FIRE SAFETY
Science and Engineering

T. Z. HARMATHY
editor

STP 882

ASTM

FIRE SAFETY: SCIENCE AND ENGINEERING

A symposium
sponsored by
ASTM Committee E-5
on Fire Standards
and by The Society of
Fire Protection Engineers
Denver, CO, 26–27 June 1984

ASTM SPECIAL TECHNICAL PUBLICATION 882
T. Z. Harmathy, National Research Council
of Canada, editor

ASTM Publication Code Number (PCN)
04-882000-31

1916 Race Street, Philadelphia, PA 19103

Library of Congress Cataloging-in-Publication Data

Fire safety: science and engineering.

(ASTM special technical publication; 882)
"Papers presented at the Symposium on Application of Fire Science to Fire Engineering"—Foreword.
"ASTM publication code number (PCN) 04-882000-31."
Includes bibliographies and index.
1. Fire prevention—Congresses. I. Harmathy, Tibor Z. II. ASTM Committee E-5 on Fire Standards. III. Society of Fire Protection Engineers. IV. Symposium on Application of Fire Science to Fire Engineering (1984: Denver, Colo.). V. Series.
TH9112.F5625 1985 628.9'22 85-20163
ISBN 0-8031-0426-X

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Library of Congress Catalog Card Number: 85-20163

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Printed in Baltimore, MD
December 1985

Foreword

This publication contains papers presented at the Symposium on Application of Fire Science to Fire Engineering, held in Denver, CO, on 26–27 June 1984. Sponsors of the event were ASTM Committee E-5 on Fire Standards and the Society of Fire Protection Engineers. The event was organized by Subcommittee E-5.32 on Research. T. Z. Harmathy of the National Research Council of Canada served as symposium chairman and as the editor of this publication.

The editor wishes to thank all those who contributed to the success of the symposium: members of Task Group No. 9 of ASTM Subcommittee E-5.32 and staff members of the Society of Fire Protection Engineers who helped in organizational matters; the authors of the papers with months or even years of hard work behind their presentations; ASTM staff who provided administrative support and monitored the reviewing of the papers; and, of course, the 72 referees who accepted the thankless but important task of reviewing the papers.

Related ASTM Publications

Fire Resistive Coatings, STP 826 (1983), 04-826000-31

Behavior of Polymeric Materials in Fire, STP 816 (1983), 04-816000-31

Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres, STP 812 (1983), 04-812000-17

Fire Risk Assessment, STP 762 (1982), 04-762000-31

Design of Buildings for Fire Safety, STP 685 (1979), 04-685000-31

Fire Standards and Safety, STP 614 (1976), 04-614000-31

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A Note of Appreciation to Reviewers

The quality of the papers that appear in this publication reflects not only the obvious efforts of the authors but also the unheralded, though essential, work of the reviewers. On behalf of ASTM we acknowledge with appreciation their dedication to high professional standards and their sacrifice of time and effort.

ASTM Committee on Publications

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Introduction

The symposium on which this book was based was the eleventh in a series arranged by Committee E-5 on Fire Standards during the past 25 years. Of the previous ten symposia, four dealt with miscellaneous topics related to fire tests and product performance in fire tests. The other six were devoted to special topics, such as moisture in materials in relation to fire tests, restraint, smoke, ignition, heat release, noncombustibility, design of buildings for fire safety, fire risk assessment, and behavior of polymeric materials in fire.

The Denver symposium differed from the previous symposia in that it looked beyond the problem of testing and product performance. The papers were planned to present a rounded and comprehensive review of the status of fire science and technology.

Some may ask why ASTM should be interested in topics not specifically related to standards and the standards writing process. The answer is that ASTM is a society strongly committed to progress, and progress means searching for solutions not attainable by the application of standard performance tests.

Every test method reflects a level of understanding with respect to the product performance. Experience and the evolution of scientific knowledge are constantly at work to invalidate some existing test methods and to render others superfluous.

