# PERSPECTIVES OF U.S. LOW-SLOPE ROOF RESEARCH CAPABILITY AND ENERGY SAVINGS POTENTIAL

**HERBERT BUSCHING**
Clemson University
Clemson, S.C.

**GEORGE COURVILLE**
Oak Ridge National Laboratory
Oak Ridge, Tenn.

**TE-CHUAN CHANG**
University of California, Berkeley
Berkeley, Calif.

**JOEL P. PORCHER, JR.**
Rettew Engineering Co., Greenville, S.C.

Increased emphasis on energy conservation and high energy costs make the thermal envelope of buildings a vital concern. For many low-rise buildings, the low-slope roof constitutes a major portion of the above-ground thermal envelope and therefore presents a significant opportunity for energy conservation. Unfortunately, problems with roofing account for approximately 50 percent of construction-related litigation. It is therefore apparent that additional research and education resulting in improved roof system performance and durability can yield major energy and cost savings.

This presentation reviews results of two study projects that were directed at identifying the United States' roofing research capability and the potential for U.S. energy savings that might be realized through roofing. Information was obtained from bibliographic searches, from personal interviews, and from numerous telephone conversations.

## ROOFING INDUSTRY MODEL

A large number of companies offer a wide variety of roofing products and services. For example, the February 1984 issue of NRCA's *Commercial, Industrial and Institutional Roofing Materials Guide* listed a total of 186 different products under seven major types of single-ply membranes. Hundreds of other deck, insulation, membrane, and fastener products augment this list.

Of the many groups that deal with roof industry issues, the following are especially important within the abbreviated categories noted:

**Tests and Specifications Groups** The American Society for Testing and Materials (ASTM), American National Standards Institute (ANSI).

**Trade Associations** National Roofing Contractors Association (NRCA) (with National Roofing Legal Resource Center and National Roofing Foundation), Asphalt Roofing Manufacturers Association (ARMA), Single Ply Roofing Institute (SPRI), Thermal Insulation Manufacturers Association (TIMA).

**Codes and Standards Groups** Building Official and Code Administrators International (BOCA); International Conference of Building Officials (ICBO); Southern Building Code Congress, International (SBCC).

**Insurance Groups** Factory Mutual (FM), Underwriters Laboratories (UL).

**Educational Groups and Information Sources** Roofing Industry Educational Institute (RIEI), NRCA publications and periodicals such as *Roofing Spec* and *Roofing, Siding, Insulation,* and the Architecture and Engineering Performance Information Center (AEPIC).

**Professional Organizations** Professional societies with special emphasis on roofing include Roofing Consultants Institute (RCI), and the Institute of Roofing and Waterproofing Consultants (IRWC). Other associations include AIA, ASCE, ASME, CSI, and ASHRAE.

**Government Agencies** National Bureau of Standards (NBS), Oak Ridge National Laboratory (ORNL), National Institute of Building Sciences' (government and private sector) Building Thermal Envelope Coordinating Council (BTECC), U.S. military service laboratories such as CERL, CRREL, NCEL.

Several descriptive models of the relationships among various manufacturers, designers, contractors and other associations and groups have been developed.[1] Two important examples of these models, one showing the principal relationships in roofing design, and one showing the dissemination of roofing information to the designer, are shown in Figures 1 and 2.

## RESEARCH PARTICIPANTS, FUNDING, AND METHODS

The principal participants in the roofing design and construction process are depicted in Figure 3. Only a few of these participants are involved with open, generic research. Most research is conducted by manufacturers and government agencies (which constitute some of the larger roofing owners). Other participants in the process are often individuals or small firms that do not have the resources needed to conduct research.

An analysis of the content of open literature on roofing from proceedings of major roofing conferences was undertaken to identify who actually does contribute to research.[1] Altogether, 237 articles were reviewed from 13 proceedings dating from 1966 to 1983.[2-14] These proceedings were concerned exclusively with low-slope roofing, or at least contained several articles on low-slope roofing. The number of such articles in the open literature has increased rapidly during the last decade. The articles were organized under the following categories: basic and applied research, current practice or information; survey of performance; development of new test procedures; development of new specifications; and development of new materials.

