BASF; Dwayne E. Sloan, Underwriters Laboratories; George and Phil Smith, FM Global; Tom Smith, T L Smith Consulting; Suzanne Snyder, Trumbull; and Ed Stewart, Gale Associates.

---

# Contents

Preface	xiii
Acknowledgments	xv

<b>Chapter 1. Introduction</b>	<b>1</b>
Why Roofs Fail	2
Lessons from History	6
Need for Research and Standards	7
<b>Chapter 2. The Roof as a System</b>	<b>9</b>
Design Factors	9
Basic Roof Components	10
Disastrous Combinations	15
Constructing the Roof	16
Divided Responsibility	17
Unified Responsibility	17
Performance Criteria	18
References	24
<b>Chapter 3. Draining the Roof</b>	<b>25</b>
Why Drain the Roof?	28
Life-Cycle Costing Example	31
How to Drain the Roof	32
Drainage Design	34
Draining an Existing Roof	41
Alerts	42
Design	42
Maintenance	42
References	42



<b>Chapter 4. Structural Deck</b>	<b>43</b>
Deck Materials	43
Design Factors	46
Slope	46
Deflection	48
Dimensional Stability	49
Moisture Absorption	51
Anchorage of Components	51
Deck Surface and Joints	53
Steel Decks	54
Recommendations for Steel Decks	55
Alerts	56
Design	56
Field	57
References	58
 <b>Chapter 5. Thermal Design</b>	 <b>59</b>
Thermal Insulating Materials	60
Rigid Board Insulation	61
Poured-in-Place Insulating Concrete Fill	63
Design Factors	64
Strength Requirements	66
Moisture Absorption	66
Venting	68
Dimensional Stability	69
Tapered Insulation	71
Anchoring Insulation to the Deck	71
Solid Bearing for Insulation Boards	72
Refrigerated Interiors	72
Effects of Increased Insulation Thickness	73
Joint Taping	74
Double-Layered Insulation	75
Principles of Thermal Insulation	77
Moisture Reduction of Insulating Value	78
Heat-Flow Calculation	80
Heat Gain or Loss	83
Cool Roofs	83
Principles of Radiant Heat Transfer	85
Complicating Factors	89
California Cool	91
Seasonal Factors	92
ANSI/IESNA	94
ASHRAE Standard 90.1	94
Alerts	96
Design	96
Field	97
References	99
 <b>Chapter 6. Vapor Control</b>	 <b>101</b>
Fundamentals of Vapor Flow	101
Techniques for Controlling Moisture	104

General Ventilation	105
Vapor Retarder	105
Self-Drying Roof System	113
The Futility of Topside Venting	117
Theory of Vapor Migration	117
Diffusion	117
Air Leakage	120
Air Barriers	122
Sample Vapor-Retarder Calculation	123
Alerts	126
Design	126
Field	127
References	127
<b>Chapter 7. Wind Uplift</b>	<b>129</b>
Historical Background	131
Mechanics of Wind-Uplift Pressure	135
Basic Wind-Speed Determinants	136
Building Shape, Size, and Enclosure	142
Determining Final Wind-Uplift Pressure	144
Procedure for Calculating Design Wind Pressure	149
Design Example: Anchored System	150
SEI/ASCE 7-02 versus FM Global	151
Perimeter Flashing Failures	152
Wind-Uplift Mechanics on Ballasted Roofs	155
Gravel Blowoff and Scour	158
Wind-Uplift Design for Ballasted, Single-Ply Roof Assemblies	160
Basic Ballasted Wind-Design Systems	163
PMR Wind Design	168
Retroactive Redesign	170
Design Example for Ballasted, Loose-Laid System	170
Wind-Uplift Testing	170
Laboratory Tests	171
Field Wind-Uplift Tests	175
Repair Procedures after Wind-Uplift Failure	176
Mechanical Fasteners	177
Alerts	183
General	183
Design	183
Field	183
References	184
<b>Chapter 8. Fire Resistance</b>	<b>185</b>
Nature of Fire Hazards	185
External Fire Resistance	186
Internal Fire Hazards	188
Below-Deck Fire Tests and Standards	189
Flame-Spread Test	189
FM Fire Classification	189
Time-Temperature Ratings	191
Fire Rating versus Insulating Efficiency	192

