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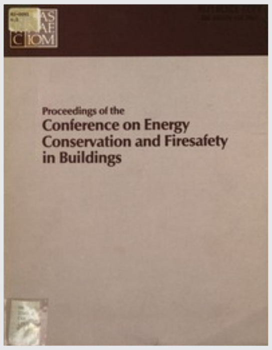

Proceedings of the Conference on Energy Conservation and Firesafety in Buildings

DETAILS

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PROCEEDINGS OF THE CONFERENCE ON ENERGY CONSERVATION AND FIRESAFETY IN BUILDINGS

June 10-11, 1981
Washington, D.C.

Organized by the
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of the
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PREFACE

The Building Futures Council (BFC) functions as one of three standing committees under the Building Research Advisory Board. Its purpose is to provide a mechanism through which the diverse building and construction constituencies are brought together to identify common problems, to ensure that the more critical problems are given priority attention, and to facilitate the dissemination of solutions and other information. In carrying out its activities, the BFC plans and conducts forums, workshops, and other programs and prepares the results for publication. Its members serve on a voluntary basis as individuals and are representative of both the private and the public sectors of the building community.

While this conference on energy conservation and firesafety in buildings was being planned, the issues became increasingly prominent and some rather spectacular and disastrous fires occurred. Thus, the subject remains a very timely one.

Conferences such as this cannot be carried out without sponsors, and we extend thanks to those organizations that supported this program. Appreciation also is extended to the members of the planning committee and its staff as well as to those experts who gave so freely of their time and knowledge by participating in the conference. Through these collective efforts we trust a contribution has been made toward a better awareness and understanding of the issues surrounding energy conservation and firesafety in buildings.

Jack M. Roehm, Chairman
Conference Planning Committee

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INTRODUCTION

Jack M. Roehm
Jack M. Roehm and Associates
Virginia Beach, Virginia

The impetus for this Conference on Energy Conservation and Firesafety in Buildings was the concern that appropriate attention was not being given to the secondary effects of energy-conservation measures on such other aspects of building performance as firesafety. The Building Futures Council (BFC), believing that there was little objective information available based on tests or fire experience related to these issues, appointed a planning committee to organize and conduct a conference designed to examine the need for a technically sound approach to measuring the impact of energy-conserving measures on the design and construction of energy-efficient, economical, and safe buildings.

The conference provided a forum in which issues were raised, problems were identified and current research and experience were reviewed. Although the conference focused on residential and other low-rise buildings, many of the design, construction, and building operation-and-management principles that were discussed apply to high-rise buildings as well. Conferees included both energy-conservation and firesafety specialists as well as other representatives of the building community.

This report presents the proceedings of the two-day conference. Three conference sessions focused on specific areas of concern: defining firesafety problems in relation to energy conservation; interaction of insulating materials with firesafe performance of buildings; and discussion of the perceived problems and potential solutions by those who design, construct, regulate, own, and operate buildings. The fourth session summarized the material presented earlier in the conference.

In these proceedings, the keynote address is followed by the introduction to and presentations made during each session. The conference participants are listed in Appendix A and biographies of the speakers are presented in Appendix B.

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KEYNOTE ADDRESS: ENERGY CONSERVATION AND FIRESAFETY IN BUILDINGS

Paul C. Greiner
Vice President, Customer Relations,
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Edison Electric Institute, Washington, D.C.

As the keynote speaker on the subject of energy conservation and firesafety in buildings, I would like to explore several avenues:

- What is energy conservation? What do people think of it?
- What are they doing about it? What kind of results do we see?
- What about energy conservation and safety? Is there a tie between them? Are we concerned about the safety aspects in design and construction?
- What should we be concerned about at this conference? What ideas can we share?

MEANINGS OF ENERGY CONSERVATION

The necessity for conservation is well established. Some view conservation as a source of energy; some have declared it to be the moral equivalent of war; and many organizations, including engineering societies and utilities, have committed themselves to its cause.

But what is conservation? Consumers view conservation as a way to alleviate the increased cost of energy. Utilities view conservation as a way of saving fuel and capital expenditure. These two views on what conservation means may be in concert or they may be divergent. Energy savings by the consumer do not result automatically in reduced capital expenditures for utilities. Energy conservation, however, can result in capital savings for utilities and their customers. With increased insulation, for example, customers may be able to purchase smaller and less expensive air conditioners while a summer peaking utility might require less capacity to serve those customers with the smaller air conditioners. Some in the federal government believe "the tigher the house and the more insulation, the better." Perhaps most important is that conservation can improve economic efficiency although, more correctly stated, economic efficiency should fuel conservation because the driving force for conservation is economics.

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What have been the major approaches to conservation so far? Some think primarily of the government activities that resulted in a march of regulatory acronyms--RCS, CACS, BEPS, and PURPA* to mention a few. Sometimes these regulatory approaches may seem draconian. They certainly are complicated, expensive, and, as we say in Washington, "a lawyer's delight." The best approach, however, is to allow the free market economy to determine the amount and type of energy conservation we need. The Energy Information Administration's annual report to Congress confirms this; it indicates that energy conservation accomplished to date is largely due to the price sensitivity of energy consumption--not to government regulation.

The free market approach assumes that consumers will act in their own self-interest if given the economic incentive and information on how to accomplish the task. A 1981 National Association of Home Builders (NAHB) survey of home buyers reveals some interesting results that display the interest of the consumer in conservation: When asked what their most important consideration will be when they purchase a home again, 79 percent of the home buyers said more energy efficiency. Those surveyed also indicated that location was most important when they purchased a home in the past, and only 60 percent said they even considered energy efficiency. When questioned about the general energy situation, 7 percent said they considered it serious 5 years ago, 36 percent said they consider it serious now, and 74 percent said they think it will be extremely serious in 5 years. When asked about what they do to conserve energy, 63 percent of those surveyed responded that they lower the thermostat in winter and raise it in summer and 33 percent said they use light bulbs with less wattage.

RESULTS OF ENERGY CONSERVATION

The NAHB survey results are verified by data from the electric utility industry. Examples of the effects of this free market conservation on electricity use since 1973 include the following:

- Growth of electricity use <u>since</u> 1973 has been approximately half of the growth of electricity use prior to the 1973 oil embargo.
- Capacity growth also has changed from 6 percent per year expected to 3 percent actual since 1973.
- Electricity use for nonweather-related uses in households has decreased since 1973 by approximately 25 percent.

*Residential Conservation Service, Commerical and Apartment Conservation Service, Building Energy Performance Standards, and Public Utilities Regulatory Policy Act, respectively.

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FIRESAFETY

If economics has been the driving force in energy conservation, safety will be the motivation for improved building firesafety. Catastrophic fires at the MGM Grand and the Hilton Hotels in Las Vegas, Nevada, and at the Stouffer's Inn in New York, New York, caused a great deal of concern about the equipment needed to protect life and property. There were 84 reported dead in the MGM Grand fire in 1980, and in 1979, 113 firefighters were killed.

The National Fire Data Center reported that in the United States fire kills over 8000 people each year and results in a $13 billion property loss and that the total cost of fire losses exceeds $20 billion. Fire claims more lives and property than all other natural forces combined. Although some may debate the economics of providing firesafety controls and equipment in buildings, I suggest that, with current building practices, we can add these features in a manner compatible with design and economics.

Smoke and fire in buildings represent a major hazard to life and property. Systems for prevention and control are of basic concern to an engineer as are systems installed to protect against other hazards such as building collapse and explosion. The engineers responsible for providing heating, refrigeration, air-conditioning, and ventilation (HVAC) systems and their controls must be involved in the design and construction process if buildings and services that are safe against fire and smoke, structural failure, explosion, and electrical defects are to be produced.

Since 1965 some fires in large structures have resulted in life-threatening hazards despite the fact that the amount of material being burned was surprisingly small. The primary hazard was the development of heavy toxic smoke and gases. Until the past decade, fire itself was claimed to be the cause of most fire fatalities. Now, however, many deaths do not occur on the fire floors (sometimes they happen many floors away), and smoke and toxic gases, not burns, cause 50 percent of fire fatalities. Air-conditioning systems can contribute to the spread of smoke both directly through circulating fans and indirectly as a result of the holes cut in floors and walls and the stack effect through duct shafts when fans are shut down. Therefore, air-conditioning systems should provide not only environmental control but also a positive means of controlling smoke and fire should these hazards develop at any time during the life span of a building.

The time required for total building evacuation may be much too long in many structures. Indeed, a large number of the occupants may be physically unable to evacuate the top areas of some high buildings.

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Recently, increased quantities of highly hazardous materials have been used in buildings as furniture and decorations as well as in construction. These materials, in combination with new construction technology and office planning involving such things as sealed windows, large central air-conditioning systems and large open work areas, may create serious hazards to life in buildings where occupants are restrained or confined. Public awareness that many modern code-conforming buildings are not as safe from fire and smoke as they should be will result in re-examination of the conceptual basis of these codes that unwittingly allow unforeseen hazards to develop.