In spite of progress, standard fire tests will, for some time to come, yield much of the information needed in fire safety design. It is very important, therefore, that all those involved in the development of test standards be fully aware of the nature and limitations of these standards and be ready to alter or even discard them if science proves them to be inadequate. As fire science probes more deeply into the mechanism of fire phenomena, it comes to light that some of the existing fire test methods were built on precarious foundations. No wonder; they were designed to solve practical problems in an age when those problems were not fully understood.

Unfortunately, altering the test standards is not an easy task. There is usually stiff resistance to any change, partly by the users of the test results and partly by the industry. Having acquired familiarity with the interpretation of the results, the users often find it difficult to adjust to changes reflecting a new level of understanding. And some segments of the industry are also less than enthusiastic. Having tests conducted is a major investment for them in the interests of the marketability of their products, and there is always a chance that the suggested changes in the test standard may lead to a loss of their market share. To minimize the burden that the changes might bring to the users and manufacturers, it is accepted generally that the updating of old test standards should not be so excessive as to invalidate the majority of available test results. Where major changes are required, the most painless route, it would seem, is to discard the old test procedure and either replace it with another less expensive procedure or allow the use of theoretical methods of performance assessment.

Fire science has come of age during the past 30 years. Although it cannot solve all fire safety problems, it can at least give guidance in the updating of old test standards and in the writing of new performance standards.

Task Group No. 2 of Subcomittee E-5.32 has undertaken the responsibility of scrutinizing all existing fire test standards in the light of available knowledge and making suggestions as to their improvement or replacement. Another task group, Task Group No. 7, has developed nine criteria for good performance tests, to be applied to new test methods. Among them are:

1. A test standard must address a well-defined component of the potential for harm.
2. Those tests that are expensive and time-consuming must be sufficiently fundamental, so that their principal features can be described analytically or by numerical follow-up techniques.
3. The set of prescribed test conditions must, even if in an idealized way, simulate those prevailing in real-world fires with overwhelming frequency. If no single set of test conditions can be regarded as overwhelmingly important, the product must be tested for a range of conditions.

Clearly, it is no longer possible to write performance standards without a thorough understanding of product behavior. Of course, the ultimate goal of fire science is to eliminate the need for performance tests, in other words to make it possible for the fire safety features of buildings to be designed on scientific considerations, supported by test data on basic material properties. The advantage of performance tests to yield early solutions without an insight into product behavior wears off with time as basic research catches up with developments. Inevitably, a stage will be reached when it will be more practical to derive solutions to all but a handful of problems directly from basic knowledge rather than from performance tests. Judging from the progress of fire science during the past 30 years, we have good reason to believe that that stage will be reached not too far in the future. The papers presented at the Denver symposium no doubt will contribute significantly to the preparation of the scientific foundations of fire protection engineering.

T. Z. Harmathy

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Harold E. Nelson[1]

The Potential of Scientifically Based Fire Protection Engineering?

REFERENCE: Nelson, H. E., **"The Potential of Scientifically Based Fire Protection Engineering?"** *Fire Safety: Science and Engineering, ASTM STP 882*, T. Z. Harmathy, Ed., American Society for Testing and Materials, Philadelphia, 1985, pp. 3-7.

ABSTRACT: Fire science advances of recent years are now creating a state of knowledge that permits the emergence of a scientifically based fire protection engineering technology. It is proposed that a clear overview of an effective engineering approach is apparent and to at least an initial degree supported by engineering capabilities. A conceptual model of the elements of an analytical method is provided along with a list of references that present procedures for calculating the impact of each element. Test methods need to provide the data required to execute the calculation procedure.

KEY WORDS: engineering, fire safety, fire protection engineering, mathematical methods, technology, technology transfer

I will discuss the inviting potential in fire protection engineering. I am particularly optimistic about the developing capabilities for competent engineering approaches to hazard and risk appraisals. The challenge lies in the need for test methods that analytically measure technically valid fire performance parameters useful in engineering analysis.