The composition of 92 U.S. and 145 foreign-authored articles is shown by research category in Table 1, where principal (first-listed) author affiliations are identified as nearly as possible. Some author identification is masked because, for example, consultants often represent owners, and government agencies are often owners of roofs as well. Furthermore, research conducted and published by consultants and educational institutions is usually sponsored by manufacturers, trade associations, or government agencies.

Ninety-three (31 percent) of 298 manufacturers representing a total of 17 different roofing product classifications were identified through the 1984 NRCA Trade Show (Atlanta) and were contacted to learn more about the roofing research budgets of manufacturers. Research budget information was also obtained for government agencies from the Tri-Services Interagency Roofing Research Coordinating Committee.

Acquisition of product information through research and testing is time-consuming and expensive. However, failure to acquire such information may incur greater costs if litigation results from improperly designed or applied materials. The roofing industry sponsors a very large research program through individual companies. However, much research presently undertaken by the industrial sector is directed toward proprietary study that supports new product development, product improvement, and roofing component and system evaluation. And the results of most industry research are not published in the open literature, but usually included instead in technical bulletins and sales literature. Of course, manufacturers' profits often depend on maintenance of a technological lead over competitors, and keeping information proprietary helps protect a manufacturer's competitive status in the market.

Eighty-five percent of the 93 firms contacted indicated that they conducted research and nearly an equal percentage indicated that their firms owned research equipment. Thirty-seven percent of the 93 manufacturers provided budgetary information, although only nine of these provided specific quantitative data. Figure 4 summarizes the responses by manufacturers to requests for information about research budgets. Nevertheless, a total of approximately $11 million annually for roofing research was reported by approximately 10 percent of the respondents. This amount would be larger, of course, if complete data were available. Estimates by industry members indicated that the total would be nearer to $50-60 million, expended annually on roofing research by U.S. industry.

Government agencies have extensive interest in roofing performance and have formulated well-defined roofing research plans and specific projects for both research and education. More than 50 project proposals were identified through a review of research program plans identified by the Tri-Services Interagency Roofing Research Coordinating Committee, the National Bureau of Standards, and Oak Ridge National Laboratory. Of course, only a portion of these projects (less than $2 million) is actually funded annually. Government-based plans for roofing research projects include training and education, roof maintenance and management, and roof inspection.

Roofing research, excluding that devoted to product development and manufacturing process improvement, may be grouped into five classifications.

These include: mathematical analysis, component testing, compact roof testing, prototype testing, and performance surveys. Table 2 lists advantages and limitations of each of these methods of research.

## RESEARCH NEEDS

Needs for additional roofing research have been identified from government agency program plans and from preliminary discussions of the Building Thermal Envelope Coordinating Council's Committee on Roofing Design and Construction. These needs include: durability testing and examination of durability's relationship to accelerated weathering; performance and baseline data; system data and component data; computer modeling and validation; residual service life prediction; long-lived roof transducers; quality assurance/quality control guidelines; wind dynamics on single-ply roofing; insurance claims; and thermal performance.

## OPERATING ENERGY SAVINGS POTENTIAL

In general, buildings are designed for an average life of at least 50 years, whereas the service life of most roofs is considerably less. Increased energy expenses incurred by building owners since the oil embargo of 1973 have motivated close examination of the roof as a building element that may be altered, through renewal or increased insulation, to save energy and thereby reduce operating costs. Approximately half of the total building energy in the United States is consumed in space heating and cooling.

The total quantity of energy now lost through low-slope roofs should be established quantitatively through regional study. No national building inventory for the United States currently exists. However, it has been estimated[15] that the total low-slope roof area in the United States consists of about 33 billion square feet (1,200 sq. mi.). If the area of low-slope roofing is proportional to the U.S. population and is distributed geographically as the population is distributed, then, based on 1980 U.S. Census data, the population and low-slope roof areas in the 10 U.S. federal regions are as shown in Table 3. These data have been used to make estimates of the range of energy savings that may be affected through improvements in thermal insulation values of roofs and in extension of roof life. Estimates of heat losses and gains through low-slope roofs have been made based on heating degree-days, cooling degree-days, and solar radiation intensity for each weather zone in the 10 U.S. federal regions shown in Figure 5[15].