The complexity and seriousness of fire and smoke problems require concerted action by the entire team responsible for the design and operation of a building, especially the air-conditioning engineer. It is most important that the entire building team meet with the owner early in the conceptual stage of building design to determine the use, operation, occupancy, configuration, and special features of the building. At this time, the building's unique requirements for firesafety and smoke-control must be recognized and resolved. For example, buildings of a similar type may have vastly different firesafety and smoke control problems because of occupancy. Elementary schools, where children must be led or directed to safety, require an approach different from that for a college or high school. Similarly, hospitals or prisons, where occupants are restrained or restricted, must be treated differently from hotels or motels. Enclosed shopping malls with many store fronts on a large, enclosed, environmentally controlled concourse require a special approach.

As already noted, firesafety and smoke-control problems are complex. Basic measures for fire prevention and control and smoke control must be considered. Fire prevention, like preventive medicine, is always more desirable than an after-the-fact cure or extinguishment. Certain aspects of prevention are beyond the influence of the engineer (e.g., human behavior) but should be recognized and treated in context.

The type of prevention and control system needed must be determined. This involves considering five basic factors that represent the most common combinations of problems and requirements in relation to economics:

1. Fire Codes--A careful study should be made to meet all requirements of applicable codes including local codes as well as codes of other regulatory bodies.

2. Local Fire Authorities--During planning stages, local fire authorities should be consulted.

3. Type of Occupancy--Occupants (ambulatory, children, bedridden), material stored or processed, and types of activities are critical factors in detection and alarm.

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4. Physical Considerations--Size and layout, ceiling height, open and confined areas, combustible construction material or contents, and numerous other factors help to determine whether or not the system should be coded.

5. Number of Buildings--In multiple-building complexes, a combination of systems in the individual buildings can be arranged to transmit an identifying alarm to one central station; the individual buildings or the central station also can be connected with the municipal system or private protection agency.

I challenge the participants in this conference to explore the various areas of conservation and possible safety concern starting with the thermal envelope of the building and the various components of the building (i.e., walls, ceilings, floors, fixed windows, and HVAC systems). A great deal of responsible research intended to answer questions about the thermal envelope system currently is under way at such institutions as Brookhaven National Laboratory in Upton, New York, and the Solar Energy Center in Atlanta, Georgia. Various universities and individuals also are experimenting with envelope systems and monitoring existing envelope structures. For example, an envelope building in Simsbury, Connecticut, designed by Richard and Allan Shope, is functioning not only as Shope Architects' office annex but also as a testing laboratory equipped to measure airflow rates, relative humidity, and temperatures throughout the structure. The design of the envelope also must take into consideration the fire and safety controls necessary to achieve adequate protection.

Have we really looked at HVAC systems and the more spohisticated controls we are designing in them? What kind of concern should we have with regard to fire detection, life safety, smoke movement and control, extinguishing action, and communications? With the right goals, the right means and the right attitudes toward energy conservation and firesafety, we can design and build an efficient, safe, and secure future in the built environment.

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Session I
DEFINING FIRESAFETY PROBLEMS IN RELATION TO ENERGY CONSERVATION

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INTRODUCTION

Harold E. Nelson
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The purpose of this first conference session is to define the problem and to provide the proper base for later discussions of possible solutions. The session will focus on three topics: the theoretical or scientific and physical phenomena related to the manner in which energy conservation changes aspects of fire development; historical data and statistical information; and practical field experience.

With this as background, I would like to present a series of figures designed to emphasize that the solution of some single fire-ignition or fire-development problem does not necessarily define the fire problem or, conversely, the fire-protection capability of energy-conservation actions.

Figure 1 is a matrix that simply provides a method for analyzing the impact of energy subsystems on the fire protection performance of a building. Figure 2 illustrates a traditional firesafety decision tree. This tree provides the basis for the matrix; it emphasizes those items that relate to heat and mass balance and energy.

In Figure 3, the items underlined are the headings from the matrix. The subsets beneath them are the next level of decisions that would be involved in an event logic tree. The headings present specific fire-safety methodologies. For example, the first column covers prevention methologies aimed at limiting fuel by limiting the amount; excluding its energy; or controlling such factors as its ignition temperature, its response to energy, its thermal interia, or its exposure.

The left column in Figure 1 presents the energy subsystems, and Figure 4 generally lists the various elements available to anyone designing an energy subsystem, the mechanical engineer or energy specialist. Figure 4 also breaks down the energy subsystems to identify the various elements that are the prime components of the subsystems.

Figure 5 shows how the matrix might be used. For example, across the top, the triangles with lines sloping upwards to the left indicate areas where the control systems inherent in the energy-management system impact on firesafety methodogies. I view these as potential uses

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		FIRE SAFETY METHODOLOGIES								
		PREVENTION		CONTROL						PROTECTION
		FUEL	IGNITION	FLAME SPREAD	RATE OF HEAT RELEASE	TOTAL ENERGY	SUPPRESS FIRE	CONFINE FIRE	CONTROL SMOKE	PROTECT "EXPOSED"
ENERGY SUBSYSTEMS	CONTROL SYSTEMS									
	ENERGY PRODUCTION SYSTEMS									
	ENERGY LOSS-GAIN CONTROL									
	ENERGY STORAGE SYSTEMS									
	ENERGY DISTRIBU-TION SYSTEMS									

FIGURE 1 Matrix for analyzing the impact of energy subsystems on the fire protection performance of a building.

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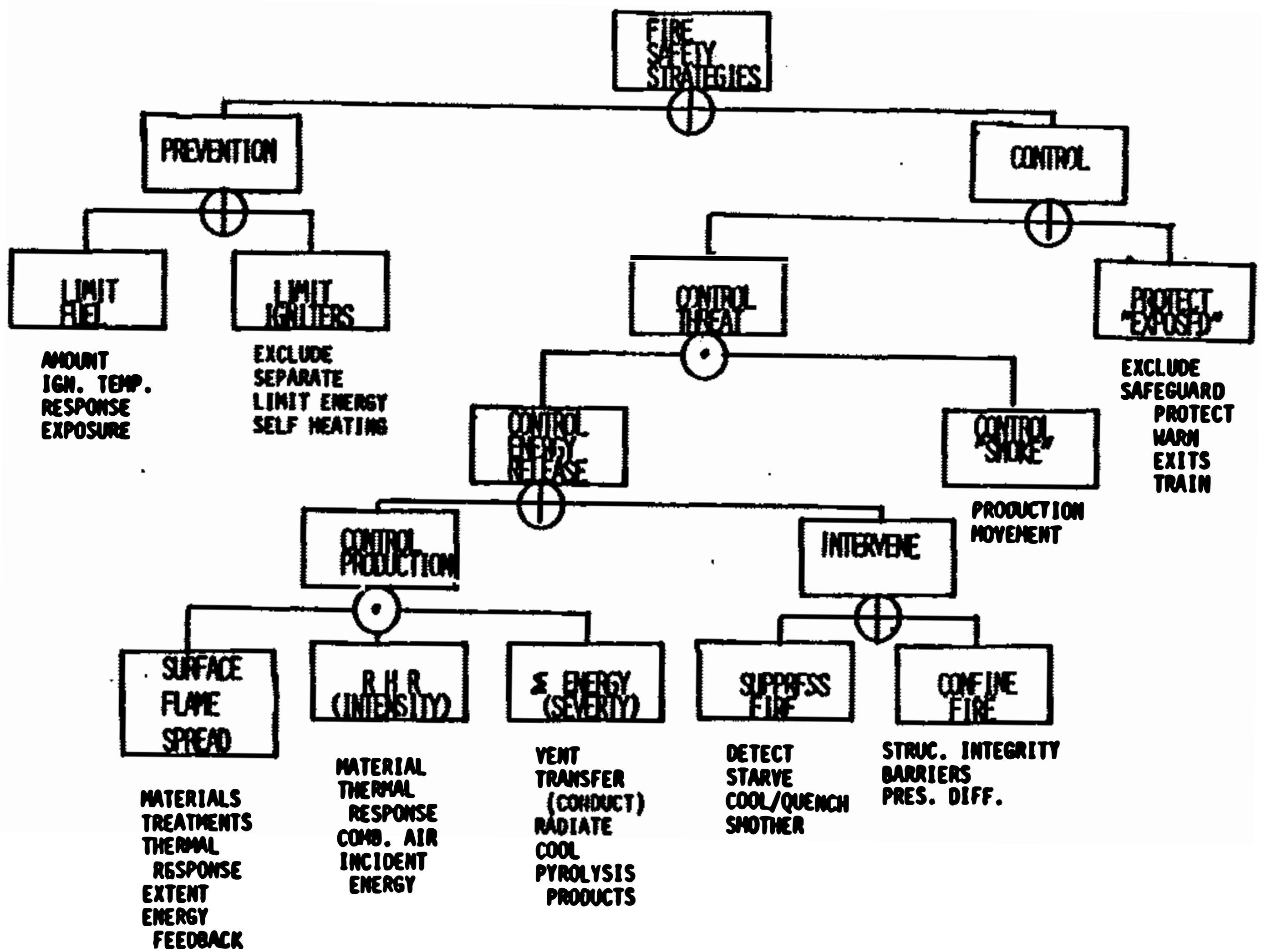

FIGURE 2 Firesafety decision tree.