Building Code Provisions	193
Alert	193
<b>Chapter 9. Historical Background of Contemporary Roof Systems</b>	<b>195</b>
Built-up Bituminous Membranes	196
The First-Generation Single-Ply Pioneers	197
The Cold-Process Dead End	198
The Second-Generation Success	198
New Roof Systems	200
Modified Bitumens	203
<b>Chapter 10. Elements of Built-up Membranes</b>	<b>207</b>
Membrane Materials	209
Roofing Bitumens	209
Incompatibility of Asphalt and Coal Tar Pitch	214
Coal Tar Pitch versus Asphalt	215
Felts	215
Surfacing	219
Smooth-Surfaced Membrane	225
Mineral-Surfaced Roll Roofing	226
Heat-Reflective Surfacing	226
Built-up Membrane Specifications	227
Shingling of Felts	227
Coated Base Sheet	229
Phased Application	230
Temporary Roofs	233
Joints in Built-up Membranes	234
Membrane Performance Standards	236
BUR Failure Modes	238
Blisters	239
Splitting	249
Ridging	254
Membrane Slippage	256
Alerts	260
General	260
Design	261
Field	261
References	263
<b>Chapter 11. Modified-Bitumen Membranes</b>	<b>265</b>
Historical Background	266
Modified-Bitumen Materials	268
Rubberizing Polymers	268
Reinforcement	269
Surfacing	274
Modified-Bitumen Specifications	275
Modified-Bitumen Flashings	278
Performance Criteria for Modified Bitumens	279
Modified-Bitumen Failure Modes	282
Defective Lap Seams	282

Checking	283
Shrinkage	285
Blistering	285
Delamination	288
Slippage	288
Splitting	290
Alerts	291
General	291
Design	291
Field	291
References	292
 Chapter 12. Elastomeric Membranes	 293
Basic Material	293
Field Seaming	296
Flashings	296
Mechanically Fastened Systems	301
Elastomeric Failure Modes	301
Alerts	305
General	305
Design	307
Field	307
References	307
 Chapter 13. Weldable Thermoplastics	 309
Materials	309
Historical Background	312
Flashings	315
Failure Modes	315
Alerts	316
References	317
 Chapter 14. Flashings	 319
Flashing Functions and Requirements	320
Materials	321
Base Flashing Materials	322
Counterflashing Materials	325
Principles of Flashing Design	326
Eliminating Penetrations	326
Reducing Openings	327
Flashing Elevation	327
Differential Movement	328
Flashing Contours and Cants	329
Flashing Connections	329
Specific Flashing Conditions	330
Edge Details	330
Vertical Flashings	331
Roof Penetrations	333
Expansion-Contraction Joints	338
Water Conductors	341

Flashing Failures	341
Sagging	341
Ponding Leakage	342
Diagonal Wrinkling	342
Postconstruction Damage	344
Alerts	344
General	344
Design	344
Field	345
Standard Details	345
 <b>Chapter 15. Protected Membrane Roofs and Waterproofed Decks</b>	 <b>367</b>
Why the Protected Membrane Roof?	369
How PMR Changes Component Requirements	372
PMR Design and Construction	373
Drain Location	374
PMR Flashings	374
PMR Insulation Performance Requirements	374
Thermal Quality of PMR Insulation	377
Refinements in Locating PMR Insulation	377
Surfacing Protected Membrane Roofs	378
Life-Cycle Costing	379
Waterproofed Deck Systems	381
Structural Decks	381
Membranes	382
Protection Boards	385
Drainage Design	385
Aggregate Percolation versus Open Subsurface Drainage	387
Insulation	387
Flashing	388
Wearing Surface Design	389
Plaza "Furniture"	390
Detailing	390
Flood Testing	390
Alerts (for PMRs)	391
Alerts (for Waterproofed Decks)	391
Design	391
Field	392
References	393
 <b>Chapter 16. Sprayed Polyurethane</b>	 <b>395</b>
Historical Background	396
Materials	399
Polyurethane Foam	399
Membrane Coating	401
Surfacing Aggregate	406
Detailing SPF Systems	407
Application Requirements	407
Foam Application	414
Coating Application	417
Quality Assurance	418

Maintenance	419
Alerts	420
General	420
Design	420
Application	420
Maintenance	420
References	420
 Chapter 17. Metal Roof Systems	 423
Historical Background	424
Metal Roof Concepts and Terminology	427
Design Factors	428
Thermal Movement	428
Drainage	429
Condensation	429
Penetrations	430
Wind-Uplift Resistance	430
Corrosion Protection	430
Metal Roofing Accessories	432
Thermal Insulation	437
Underlayments	438
Vapor Retarders	439
Detailing Metal Roofing	439
Metal-Roof-System Defects	442
Aesthetic Problems	442
Functional Problems	444
Metal Roof Evaluation	447
References	447
 Chapter 18. Field Inspections	 449
Quality Assurance	449
QA Inspections	450
Application Checklists	456
Visual Roof Surveys	463
Nondestructive Moisture Detection	465
Benefits of Nondestructive Moisture Detection	467
Limitations	468
Principles of Nondestructive Moisture Detection	468
Other Moisture-Detection Techniques	471
References	473
 Chapter 19. Reroofing and Repair	 475
Re-covering or Tearoff-Replacement?	477
Investigation and Analysis	478
Preliminary Investigation	478
Leak-Detection Technique	479
Visual Inspection and Analysis	479
Field-Test Cuts	481
Large-Scale Moisture Surveys	481
Assessment for Remedial Action	481
New Performance Criteria	482