Naturally, the exact quantity of energy transferred through low-slope roofs depends on convection, thermal mass, thermal transmittance, surface absorption coefficients, and other factors. Annual heat losses through roofs for each weather zone have been estimated for various thermal transmittance ($U = 0.04$ to $0.20$, Btu/hr ft$^2$ F) and for two roof absorption coefficients ($a = 0.3$ and $0.8$). Heat gains were estimated similarly. A summary of some of these heat gains and losses is given in Table 4. For example, if roofs are improved from a U-value of 0.20 to 0.04 (R-5 to R-25), then the savings in heat loss will be the equivalent of 70.6 million barrels of No. 2 oil per year and the savings in heat gain will be 54.3 million barrels of No. 2 oil per year (one 42-gallon barrel of No. 2 oil = 5,838,000 Btu). These savings are *operational* energy savings. Net energy savings can be computed by subtracting *embodied* energy (i.e. energy expended in extracting, manufacturing, transporting, assembling, roofing materials) from operational energy savings.

## EMBODIED ENERGY ESTIMATES FOR SOME COMMON ROOFING MATERIALS

Embodied energy estimates for roofing membranes, thermal insulation and roof deck materials may be approximated using tabulated values available in a few references[15,16]. Data regarding the embodied energy of many roofing materials are sparse, especially for new, single-ply membrane materials. An example of the embodied energy contained in a typical steel deck roofing system is presented here as an illustration. The example roofing system used *(Table 5)* consists of a ¾-inch gravel covering, a three-ply bituminous built-up roofing membrane, two layers of 2¼-inch fiber glass insulation and a 20-gauge corrugated steel deck.

The energy payback period (as opposed to the economic payback period) for a new or retrofitted roof may be computed by dividing the embodied energy expenditure by the total savings in annual heat loss and heat gain.

Compare this example of a roof system with an R-value = 20.68 (U = .048) and embodied energy of 277,180 Btu/sq. ft. with a system that consists of the same components, except for use of a single ¾-inch layer of fiber glass insulation and an R-value of 5.28 and embodied energy of 181,900 Btu/sq. ft. If the two systems are located in a cold weather area with 6,000 heating degree-days, 3,100 cooling degree-hours, and 350 langleys mean solar radiation (e.g. Chicago area) and the roof has an absorption coefficient of 0.8, then, the annual heat losses of the R = 20.68 roof and the R = 5.28 roof can be estimated as 4,600 Btu/sq. ft. and 18,900 Btu/sq. ft., respectively. Likewise, the annual heat gains for these two systems can be estimated as 1,300 Btu/sq. ft. and 9,800 Btu/sq. ft., respectively. Comparisons of embodied energies and operating energies shown for the two systems *(Table 6)* can be used to evaluate the total annual heat gains and losses through the two systems and the payback period.

The estimate of a 4.2 year energy payback period is based on consistent performance of all components. If the R-value of insulation is reduced by aging or wetting, then additional time will be required to recover the investment of embodied energy.

Thus, it is apparent that potential for energy conservation is significant if the entire national inventory of low-slope roofs were considered. If just one Btu/sq. ft. were conserved through each of the nation's approximately 33 billion square feet of low-slope roofing, the savings would amount to an energy equivalent of 1.9+ million pounds of No. 2 fuel oil (equal to 5,653 barrels of 237,426 gallons of No. 2 fuel oil).

## CONCLUSIONS

Roofing research expenditures by manufacturers are much greater than expenditures by government agencies and other roofing-related groups. However, numbers of research reports in the open literature are nearly equally authored by government agencies and by manufacturers. The technical literature in roofing is relatively recent and has obviously been stimulated by major roofing conferences during the past 10 years.