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PREVENTION		CONTROL						PROTECTION
FUEL	IGNITION SOURCES	FLAME SPREAD	RATE OF HEAT RELEASE	TOTAL ENERGY	SURPRESS FIRE	CONFINE FIRE	CONTROL SMOKE	PROTECT "EXPOSED"
•Prohibit/ Limit •Control Amount •Control Location •Raise Ignition Tempera- ture •Shield	•Prevent/ Exclude •Separate From Fuel •Limit Potential Energy Level •Prevent Self- Heating	•Use Noncombus- tible Materials •Use Fire- Retardent Materials •Control Thermal Response •Limit Combustible Surfaces •Control Radiant Feedback/ Reinforcement	•Use Low RHR Materials •Control Thermal Response of Materials •Control Combustion Air •Control Incident Energy	•Vent •Transfer to Solids •Radiate Out •Convect Pyrolysis Products Out •Cool	•Detect •Starve •Cool/ Quench •Smother	•Maintain Structural Integrity •Provide Barriers -Complete- ness -Structural Resistance -Thermal Resistance •Provide Pressure Differen- tials	•Control Production •Manage Movement -Dilute -Exhaust -Pressurize -Barriers -Buoyancy of Gases	•Limit/ Exclude •Safeguard -Exclude Harmful Effects -Increase Tolerance -Provide Warning -Provide Route -Protect Route -Train/ Educate

FIGURE 3 Firesafety methodologies.

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FIGURE 4 Energy-related building subsystems.

ENERGY RELATED BUILDING SUBSYSTEMS

ENERGY CONTROL SUBSYSTEMS

THERMOSTATS/SENSORS
CONTROL CENTERS
COMPUTERIZED ENERGY MANAGEMENT

ENERGY PRODUCING SYSTEMS

FURNACES/BOILERS
COMPRESSORS/HEAT PUMPS
HEATERS
WOOD BURNING EQUIPMENT
SOLOR COLLECTORS
WINDMILLS & OTHER GENERATORS

ENERGY STORAGE SYSTEMS

HEAT SINKS
FLUIDS (HOT WATER, REFRIGERANTS)
BATTERIES

ENERGY DISTRIBUTION SYSTEMS

DUCTS
OPENINGS (ATRIUMS, SHAFTS, ETC.)
NATURAL CONVECTION
FANS, PUMPS
PIPES
CONDUCTORS, RACEWAYS

ENERGY LOSS-GAIN CONTROL SYSTEMS

BUILDING INSULATION
BUILDING ENVELOPE (TIGHTNESS)
DUCT INSULATION
PIPE INSULATION

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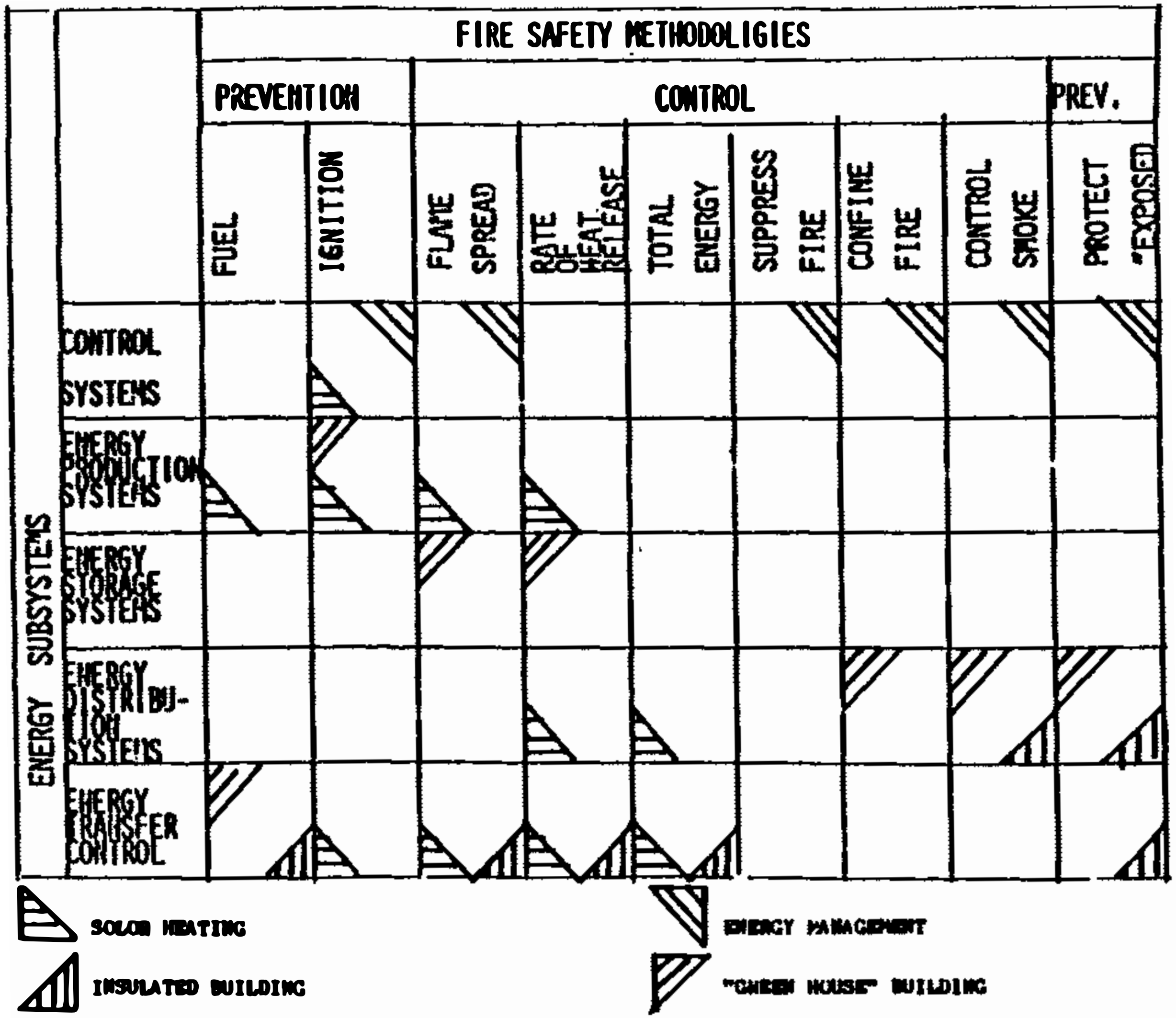

FIGURE 5 Illustration of how the firesafety matrix can be used.

of energy-conservation measures that can aid in such things as preventing ignitions, controlling flame spread, initiating suppression, and confining fire. The triangles with horizontial lines show the use of the matrix to evaluate the firesafety-energy interfaces in an insulated building. The main considerations relate to the impact of insulation on fuel, flame spread, the rate of heat release, the total amount of energy or the severity of a fire, the protection of the exposed, and smoke control. Also indicated in lower rows of the matrix are the considerations related to the energy distribution system (i.e., how it relates to controlling smoke and protecting the exposed). The goal here was only to demonstrate one mechanism for using this matrix.

Figure 6 is a state transition model that emphasizes the fact that fire is a state transition, a multiplying level situation. If you are considering the impact of a firesafety feature or if you are a code authority considering trade-offs, it is important to determine at what state(s) of fire development impacts on the firesafety feature involved will occur. Exposed insulation material may well be most important in the transition to ignition whereas the impact of insulation on fire resistance may become important only when considering full room involvement and compartment failure.

Figure 7 is a reminder that no building was ever built for the purpose of firesafety. Firesafety is a constraint on a building, rather than a purpose, and no energy-conservation program was ever designed for the purpose of firesafety. Anyone seeking energy conservation has many primary and secondary objectives in addition to firesafety. Those who have firesafety as their primary objective will be better able to achieve their goals if they consider all of these impacts, including the total safety impacts and the conservation of energy and resources. This, of course, means considering such things as the national supply of energy, cost control, comfort, production, functional needs, air quality, and whether the computer will run right.

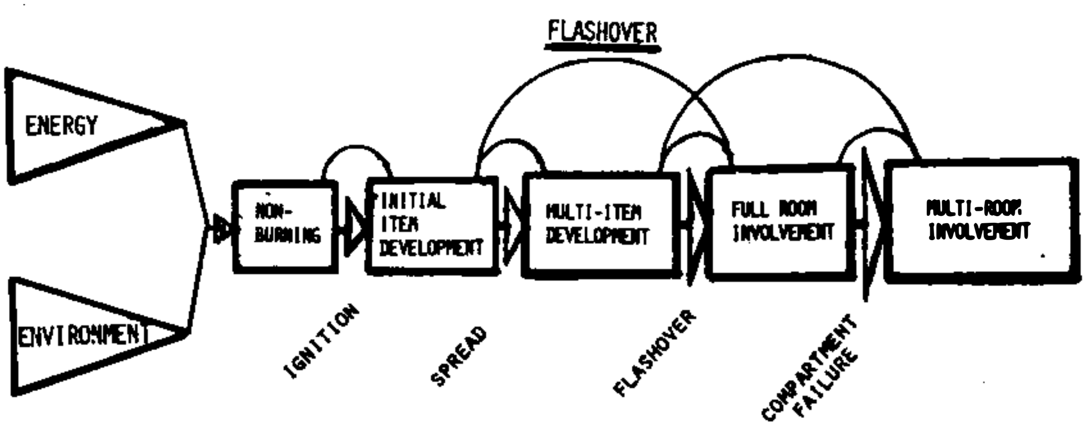

FIGURE 6 State transition model.