I believe that there is an emerging scientifically based fire protection engineering technology awaiting those who will make the effort to acquire it. I also believe that such a technology is critically needed to bridge the communication gap between the science and testing community and the applied world of building regulation, design, and operation.

Historically, at least until the past decade, fire research was largely empirical and much of fire testing was abstract and definable only in terms of the testing apparatus used. While empirical research has resulted in some major impacts on methods that have been applied to fire safety, these impacts have

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been sporadic. Conversely, many test procedures have become dominant forces unto themselves without a base in science.

Three or four decades ago this combination of empirical research, surrogate test values, and validation by experience was sufficient. Most buildings were inherently massive and highly compartmented. Wood and paper were the prime combustibles of concern. The rate of change in building technology was slow, and the cumulative history of how buildings reacted when exposed to fire or other stress was a reasonable prediction of future expectations. Our current system of consensus code and test standards arose in that atmosphere.

The code and its companion standard and test system was designed to address not just fire safety but rather the total scope of public health and safety. Wherever credible technology existed, it was incorporated. But when it was not available, committee consensus judgment was used. In the case of fire safety, technology input has been a minor influence; judgment has been the dominant force. The result is a rigid set of requirements and a regulatory system that has difficulty in accommodating to new materials, new designs, and new expectations on both cost and safety. Until recently it was not the practice of consensus bodies to record their objectives or expectations when setting requirements. Even today only a few bodies, such as ASTM, include any type of commentary as part of their official output. Usually the value and intent of code-type requirements are not apparent.

Virtually every code has an equivalency clause that permits alternative approaches provided equal performance can be achieved. It is, however, difficult to demonstrate the required equivalency when the factors which need to be considered are established by consensus. As a result, the code document rather than its original purpose frequently becomes the objective. Expertise becomes entombed in relating fixed requirements to building materials and systems. Sometimes the ability to test and measure a parameter rather than the importance of that parameter determines the requirement. Under this concept, innovation, rational design, and cost control have frequently been constrained and frustrated.

Over the past several decades, however, a relatively small but fortunately persistant group of research scientists and engineers have labored in laboratories and universities around the world. They have dedicated their efforts to determining the basic principles of unwanted fire, to measuring the variables involved, and (in recent years) to developing coordinated engineering approaches to predict the course of fire, the response of fire safety features, and the resulting impact on people, property, and productive missions. As a result, there is a progressively emerging fire protection engineering technology that can potentially be used to evaluate the fire safety performance of a building or structure that differs widely from the current prescriptions of the code. It will also provide an assessment of the impact of a code requirement as it applies to a specific building or set of circumstances.

With the current state of knowledge and data, it is now possible to make at least a first order quantitative engineering evaluation of fire development and impact from the moment of ignition to the final determination of the results of the fire.

Such an engineering approach can be the basis for individual building analysis or for the appraisal of the generalized requirements for regulatory purposes. Also, by combining engineering technology with a probabilistic evaluation of the liklihood of events and conditions, significant advances can be made in the technology of fire risk analysis.

In order to assemble this emerging technology in a useful fashion, a conceptual model that partitions the problem in a manner responsive to the current available and emerging engineering capabilities is needed. Figure 1 is a diagram of such a model. The model is designed to treat fire as an energy-induced stress on the building and to measure the response of the building and its fire protection systems to that stress. The model also considers the analytical aspects of human response. From an engineering calculation standpoint, the key elements are those in the boxes labeled GROWTH & TRANSPORT, FIRE SAFETY SYSTEMS, and ACTIONS.