The quantity of energy that is transferred through low-slope roofs is large, although the precise amount is difficult to measure. The quantity of operating energy that potentially can be saved by increasing roof insulation in the U.S. may be in the range of 3 to 15 gallons of No. 2 fuel oil per capita annually. In addition, embodied energy of many roofing materials can be estimated together with energy payback periods. For long-lasting roofs, operating energy expenditures greatly exceed embodied energy expenditures indicating that increased amounts of insulation are generally justifiable.

## REFERENCES


1. Busching, Herbert W. and Porcher, Joel, P., Jr., Roofing Industry Perspective and Research Capability, *Final Report* to Oak Ridge National Laboratory, Oak Ridge, Tenn., March 1985.
2. American Society for Testing and Materials, *STP 409, Engineering Properties of Roofing Systems,* Atlantic City, N.J., July 1966.
3. *International Symposium on Roofs and Roofing,* Society of Chemical Industry, Brighton, England, September 1974.
4. American Society for Testing and Materials, *STP 603, Roofing Systems,* Montreal, Canada, June 1975.
5. *Proceedings of the Symposium on Roofing Technology* NBS-NRCA, Gaithersburg, Md., September 1977.
6. *The First International Conference on the Durability of Building Materials and Components,* Ottawa, Canada, August 1978.
7. *Proceedings, Fifth Conference on Roofing Technology,* NBS-NRCA, Gaithersburg, Md., April 1979.
8. *Proceedings, Sixth Conference on Roofing Technology,* NBS-NRCA, Gaithersburg, Md., May 1981.
9. *Proceedings, Second International Conference on the Durability of Building Materials and Components,* Gaithersburg, Md., September 1981.
10. American Society for Testing and Materials, *ATP 790, Single-Ply Roofing Technology,* Detroit, Mich., 1982.
11. American Society for Testing and Materials, *STP 779, Moisture Migration in Buildings,* Philadelphia, Pa., 1982.
12. *Proceedings, Second International Symposium on Roofs and Roofing,* Society of Chemical Industry, Brighton, England, 1981.
13. *Proceedings, Seventh Conference on Roofing Technology,* NBS-NRCA, Gaithersburg, Md., April 1983.
14. American Society for Testing and Materials, *STP 789, Thermal Insulation, Materials and Systems for Energy Conservation in the '80's,* Philadelphia, Pa., 1983.
15. Chang, Te-Chuan and Busching, Herbert W., Energy Savings Potential of Roofing Research, *ORNL/Sub/82-22293/1,* Oak Ridge, Tenn., December 1983.
16. Stein, R.G., Stein, C., Buckley, M., and Green, M., Handbook of Energy Use for Building Construction, *DOE/CE/20220-1,* U.S. Department of Energy and the Stein Partnership, March 1981.

| Author Affiliation | Contributions per Group | Percentage (Number) of Contributions Domestic | | Foreign | |
|---|---|---|---|---|---|
| Manufacturers | 70 | 36 | (25) | 64 | (45) |
| Government Agencies | 66 | 24 | (16) | 76 | (50) |
| Consultants | 44 | 52 | (23) | 48 | (21) |
| Educational Institutions | 23 | 43 | (10) | 57 | (13) |
| Contractors | 16 | 63 | (10) | 37 | (6) |
| Trade Associations | 17 | 35 | (6) | 65 | (11) |
| Owners | 1 | 100 | (1) | 0 | (1) |
| **Research Category** | | | | | |
| Basic and Applied Research | 81 | 48 | (39) | 52 | (42) |
| Current Practice/Inform. | 86 | 33 | (28) | 67 | (58) |
| Performance Survey | 17 | 47 | (8) | 53 | (9) |
| Developm't New Test Procedures | 21 | 48 | (10) | 52 | (11) |
| Developm't New Specs | 15 | 27 | (4) | 73 | (11) |
| Developm't New Materials | 17 | 18 | (3) | 82 | (14) |

Example: Manufacturers have published 70 articles, 36 percent of which were authored by U.S. manufacturers and 64 percent by foreign manufacturers.