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ENERGY RELATED NEEDS AND OBJECTIVES

THE TOTAL EVALUATION OF THE IMPACT OF AN ENERGY MANAGEMENT DESIGN DECISION SHOULD CONSIDER:

A. SAFETY IMPACTS

- FIRE
- ACCIDENT
- HEALTH
- SECURITY
- OTHER EMERGENCIES

B. CONSERVATION OF ENERGY RESOURCES

C. COST CONTROL

- ENERGY COSTS
- INSTALLATION COSTS
- LIFE CYCLE COSTS
- ETC.

D. COMFORT/OPERATIONAL EFFICIENCY

E. PRODUCT/FUNCTIONAL NEEDS

F. AIR QUALITY

- WITHIN BUILDING
- EXTERIOR ENVIRONMENTAL IMPACT

FIGURE 7 **Energy-related needs and objectives.**

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PRESENTATION

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The realization in the early 1970s that the most valuable energy resources of the world would dwindle away in a few decades if their exploitation were to continue at the current rate and the political and economic crises that followed have advanced the issue of energy conservation, long regarded as merely one of economics, into an issue almost synonymous with national survival. In North America, the heating and air conditioning of buildings accounts for roughly one-third of total energy consumption. It is not surprising, therefore, that the energy-efficient operation of buildings, to be achieved either by upgrading existing buildings or using improved technology in the construction of new ones, has an important part to play in a drive for energy conservation. Yet, if applied rashly, such measures could result in undesirable side effects with respect to the health or safety of building occupants. Among these side effects, as discussed by Degenkolb (1978) and Lie (1981), the possible reduction in firesafety is certainly one to be considered. How to reconcile the aspects of energy construction with those of firesafety in buildings is the subject of this presentation.

Energy conservation measures related to the architecture of buildings will be reviewed. Then, starting with a survey of preignition conditions, the various phases of a building fire--ignition and initial fire spread, preflashover fire growth, fully developed fire, and intercompartmental fire spread--as well as the smoke problem that may be associated with any of these phases will be analyzed. Finally, in light of the perception developed, the most common methods of conserving energy will be re-examined in more detail.

ENERGY CONSERVATION IN BUILDINGS

Studies conducted by government agencies and professional organizations in the United States and Canada (American Society for Heating, Regrigerating and Air Conditioning Engineers, Inc. 1975, Housing and Urban Development Association of Canada 1980, National

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Research Council of Canada 1978) have provided guidelines for the design and construction of energy-efficient buildings. The overall aim is to minimize the energy supply needed to maintain, throughout the year, a comfortable temperature level inside buildings by, as a rule, heating during the cool months of the year and, in a major part of the United States and some parts of Canada, cooling during the summer season.

Energy exchange between the building interior and the outside atmosphere is, more often than not, of an adverse kind that works against the maintenance of the comfort level in the interior. Heat exchange by convection (air movement) and conduction through the building envelope are almost always such adverse processes. Convective exchange by air leakage can account for 20 to 40 percent of the total undesirable energy exchange for buildings of average air tightness (Tamura 1975, Tamura and Shaw 1976). Conductive heat exchange amounts, on an average, to 70 percent of the total undesirable energy exchange.

Heat losses by a combined heat-transmission mechanism through windows facing north may be substantial. On the other hand, there is usually a net heat gain by solar radiation in the daytime through windows facing south; this heat gain is beneficial during the winter and adverse during the peak summer season.

Clearly, there are three ways of minimizing the energy demand: (1) decreasing the convective energy exchange with the outside atmosphere by making the building more airtight, (2) decreasing the conductive energy exchange through the envelope by augmenting the thermal resistance of the building envelope, and (3) adjusting (either decreasing or increasing, depending on the circumstances) the radiative energy exchange by the appropriate selection of window areas or by the use of fixed shades.

Making buildings more airtight is always an effective measure for improving energy efficiency, but there are some limits. It is believed that one complete air change every two to three hours is required for health reasons as well as for warding off certain humidity problems. Since a large portion of the undesirable heat exchange usually takes place by conduction through the outside boundaries of the building, increasing the thermal resistance of the building envelope by added or higher quality insulation may be an even more effective way of cutting down on energy consumption. Finally, the regulation of radiative energy exchange between the building interior and the environment can be achieved by the appropriate selection of window areas or the installation of exterior shading devices.

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BUILDING BEFORE OUTBREAK OF FIRE

It has been almost traditional among fire researchers to study various fire-related phenomena as though the fire process takes place in a building space neatly isolated from the rest of the building. Because the temperature and draft conditions characterizing the building at the outset of fire are of vital importance in the course the fire will take, it is not surprising that the results of research studies are sometimes at variance with observations derived from real-world fires.

The distribution of drafts in a building prior to ignition is a profoundly important factor. Their intensity increases with the building height. In order to emphasize the role they may play in the fire process, a multistory building will be discussed here. Naturally, all conclusions will remain applicable, to a lesser extent, to low buildings as well.

Drafts in a building are brought about by two factors: the temperature difference between the building interior and the outside atmosphere and the "air-leakiness" of the various building components. Owing to the former, drafts are, in most parts of the United States and in Canada, especially strong during the winter heating season; for this reason the winter situation will be discussed.

Leakage of building elements results from the presence of channels that usually are not visible (e.g., cracks, gaps, joints, and holes). Since the flow of air through them is analogous to flow through orifices, the aggregate area of these small channels per unit area of the building element often is referred to as "equivalent orifice area."

The intensity and direction of air currents is illustrated in Figure 1a, which shows the situation in a nine-story building on a calm day after shutdown of the air-handling system. (The shutdown is effected by devices installed in compliance with mandatory code regulations.) If the leakage characteristics of the building envelope are uniform with height, the air will infiltrate into the building below its mid-height. Perhaps after passing through one or two partitions, it will enter the "shafts" of the building (e.g., stairwells and elevator shafts), rise to the upper floors, and exfiltrate to the outside atmosphere. (Because of the important role the stack-like shafts play, the phenomenon is often referred to as air movement by "stack effect.") Naturally, strong winds may bring about substantial changes in the intensity and distribution of air currents. Since the equivalent orifice area of outside walls is usually smaller than that of internal partitions, it is a reasonably good approximation to assume that the principal resistance to movement of air is that offered by the building envelope. With this assumption, the total rate of air infiltration can be expressed as follows (McGuire and Tamura 1975):

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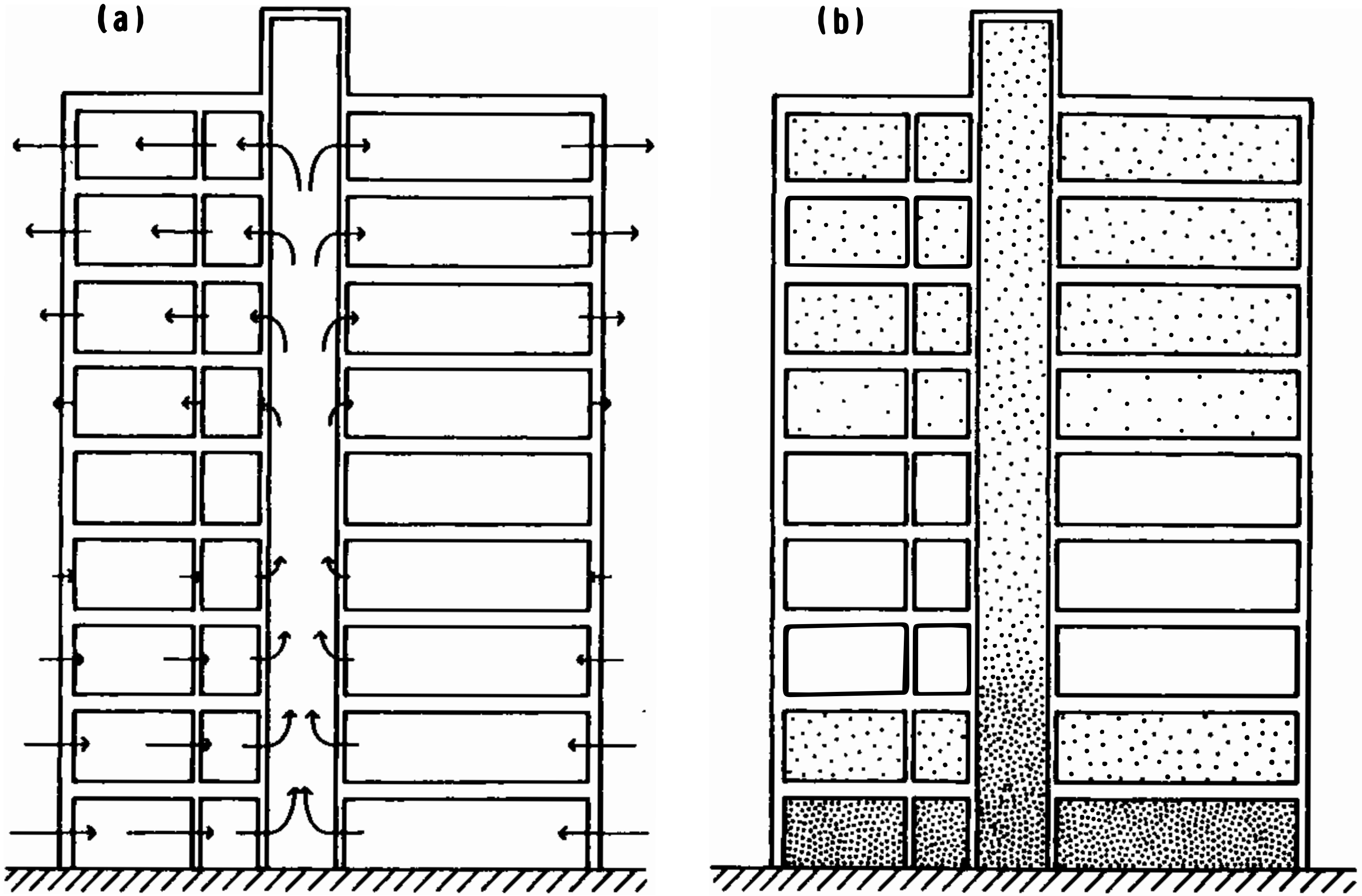