Reroofing Specifications	483
Isolating the New Membrane	484
Flashings	484
Surface Preparation of Existing Membrane	485
Retrofit Metal Roofing	486
Alerts	487
For Replacement Bituminous Roof Membranes	487
For Loose-Laid Synthetic Single-Ply Membranes	490
For Sprayed Polyurethane Foam (Plus Fluid-Applied Coating)	490
 Chapter 20. Roof-System Specifications	 493
Specifications and Drawings	494
Drawing Requirements	494
Specification Requirements	494
Writing Style	495
Specifying Methods	495
Master Specification	496
Division of Responsibility	497
Temporary Roofing	498
Special Requirements	498
Specifying New Roofing Products	499
Quality Assurance	500
Coordination	501
Test Cuts	502
Alerts	504
General	504
New Products	504
General Field	504
Technical	505
References	505
 Chapter 21. Roofing Guarantees and Warranties	 507
Manufacturer's Bond	507
Manufacturer's Warranty	509
Analyzing the Warranty	510
Warranty Checklist	513
Roofer's Guarantee	514
Roof-Maintenance Program	515
 Glossary of Roofing-Related Terms	 517
Appendix A ASTM International Conversion Factors and Roofing Standards	547
Appendix B Index and Abstracts of ASTM Test Methods for Roofing Materials	551
Index	571

## Introduction

Contrasted with the drastic changes reported in the third edition (1996) of this manual, the developments reported in this fourth edition are more evolutionary than revolutionary. By the mid-1990s, the roughly 140-year dominance of built-up bituminous roofing (BUR) systems was long gone. BUR's decline has continued during the past decade, falling from roughly one-third of the low-slope market in the mid-1990s to about 15 percent in 2005. Single-ply elastomeric and weldable thermoplastic sheets now account for nearly half the market; modified bitumens have declined from their peak in the 1990s to about 20 percent of the market; metal roofing has grown to 10 percent, and sprayed polyurethane and cold-applied systems account for 8 percent or thereabouts. Among these material changes, the most spectacular is the emergence of thermoplastic olefin (TPO) membranes, which have exceeded both Hypalon and polyvinyl chloride (PVC) in popularity.

Besides these material changes, the past decade has brought intensified concentration on environmental pollution, safety, and energy concerns. This last-cited trend necessitated a new section, on "cool" roofs. (Besides the private benefits of reducing escalating energy costs, "cool" roofs are part of a program to limit peak power demand, a problem dramatized by California's rolling blackouts in the summer of 2000. Environmental and safety concerns pose a challenge to roof-system integrity; in modified-bitumen systems, they may require the substitution of less dependable but more environmentally friendly adhered-lap seams for more dependable torched or hot-mopped seams. Rising roofing contractor insurance premiums for torched application add their pressure to this trend.

While roof materials and systems have changed, the tide of low-slope roof construction rolls serenely on. Roughly \$19 billion is spent annually constructing (and reconstructing) low-slope roof systems in the United States, according to the National Roofing Contractors Association (NRCA). In area, this vast volume would cover Washington, D.C., more than twice. Low-slope



roof systems retain their popularity despite several decades of rampant litigation over roof failures. According to some estimates, the number of lawsuits involving low-slope roof systems equals (or exceeds) the total number of lawsuits filed over all other building systems combined. Regardless of whether this estimate is strictly accurate, it conveys an incontrovertible fact: No other building system can approach the roof system as a source of litigation.

Yet, despite their many recurring problems, low-slope roofs maintain their predominance. Steeply sloped roofs on the large, sprawling buildings that dominate today's construction would drastically cut the costs of reroofing, repair, and litigation for problem-prone low-slope roofs. But they would raise construction costs by a far greater amount through the costs for additional building volume. Low-sloped roofs will maintain their predominance in commercial roofing for a simple economic reason: The costs of steeply sloped roofs over the vast acreages covered by shopping centers and other modern buildings are simply too high a price to pay to avoid the problems posed by low-slope roof systems. Roofing a single-story, 200-ft-wide building with 100-ft-span trusses sloped 25 percent (i.e., 3 in 12) would increase building volume by roughly 40 percent.\*

## Why Roofs Fail

Premature roofing failures are caused by both economic and technical factors. Economically, a building's roof system normally lags far behind the more architecturally glamorous building subsystems competing for the building owner's money. Pennywise, dollar-foolish decisions underlie many premature roofing failures: Whether through ignorance, laxity, or sheer perversity, many roof designers and building owners refuse to pay the slight additional cost for sloping the roof to avoid the ponding of rainwater (see Fig. 1.1).

Technically, the factors contributing to premature roof failures can be listed as follows:

- The extraordinary rigors of roof-performance requirements
- Proliferation of new materials
- Complexity of roof-system design
- Expanding roof dimensions
- Field-application problems
- The modern trend toward more flexible buildings

Roofs must withstand a much broader attack from natural forces than other building components. In some parts of the continental United States, roof surfaces experience annual temperature changes exceeding 200°F and daily changes

---

\*If the building were 15 ft high, the additional space required for the 25 percent slope would increase building volume by  $2 \times \frac{1}{2} (12.5 \times 100) / (15 \times 200) = 42$  percent.