*Table 1 Content analysis of roofing research literature*

| Research Classification | Advantages | Limitations |
|---|---|---|
| MATHEMATICAL ANALYSIS | Relatively inexpensive | Physics must be correctly formulated |
| | Versatile | Material properties must be known |
| | Immediate simulation | Boundary conditions must match field conditions |
| | | Implementation barriers |
| COMPONENT TESTING | Controlled environmental simulation | Similitude uncertain |
| | Relatively inexpensive | System interaction excluded |
| | Efficient evaluation of many components | |
| COMPACT ROOF TESTING | Controlled environment simulation | Similitude uncertain |
| | Synergistic effects included | Industry acceptance |
| PROTOYPE TESTING | Actual installation conditions | Time lag between test and results |
| | Actual field conditions | Cause and effect difficult to assess |
| PERFORMANCE SURVEY | Evaluation of entire industry | Serious defects not included |
| | Appraisal of service performance | Quasi-subjective data |

*Table 2 Summary of research methods*

| | Federal Population | | Low-Slope Roof Area (Million sq ft) | | | |
|---|---|---|---|---|---|---|
| Region | (1000) | (%) | Residential | Industrial | Commercial | Total |
| 1 | 12,348 | 5.48 | 448 | 82 | 1,280 | 1,810 |
| 2 | 24,891 | 11.04 | 903 | 165 | 2,579 | 3,647 |
| 3 | 24,560 | 10.89 | 890 | 162 | 2,545 | 3,597 |
| 4 | 38,879 | 17.25 | 1,410 | 257 | 4,030 | 5,697 |
| 5 | 45,758 | 20.80 | 1,659 | 303 | 4,743 | 6,705 |
| 6 | 25,032 | 11.10 | 907 | 165 | 2,594 | 3,666 |
| 7 | 11,764 | 5.22 | 427 | 78 | 1,220 | 1,725 |
| 8 | 6,951 | 3.08 | 252 | 46 | 720 | 1,018 |
| 9 | 27,196 | 12.06 | 986 | 180 | 2,818 | 3,984 |
| 10 | 8,064 | 3.58 | 293 | 53 | 836 | 1,182 |
| **Total** | **225,443** | **100.00** | **8,175** | **1,491** | **23,365** | **33,031** |

**Notes:** Commercial Roof Area estimated using ORNL Model; 94 percent of non-residential bldgs are commercial and 6 percent are industrial. Commercial and industrial roofs are assumed to be low-slope. Ten percent of residential roof areas are assumed to be low-slope.

*Table 3 Low-slope roof area in the 10 U.S. federal regions (1980)*

| Existing U-Value | Savings in Heat Loss | | Savings in Heat Gain | | Total Savings | Existing R-Value |
|---|---|---|---|---|---|---|
| | BBY | MBY | BBY | MBY | MBY | |
| Absorption Coefficient = 0.8 | | | | | | |
| .20 | 412,008 | 70.6 | 317,096 | 54.3 | 124.9 | 5.00 |
| .16 | 306,681 | 52.5 | 271,152 | 46.4 | 98.8 | 6.25 |
| .12 | 203,218 | 34.8 | 171,494 | 29.4 | 64.2 | 8.33 |
| .08 | 99,236 | 17.0 | 82,748 | 14.2 | 31.2 | 12.50 |
| Absorption Coefficient = 0.3 | | | | | | |
| .20 | 466,609 | 79.7 | 186,080 | 31.9 | 111.6 | 5.00 |
| .16 | 351,350 | 60.2 | 137,192 | 24.5 | 84.7 | 6.25 |
| .12 | 232,751 | 39.9 | 84,472 | 14.5 | 54.4 | 8.33 |
| .08 | 117,695 | 20.2 | 41.003 | 7.0 | 27.2 | 12.50 |