FIGURE 1 **Intensity and direction of air currents.**

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$$V_a = \frac{\beta \alpha_w PC}{3T_a} \sqrt{g\left(1 - \frac{T_a}{T_i}\right) h_B}, \quad (1)$$

where V_a is the mass flow rate of air, β is a constant (orifice factor), α_w is the equivalent orifice area for the outside walls, P is the perimeter of buildings, C is a constant (related to the gas constant), T_a is the (absolute) temperature of the outside atmosphere, T_i is the (absolute) temperature of the building interior, and h_B is the height of the building.

Certain problems related to the dispersion of smoke in a fire-stricken building can be prevented by pressurizing it or a major part of it. The required air supply, W_a, is (McGuire and Tamura 1975):

$$W_a = 2^{3/2} V_a, \quad (2)$$

or roughly three times the rate of infiltration of air into the building under normal conditions.

IGNITION AND INITIAL FIRE SPREAD

Since at least four of every five fires start from relatively small ignition sources (Berl and Halpin 1976), the risk of outbreak in a building is directly related to the extent of use of products not resistant to ignition by small energy sources. Ignition is a very complex problem; the scope of this presentation allows no more than a cursory discussion of the subject. Those who wish to acquire a deeper understanding are advised to read such review articles as those by Fang (1970) and Thomas (1975).

The factors that control the ignition of solids are partly intrinsic to the materials and partly extraneous. Their roles depend a great deal on whether ignition is *piloted* or *spontaneous* (i.e., whether it occurs with or without the aid of a flame, spark, or glowing wire). Much speculation is related to defining the conditions *immediately preceding ignition* in terms of such material-intrinsic factors as the geometry of the solid and the thermophysical and thermochemical properties of the material and its pyrolysis products and such extraneous factors as the nature and total energy of the ignition source and the ambient conditions.

If gaining a fair insight into the material-intrinsic factors of ignition is sufficient, one can achieve that by examining the energy

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balance immediately following ignition. (That the understanding so acquired is not complete is clear from the observation that some fire-retardant-treated plastics that show substantial resistance to ignition burn just as rapidly as their untreated counterparts once ignited (Friedman 1975).) Sustained combustion clearly is possible only if the flame that remains attached to the surface of the solid after removal of the ignition source is capable of evolving energy at a sufficient rate, discounting the energy dispersion to the surroundings, to maintain the surface at the temperature level of pyrolysis and, if the pyrolysis is endothermic, to provide the heat of pyrolysis, the process that feeds the flame with gaseous fuel. Studies indicate that the energy requirement for maintaining the surface at the level of pyrolysis temperature is related to the heat capacity of the solid (the product ρc where ρ is density and c is specific heat) if the solid is thin and to its thermal inertia (the group $\sqrt{k\rho c}$ where k is thermal conductivity) if it is thick.

This simple visualization of the post-ignition energy balance suggests that the most important factors abetting ignition are: (1) high radiant heat output by the flame, which in turn is determined by the size of the flame, by its luminosity, and by the heat of combustion of the gaseous combustion products; (2) low pyrolysis temperature; (3) low (endothermic) heat of pyrolysis; and (4) low heat capacity (for thin materials) or low thermal inertia (for thick materials).

Studies conducted by deRis (1969), Lastrina and co-workers (1971), and Fernandez-Pello (1978) indicate that these are also the principal factors controlling the velocity of spread of flame across the surface of an ignited object in the earliest stage of fire when spread is as yet unaided by heat emitted from neighboring burning objects. One is led to believe, therefore, that products that tend to ignite easily also tend to burn rapidly at the onset of fire.

This rule becomes somewhat clouded, however, when applied to lightweight foam plastics of very low thermal inertia, to materials that melt on heating before reaching the pyrolysis temperature, and to char-forming materials. With foam plastics, the energy of the ignition source and the surface area exposed to the source dictate whether or not ignition will occur. Although the surface temperature of such materials rises quickly to the level of pyrolysis if exposed to even a small energy source, the heat penetration will remain shallow and the production of pyrolysis gases following removal of the ignition source probably will not be sufficient to evolve energy at a rate necessary to keep the process going because of the extremely low density and thermal inertia of the material. If, however, the ignition energy is large enough to produce a sizable initial flame and the energy supply to the surface is perhaps fortified by radiative feedback from nearby objects, the burning will quickly spread over the entire surface of the material.

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Keeping the temperature of the surface of melting materials (of which polyethylene, polypropylene, and polystyrene are prime examples) at the level of pyrolysis may be difficult if their orientation is such that the melt flows away from the sight of the flame. With char-forming materials (of which cellulosics are of principal importance), pyrolysis produces a porous carbonaceous coating on the surface; again dependent on the orientation of the surface, this may be prevented if the departing gaseous pyrolysis products are prevented from coming into contact with air and, thus, from being continuously removed by oxidation. The char layer thus may build up gradually, blocking the radiation from the flame so that it eventually may quell pyrolysis and cut off the fuel supply to the flame.

Even if flaming combustion is stopped, charring material may continue to undergo combustion of a different kind: smoldering. Whereas flaming combustion of charring materials usually consists of three kinds of simultaneous reaction (gas-phase combustion, pyrolysis, and char oxidation), smoldering consists of two kinds only, the consumption of the surface char by oxidation and the renewal of the char zone by pyrolysis driven by the heat produced in the oxidation.* Cellulosic materials of complex surface structure and low thermal inertia (e.g., loose fill cellulosic insulation) are especially prone to smoldering.

The so-called oxygen index method, (American Society for Testing and Materials 1976a, Fenimore and Martin 1966) provides a convenient way of arranging materials according to their propensity for sustaining flaming combustion following ignition by a small-energy pilot flame. Table 1 gives the oxygen indexes for the most common materials used in furnishings and in building construction. Unfortunately, the oxygen index does not reflect the increase or propensity associated with the energy of the ignition source; the nature of the ignition source; and the shape, mass, and surface texture of the material.

PREFLASHOVER FIRE GROWTH

Once a fire has grown beyond its incipient phase, the burning of materials becomes influenced more and more by such extraneous factors as thermal radiation from external sources and oxygen content and velocity of the ambient air. There is, unfortunately, no reliable performance test that can be used to predict the burning characteristics of materials under advanced preflashover conditions. The

*Some authors extend the meaning of smoldering to pyrolysis without flaming under strong radiative fluxes.

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TABLE 1 Oxygen Index for Selected Materials

Material	Oxygen Index[a]
Carbon, porous	55.9
Epoxy, conventional	19.8
Foam rubber	16.0
Neporene	31.0
Polyamide (nylon)	29.0
Polycarbonate	26.0
Polyester (FRP)	18.2
Polyethylene	17.4
Polyisocyanurate foam, rigid	23.9
Polymethyl methacrylate	15.9
Polypropylene	17.4
Polystyrene	18.1
Polystyrene foam	18.8
Polystyrene foam, flame retardant	24.1
Ploytetrafluoroethylene (teflon)	95.0
Polyvinyl chloride	46.6
Polyurethane foam, flexible	16.1
Polyurethane foam, rigid	15.3
Urea formaldehyde	23.8
Wood, white pine	20.9
Wood, sugar maple	21.2
Wood, plywood	19.7

Source: Hilado 1969, Tsuchiya and Sumi 1974.
[a] Oxygen index equals the minimum oxygen concentration, expressed as volume percent, required to support flaming combustion.

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unresolved dilemma of performance tests is that, for the sake of arranging the test results on a unique scale of merit, the tests are conducted under a specified set of conditions that rarely, if ever, coincide satisfactorily with those arising in advanced stages of preflashover fires.

Benjamin (1976) documented, with data borrowed from Castino and co-workers (1975), that for lining materials the sequence of merit with respect to spread of flames, as derived from the most commonly used standard performance test, the tunnel test (American Society for Testing and Materials 1976b), is not necessarily valid under advanced preflashover conditions. This is not surprising if one considers that the rate of flame spread depends rather strongly on external radiation to the burning object (Alvares 1975, Fernandez-Pello 1977, Kashiwagi 1974). Changes in the merit rating due to changed radiation level are consistent with Tewarson and Pion's (1976) finding that different materials respond differently to external radiation.