Usable analytical calculation methods now exist for each of the elements shown in these boxes. In a number of cases, several established engineering approaches are available. I have selected a series of established procedures

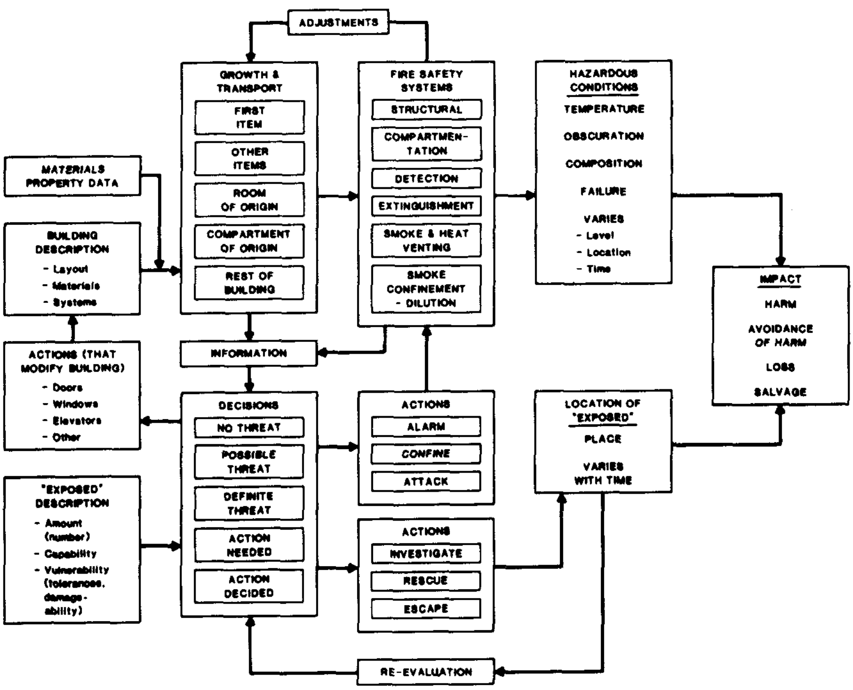

FIG. 1—*Model of elements of an engineering approach.*

that are expressed in terms of level of imposed energy stress, the response of the building and protection systems to that stress, and the resulting impact on environmental conditions in the building. Sources for these procedures are listed in the Bibliography. The listed references are not necessarily the most advanced engineering methodology but are rather those that are available in the open literature to engineers or scientists willing to expend the effort to obtain and use them.

As the new fire protection engineering technology emerges, it produces an increasing demand for data. The type of data needed are measurements of physical values that meet the demands of the calculation systems. The testing community must concentrate on the development of valid reproducible tests of engineering quantities and step away from tests that only rank order or provide measurements in terms of arbitrary values relatable only to the test device involved.

Meeting the dual challenge of improvement of the calculation methods and the provision of the supporting data is the key to moving fire safety from an indefinite to a definite technology.

Fire protection engineering technology is past the embryotic stage but is still a struggling child that continues to require support and encouragement. The development of the underlying science and the production of scientifically based data must continue to nurture this technology.

I am, however, firmly convinced that the maturity of fire protection engineering as a fully useful and credible technology will occur. The pace at which technology replaces subjective judgment is a function of the level of interest, demand, and support given by the fire protection engineering and related research and testing communities. Key to this technology development are the assembly of research into appropriate engineering forms, the production and cataloging of the essential data, and continued emphasis on proof testing and other verification programs.

Acquiring a truly scientifically based fire protection engineering capability will be essential to those who wish to continue in the field of fire protection engineering. Development of scientifically based analytical measurement methods is essential to this. Changes must take place. Past practices have required expenditures for fire safety beyond that appropriate for the level of safety provided.

Finally, I believe that the time of "burn to learn fire research," "test to rank" measurements, and unengineered arbitrary requirements has passed whether or not those of us in the field recognize that fact. We now have made critical advances so that all fire experiments large and small should be preceded by the best engineering predictions and the results used to verify and improve analytical methods.