**Note:** One 42-gallon barrel No. 2 oil = 5,838,000 Btu.
BBY = Billion Btu/year; MBY = Million barrels No. 2 oil/year

*Table 4 Potential national energy savings through low-slope roofs improve roof to U = 0.04 (R = 25)*

| Description | R-Value* | Embodied Energy (Btu/sq ft) |
|---|---|---|
| Outside air surface (15 mph wind) | .17 | — |
| 3-ply bituminous built-up roofing | .33 | 68,400 |
| Fiber glass insulation<br>2 layers of 2¼ in. (4.5 lb/sq ft) | 18.18 | 114,300 |
| Steel deck<br>20-gauge galvanized corrugated steel decking (1.81 lb/sq ft) | Negligible | 53,000 |
| 18LHO2 steel joist (13 lb/ft) at 6 ft spacing | Negligible | 34,500 |
| Air space (heat flow up) | .94 | — |
| Gypsum board ceiling (½ in) | .45 | 6,980 |
| Inside air surface (still air) | .61 | - |
| **Total** | **20.68** | **277,180** |

*R-values taken from NRCA Energy Manual, *Good Roofs Save Energy*, 1977, and ASHRAE *Cooling and Heating Load Calculation Manual*, 1979.

*Table 5 Estimates of R-value and embodied energy of typical roofing system with 3-ply bituminous built-up roofing membrane*

| Description | Roofing System R = 20.68(U = 0.048) | Roofing System R = 5.28(U = 0.189) | Remarks |
|---|---|---|---|
| Embodied energy | 277,180 Btu/ft² | 181,900 Btu/ft² | inc. 95,250 |
| Annual heat loss | 4,600 | 18,900 | dec. 14,300 |
| Annual heat gain | 1,300 | 9,800 | dec. 8,500 |
| Total annual heat loss and gain | 5,900 | 28,700 | dec. 22,800 |
| Payback Period | | | 95,250/22,800 = 4.2 years |