Concerned mainly with plastic foam insulation, McGuire and co-workers (1980) and McGuire and Campbell (1980) offered an explanation of the well known fact that the merit rating of an insulation board, with respect to flame spread, also may be affected by the nature of the backing material if the fire incident (test or real-world fire) is relatively slow. When the circumstances are such as to cause the flames to propagate relatively slowly, as, for example, in the course of a tunnel test, the heat penetration will reach deep into the backing material so that its presence will be felt directly by a reduction or increase of the temperature of the flaming surface of the board and indirectly by moving the ranking of the product up or down on the scale of merit. In contrast, such a change in the merit rating as a result of the presence of backing material rarely occurs if flame propagation is relatively fast, as, for example, in the course of corner wall tests (Christian and co-workers 1977).

Whether a small fire dies out or grows into a large fire depends on four factors: (1) the rate of heat release by the object first ignited, (2) the total "fire load" (i.e., the total amount of combustible material in the compartment), (3) the nature of the compartment lining materials from the point of view of supporting combustion, and (4) the thermal inertia of the lining materials. If these factors create a condition favorable to unlimited fire growth, flashover will ensue and the entire compartment containing the item first ignited will eventually become involved in fire. Flashover, if it occurs, follows the ignition of the first object usually in 5 to 20 minutes.

The time to flashover is extremely important because it indicates the maximum length of time that occupants have to escape or be rescued. For this reason a thorough understanding of the chain of events connecting ignition of the first item with flashover has become one of the major goals of theoretical and experimental fire research (Croce 1975,

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Croce and Emmons 1974, Emmons 1977, Gross 1974, Modak 1976, Quintiere 1976, Smith and Clark 1975). An excellent review of recent advances in the mathematical modeling of preflashover compartment fire has been given by Pape and Waterman (1979).

The first two of the factors of fire growth (i.e., rate of heat release by the item first ignited and total fire load) relate largely to the nature of the compartment furnishings; they are subject to statistical probabilities and are beyond the control of the building designer. The designer, however, does have at least partial control over the other two factors (i.e., combustibility and the thermal inertia of the compartment boundaries).

As has been pointed out, for some time following ignition the first item ignited will burn in approximately the same way as it would in the open. Then, as the flames grow tall and perhaps other items are ignited, the process of burning becomes more and more influenced by factors characteristic of the compartment as a whole. With increasing rapidity, a smoky layer of combustion and pyrolysis gases builds up below the ceiling. As Figure 2 shows, intense radiant energy fluxes, originating mainly from the hot ceiling and the adjoining gas layer, gradually heat the contents of the compartment until, upon reaching a level of about 1.7 to 2.1 $\cdot$ 10^4 W/m^2 (Fang 1975), all combustible items are ignited in quick succession; flashover occurs.

A few fire scenarios of practical interest were surveyed by Benjamin (1976). He pointed out that combustible wall and ceiling linings may or may not play a substantial part in the chain of events leading to flashover depending on the total fire load, the nature and distribution of the combustible items, and the location and size of the item first ignited. Bruce's experiments (1959) showed that the combustibility of the wall lining had very little effect on the time to flashover if no furnishing item was closer than 0.45 m to the walls.

Further experimental studies have indicated (Gross 1974, Hagglund et al. 1974) that the attainment of a temperature of 500 to 600°C by the hot gas layer under the ceiling (Figure 2) can be regarded as a flashover criterion. Such a criterion is, of course, of little practical utility unless the conditions of attaining that temperature level can be expressed in terms of the fire load and the geometric and thermal characteristics of the compartment boundaries.

Using the rise of temperature of the hot gas layer above a critical level as the flashover criterion, Babrauskas (1980) and McCaffrey and co-workers (1980) developed criteria for assessing the likelihood of the occurrence of flashover in a compartment. The latter workers suggested:

$$\dot{Q}/(\sqrt{k\rho c}\; A_t \Phi)^{1/2} \geq 8100 \tag{3}$$

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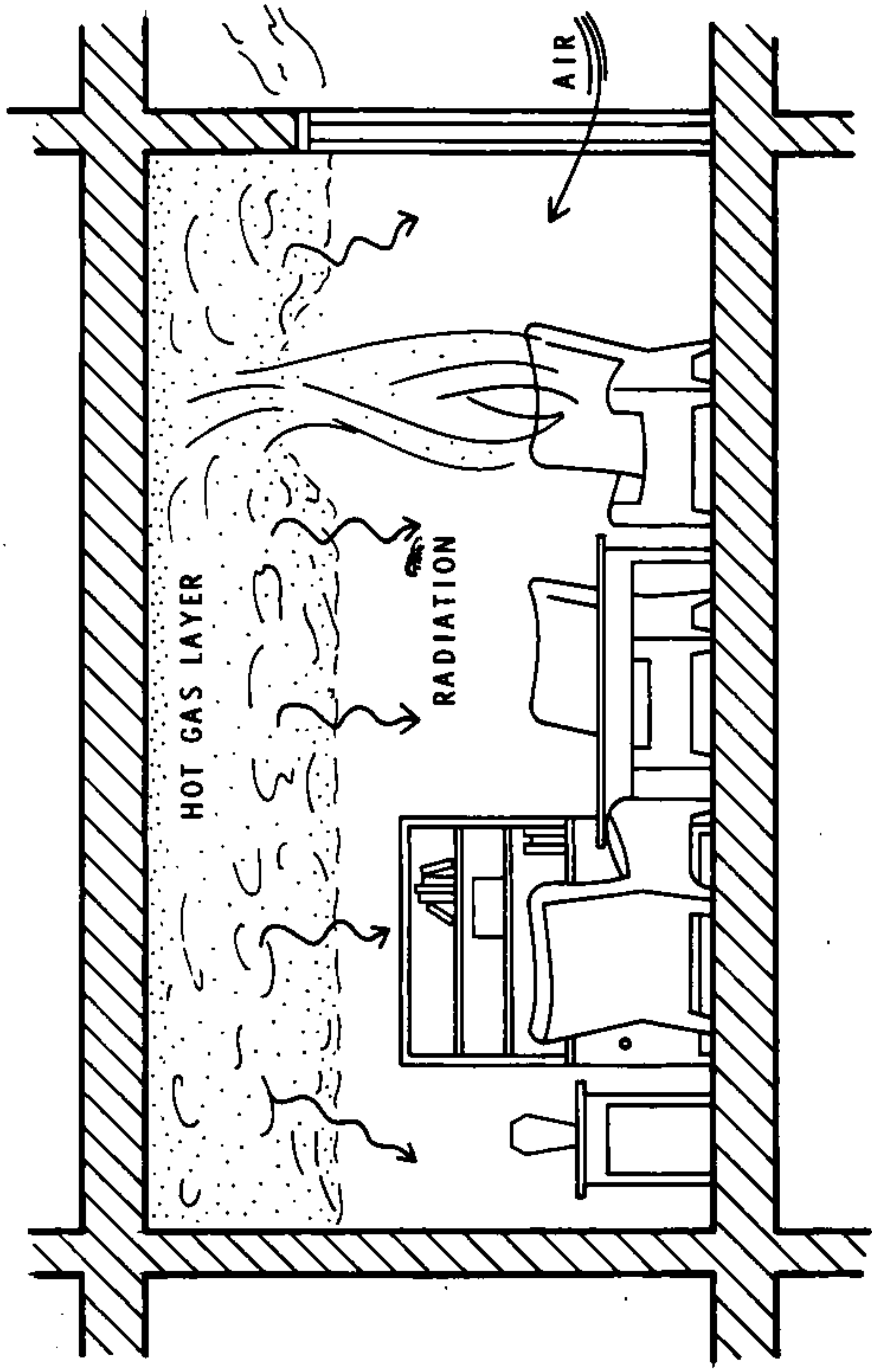

FIGURE 2 Intense radiant energy fluxes.

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where Φ is the so-called ventilation parameter that characterizes the (minimum) rate of airflow into the compartment under classic, draft-free conditions. Its expression is:

$$\Phi = \rho_a A_V \sqrt{g h_V} \tag{4}$$

In these equations, Q is the rate of evolution of heat by the fire, A_t is the total surface area of the compartment boundary, ρ is the density of atmospheric air, A_V is the area and h_V is the height of the ventilation opening, and $\sqrt{k\rho c}$ is the thermal inertia of the compartment lining materials. (Under non-classic, drafty conditions, Φ is to be regarded as a descriptor of the actual airflow rate, which may assume values such that $\Phi \gtrsim \rho_a A_V \sqrt{g h_V}$.)

Eq. (3) allows the estimation of whether or not the burning of a large furnishing item (e.g., a sofa or bed) can lead to flashover. The rate of heat evolution from the burning of such items can be assessed from available data (Quintiere 1976) or from experimental burn tests (Babrauskas 1980).

Of particular interest is the contribution of the thermal inertia of the compartment boundaries, the group $\sqrt{k\rho c}$, to the likelihood of flashover. Typical values for the thermal properties of the many common construction materials are listed in Table 2. Eq. (3) indicates an increased likelihood of flashover for compartments lined with good insulation (i.e., with materials of low thermal inertia).