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Fire Performance Standards for Buildings

REFERENCE: Marchant, E. W., "**Fire Performance Standards for Buildings,**" *Fire Safety: Science and Engineering, ASTM STP 882*, T. Z. Harmathy, Ed., American Society for Testing and Materials, Philadelphia, 1985, pp. 8-20.

ABSTRACT: A building is described as a multifunctional agent of environmental change that has to achieve adequate and acceptable performance so that a safe and comfortable environment will result for any human activity. The 14 aspects of whole building performance are listed and examples of advantageous and disadvantageous interactions are offered. Fire safety performance interacts with all other aspects and is distinguished by not being part of the day-to-day environment. All fire safety problems cannot be solved by the application of conventional elements of fire safety technology, and, therefore, the performance approach to fire safety is important as more flexibility in the selection of solutions becomes possible. The identification of relative values of the components of fire safety is an important problem, and these values change according to building type. Performance profiles and levels of acceptability are discussed. Difficulties associated with the measurement of fire safety performance are discussed, and the selection of appropriate appraisal techniques is emphasized. The control of fire safety standards by governmental officials and private professionals is examined, and mention is made of the possible introduction of self-regulation for continuing fire safety standards in buildings.

KEY WORDS: building, performance, interactions, fire safety, testing, regulations, control

The production of an efficient building depends on the ability of the designer and his consultants to assess clearly the functional or performance requirements that the building will be expected to fulfill. The requirements should be capable of definition as they will reflect the activities to be carried out within the completed building. The building design team interprets and integrates the functional requirements into a building design that is likely to result in a pleasant, comfortable, and safe building.

The need for a building is established easily as very few human activities

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can be pursued outside a building, and a major reason is because the natural environment is not always an acceptable one in which work or leisure tasks can be pursued effectively; a building is definitely required if the general security of an activity is an important subfunction. A building therefore will displace part of the natural environment and replace it with an environment that is cooler or warmer, lighter or darker, safer or more dangerous than the environment that it replaces.

A building is therefore a multifunctional agent of environmental change and acts principally as a modifer of the natural environment. This concept has been discussed by Jokl [*1*], who regarded the environment in which a "subject" (man) exists as the "transfer field" that contained all the agents of environmental change, and who proposed that combinations of agent-flux and agent-intensity produce the environmental stress at a particular instant. Human reaction (the reaction of the subject) to the environmental stress was considered capable of depression as a syndrome—a general state which comprises any number of "symptoms," that is, the manifestation of a general human reaction to a specific stressful agent. For example, the change in physiological and psychological responses which the illumination levels in an environment change beyond the limits of perception at an instant in time would be regarded as a symptom of the change in an environmental agent. An overall expression of "well being" would describe a "syndrome," a combination of reactions that allows man (the central subject) to perceive an acceptable environment.

It can therefore be understood easily that if a building is to produce a satisfactory environment, an analysis must be carried out of the differences between the properties of the natural environment and the desired properties of the environment to be created within a building. Only with a knowledge of these differences and their consequences on "the subject" can the designer progress towards the creation of an acceptable and safe building.

As an aid to the classification of the components of the natural environment and to assess the degree of change needed to achieve an acceptable environment, Berköz [*2*] has proposed a design model for a natural climatization subsystem. The use of this model will help the designer to specify the optimum performance required of the building, as a sequence of barriers, to modify the natural climate so that comfort conditions are achieved. The model, an interactive network similar to those being developed for aspects of fire safety design, contains required performance profiles for the various subcomponents of climate, and the quantitative performance requirement for each climatic subcomponent will vary according to its quantity in the natural environment and the acceptable range of quantitative values for that component in the building space. An example of a climatic subcomponent that affects fire safety directly is the natural wind [*3,4*]. The natural wind can negate all the advantages of a smoke vent system in simple buildings and can reduce the additional safety provided by mechanical smoke control to an unaccepta-

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