*Table 6 Comparisons of embodied and operating energies for two roofs*

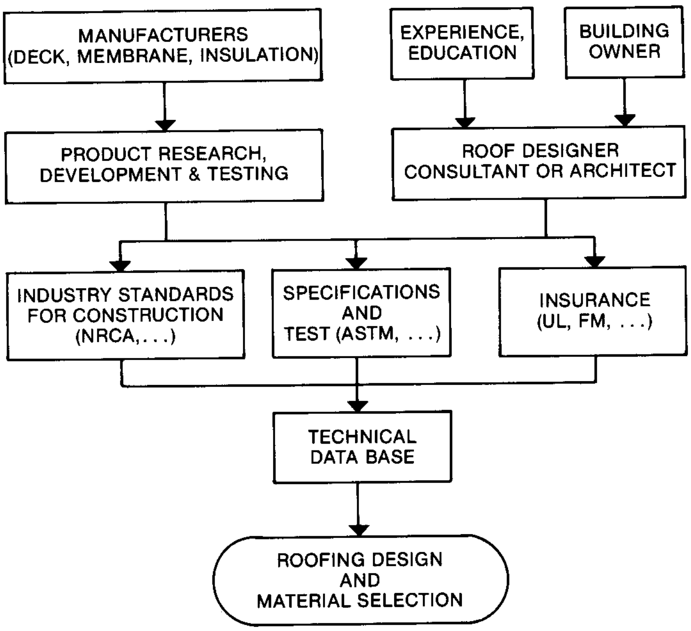


*Figure 1 Principal relationships in roofing design*

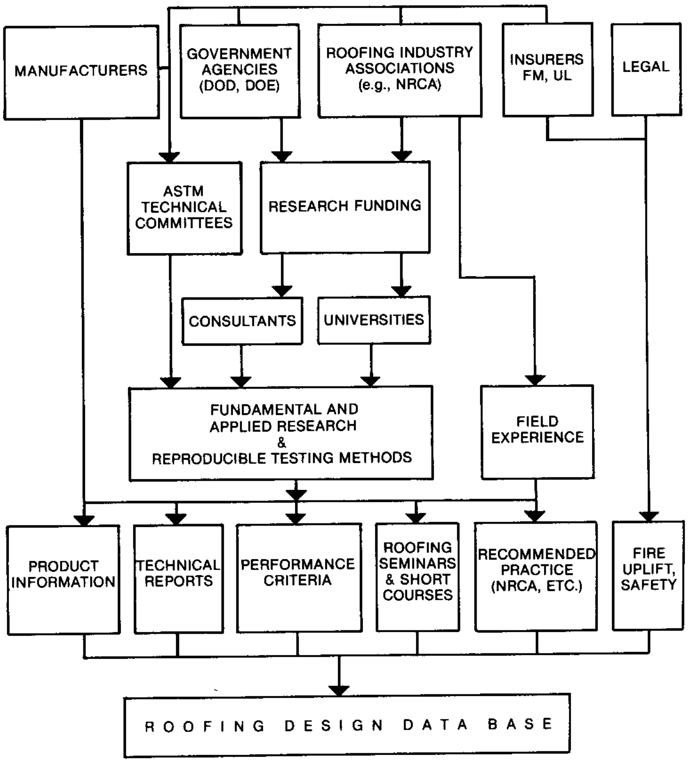


*Figure 2 Dissemination of roofing information to the designer*