A theoretical study conducted by Thomas and Bullen (1979a and 1979b) deserves further attention. They showed that the correlation between the time to flashover, t_f, and the thermal inertia of the compartment lining materials is of the following general form:

$$t_f = A + B(\sqrt{k\rho c})^n \tag{5}$$

where the value of the exponent n is always less than 1, typically between 0.25 and 0.5, and A and B are empirical constants. The values of A and B depend strongly on the rate of growth of the fire. For fires growing at more or less normal rates, A is zero. On the other hand, for very fast fires (with exponential rise in growing rate) A may be high enough to control the value of t_f. Eq. (5) indicates, what has indeed been known, that lining a compartment with insulating materials tends to reduce the flashover time except when the fire develops extremely rapidly, in which case the time to flashover is so short that the reduction is hardly noticeable.

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TABLE 2 Representative Values of Thermal Properties of Selected Construction Materials (in moistureless condition) for Appropriate Temperature Intervals

Material	Thermal Conductivity, k ($W\ m^{-1}K^{-1}$)	Density, ($kg\ m^{-3}$)	Specific Heat, c ($J\ kg^{-1}K^{-1}$)	Thermal Inertia ($J\ m^{-2}s^{-1/2}K^{-1}$)
Steel	42.0	7800	530	13177
Marble	2.0	2650	975	2273
Normal weight concrete	1.68	2200	1300	2192
Brick	1.10	2100	1000	1520
Lightweight concrete	0.46	1450	1300	931
Plaster board	0.27	680	3000	742
Vermiculite plaster	0.25	660	2700	667
Wood	0.15	550	2300	436
Mineral wool (fiberfrax)	0.04	160	1150	86
Polyurethane foam	0.02	32	1400	30
Polystyrene foam	0.02	34	980	26

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FULLY DEVELOPED FIRE

Once fire has grown beyond the flashover stage, human survival in the fire compartment becomes impossible. The strategy of defense from this point is aimed at preventing the fire from spreading to other compartments.

It has long been believed that the concept of fire-resistant compartmentation provides the answer to the problem of spread of fire through buildings. This concept pictures a building as composed of a number of compartments perfectly isolated from each other and the fire as spreading by destruction of successive compartment boundaries.

The idea of perfectly isolated compartments is, of course, a crude abstraction. Fire must have access to air; it cannot develop in a fully isolated space. The fire compartment must communicate with at least one other inside or outside space (e.g., through an open door, a broken window, or any kind of ceiling or wall opening). There must be at least one route along which it can spread by convection (i.e., by the advance of flame and hot gases). Thus, defense against the spread of fully developed fire has two components: countering the potential of fire for destructive spread by the use of fire-resistant compartment boundaries and countering its potential for convective spread by such safety measures as self-closing doors, flame deflectors, or fire stops. Observations over the past several decades have clearly indicated that the potential of fire for convective spread far outweighs its potential for destructive spread.

The potential for destructive spread depends (Harmathy 1980a and 1980b) on the "normalized heat load," H, defined as:

$$H = E_s/\sqrt{k\rho c} \tag{6}$$

where E_s is "heat load," the total heat absorbed by unit surface area of the fire compartment during fire exposure, and $\sqrt{k\rho c}$ is again the thermal inertia of the compartment boundaries. An important characteristic of the normalized heat load is that, for a given compartment fire, it has approximately the same value for all boundaries of the compartment (irrespective of possible differences in their thermal inertia) as for the compartment as a whole. The uniformity of the normalized heat load is an expression of the fact that the heat load on any element of the compartment boundary is proportional to its thermal inertia.

The upper limit for the normalized heat load for a compartment on fire can be calculated on the assumption that all heat released by the combustible materials eventually becomes absorbed by the compartment boundaries. With this assumption:

$$H_m = \frac{1}{\sqrt{k\rho c}} \frac{G\Delta H}{A_t} \tag{7}$$

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where H_m is the conceivable maximum for H, G is the total fire load (total mass of combustible materials in the compartment), ΔH is the heat of combustion of the combustible materials, and $\sqrt{k\rho c}$ is the average thermal inertia for the compartment boundaries.

Fortunately, it has been found that the actual heat load on the compartment boundaries is only 10 to 40 percent of the value calculable from Eq. (7). Some of the energy contained in the fire load is released by the gaseous pyrolysis products burning outside the compartment, but even of that released inside some will leave the compartment with the fire gases as sensible heat and some will be lost by radiation through the ventilation opening. Mehaffey and Harmathy (1981) have shown that if the fire load consists predominantly of cellulosic materials, the following semi-empirical equation is applicable:

$$\frac{H}{H_m} = \frac{0.585\delta + 0.085}{1 + 935 \dfrac{\sqrt{G\Phi}}{A_t\sqrt{k\rho c}}} \tag{8}$$

where δ is a factor that accounts for the fact that, in general, only part of the energy of the gaseous pyrolysis products of the combustibles is released inside the compartment. Its value can be calculated from the empirical formula:

$$\delta = \begin{cases} 0.79\sqrt{h_c^3/\Phi} \\ 1 \end{cases}, \text{ whichever is less} \tag{9}$$

where h_c is the height of the compartment. A feature of Eq. (8) is that it describes the fractional fire load on the compartment boundaries as a function of two variables only, the group $\sqrt{G\Phi}/(A_t\sqrt{k\rho c})$ and δ. Figure 3 shows the dependence of H/H_m on the two variables.

As the fire load, G, may vary rather markedly from compartment to compartment, its selection usually is based on an analysis of statistical data available on the specific fire loads, G/A_F (where A_F is floor area), for various occupancies. A conservative estimate of G can be obtained from Lie's arguments (1979).

Because of drafts, which are scarcely avoidable, compartment ventilation is also a random variable. Its minimum value for classic conditions is defined by Eq. (4). For drafty conditions, $\Phi > \rho_a A_v\sqrt{gh_v}$. Since (as can be seen from Eq. (8) and Figure 3) the potential of fire for destructive spread decreases with any increase in the value of Φ, use in Eq. (8) and (9) of the minimum conceivable value of Φ, that defined by Eq. (4), is clearly a practice that cannot lead to unsafe conclusions.

Standard test fires are not basically different from compartment fires; therefore, it is possible to characterize their destructive

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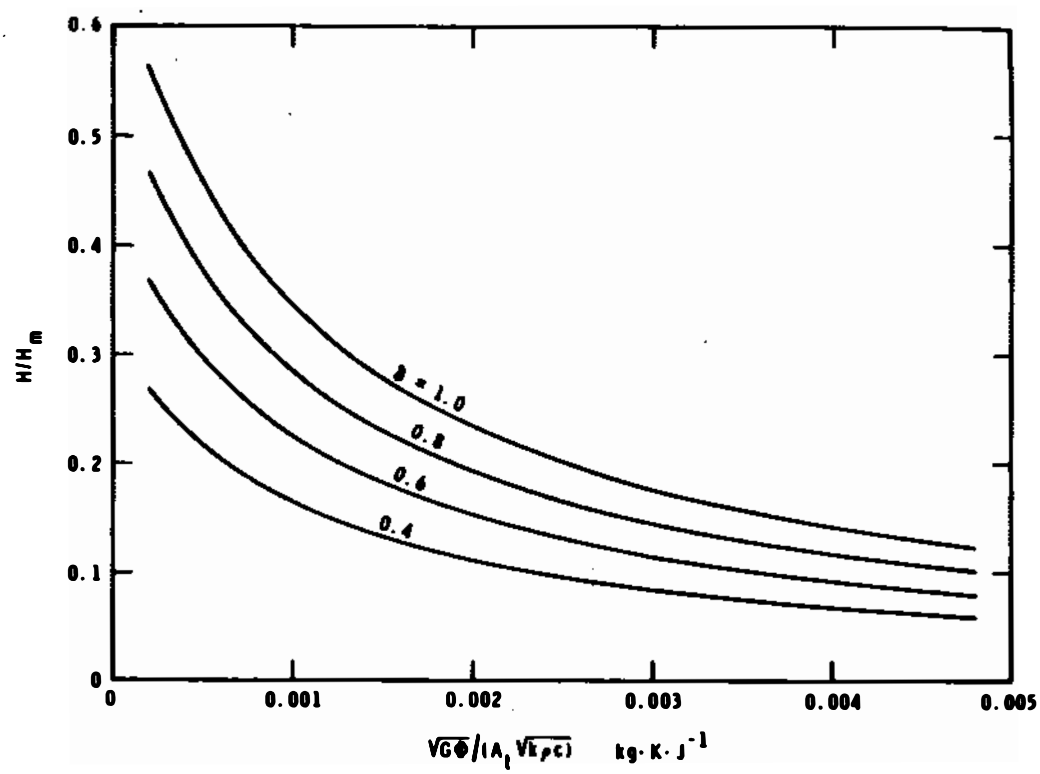

FIGURE 3 Normalized heat load imposed on compartment boundries as a fraction of its hypothetical maximum vaule.