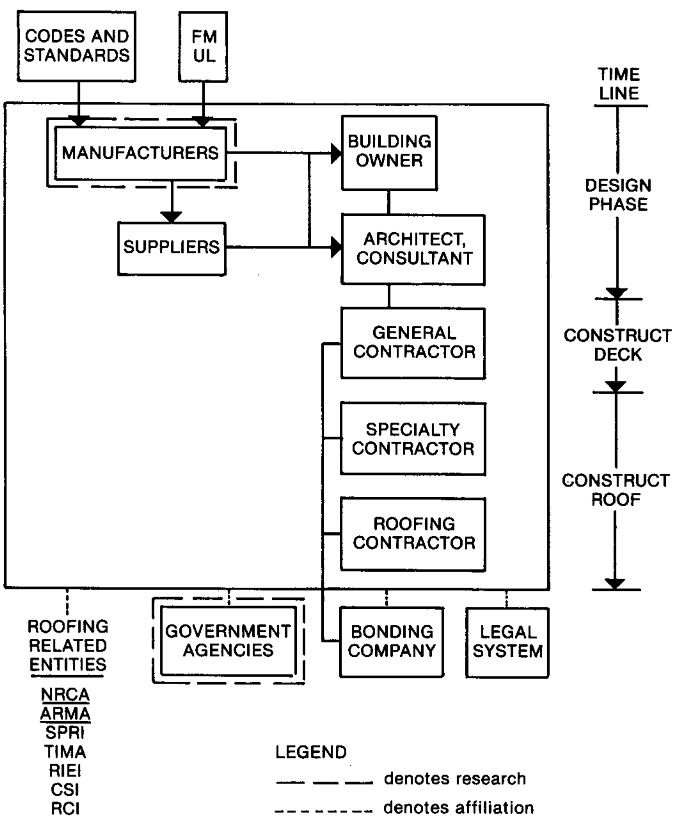


*Figure 3  Principal participants in roofing design and construction*

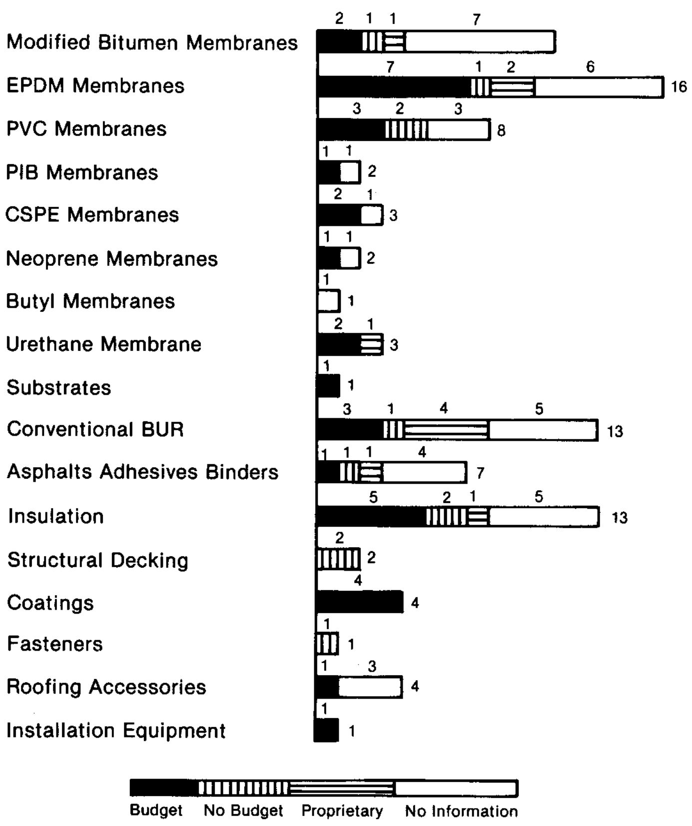


*Figure 4  Types of budgetary information obtained*

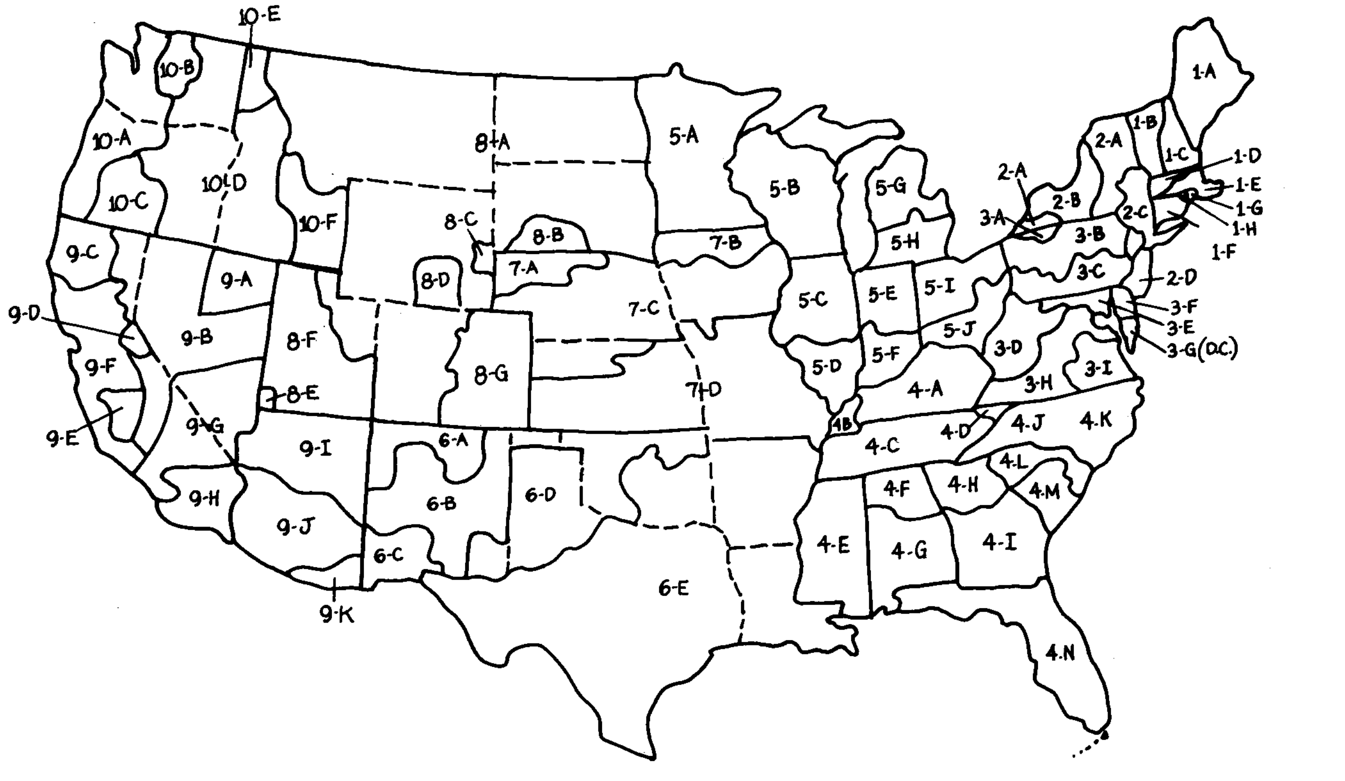

*Figure 5  Weather zones in the ten U.S. federal regions*