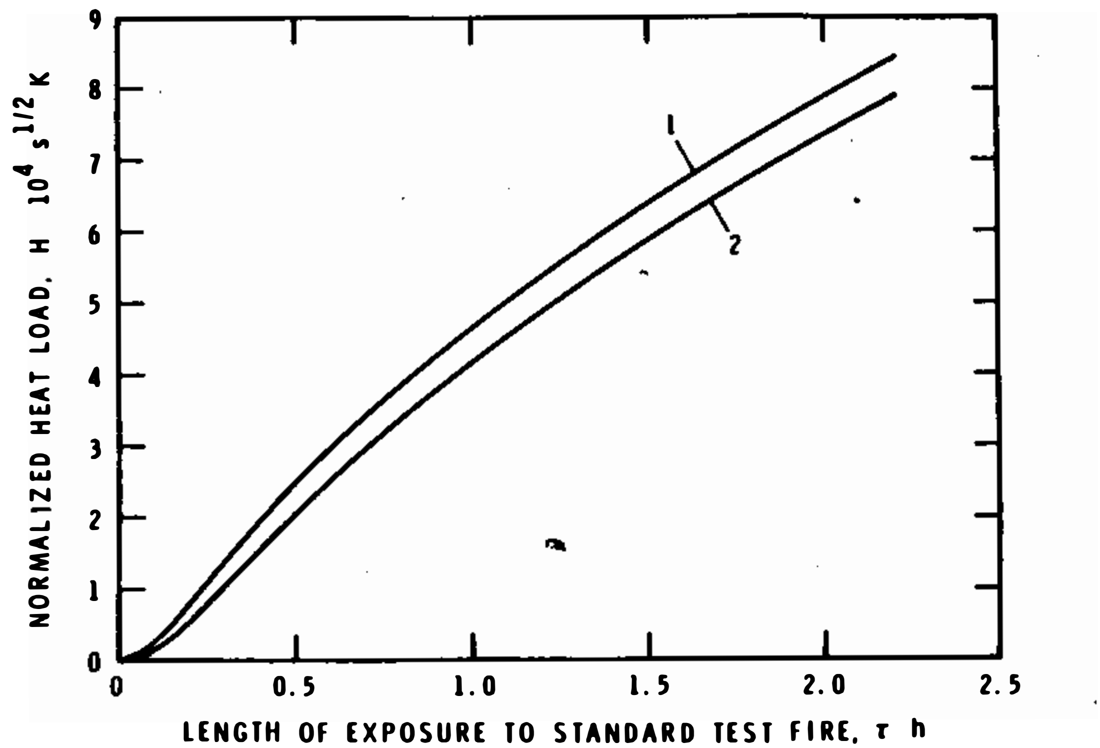

FIGURE 4 Correlations between H and τ for standard fire tests.

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effect on the test specimen also by the normalized heat load, which now, because of the uniqueness of the test, is primarily a function of the duration of the test fire, τ. The normalized value of the heat load imposed on the test specimen has been investigated (Harmathy 1981) using the ASTM E119 fire test (American Society for Testing and Materials 1976c). Curve 1 in Figure 4 shows the relation between normalized heat load and test fire duration for an ideal, high-efficiency furnace heated by highly emissive "black" gases. Curve 2 represents the same relation for an actual furnace, the floor test furnace used at the Division of Building Research, National Research Council of Canada (DBR/NRCC).

To determine the condition under which the boundaries of a compartment can withstand the destructive potential of fire, in terms of time of exposure to standard fire test, enter the value of the normalized heat load on the compartment along the ordinate axis of the H versus τ correlation applicable to the specific test furnace (e.g., curve 2 in Figure 4 for the floor furnace in the DBR/NRCC laboratory) and read the corresponding value of τ, the required testing time, along the abscissa axis.

It has been shown that if the fire load consists predominantly of cellulosics, drafty conditions in a building tend to reduce the potential of fire for destructive spread. It remains to be seen whether this will be applicable to noncellulosic fire loads and whether drafty conditions also will be favorable from the point of view of potential for convective spread, which is usually the greater problem. It is known that some materials, noncharring plastics in particular, have a tendency to pyrolyse very quickly. Unable to come in contact with sufficient amounts of air, part of the uncombusted pyrolysis gases may spill out through the ventilation openings and carry flames to spaces far from the burning compartment. Clearly, materials and burning conditions that are conducive to massive combustion of the gaseous pyrolysis products outside the compartment boundaries present a very grave danger from the point of view of fire spread, irrespective of the support the combustion can get from combustible lining materials in the surrounding spaces.

A factor has been introduced to characterize the convective spread potential of fire (Harmathy 1980b). It is denoted by μ and defined as:

$$\mu = \frac{\text{rate of heat evolution outside fire compartment}}{\text{total rate of heat evolution from fire load}}. \tag{10}$$

To gain a thorough understanding of all aspects of fire spread, the potential of fires for both destructive spread, as quantified by the normalized heat load, and convective spread, as quantified by the μ-factor, were studied in two series of computations as functions of fire load and ventilation. The calculations were performed as

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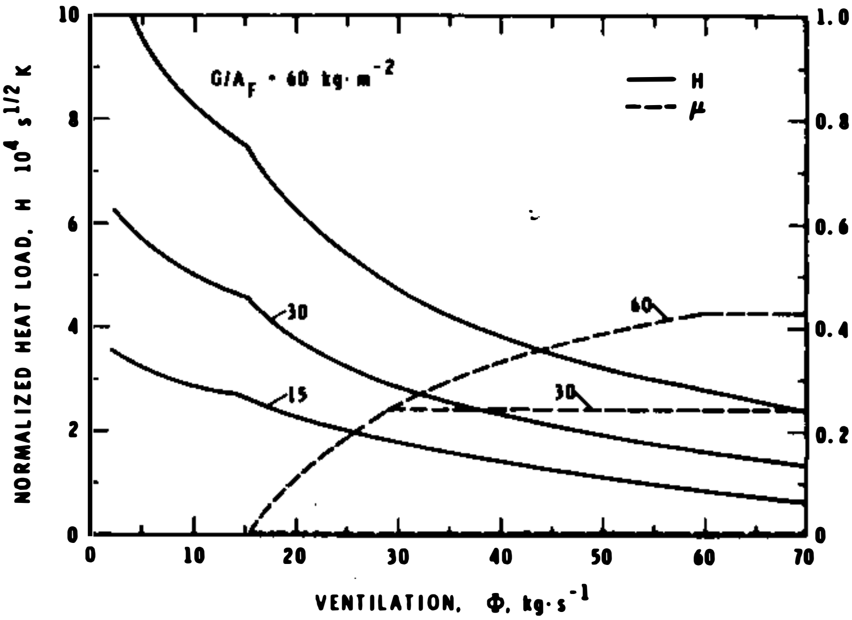

FIGURE 5 Cellulosic fire load.

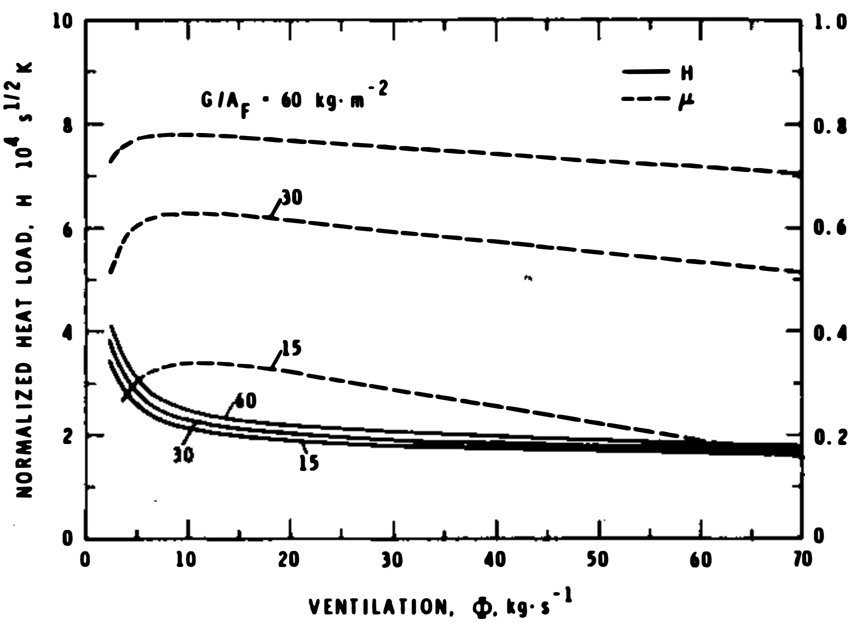

FIGURE 6 Fires of noncharring plactics.

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described by Harmathy (1980b); the results are presented in graphical form in Figures 5 and 6. Figure 5 relates to cellulosic fire load, which up to this point received exclusive attention.* Figure 6 represents fires of noncharring plactics. The figures show the variation of H and μ against the ventilation parameter, ϕ (which in these graphs is looked upon as an independent variable representative of the airflow rate into the compartment), at three typical values of the specific fire load, G/A_F = 60, 30, and 15 kg/m^2. Although the calculations relate to a room of specific geometry lined with a specific set of materials, the plots can be regarded as typical of a broad range of conditions.

The following conclusions can be drawn:

1. From the point of view of destructive spread potential, fires of cellulosics are usually more dangerous than fires of noncharring plastics. From the point of view of convective spread potential, the opposite is true.

2. For both types of fire load, the destructive spread potential decreases with increasing ventilation (as characterized by the ventilation parameter, Φ).

3. The convective spread potential of fire decreases with increasing ventilation if the fire load consists of noncharring plastics and increases with increasing ventilation if the fire load consists of cellulosics.

INTERCOMPARTMENTAL FIRE SPREAD

The fully developed period of fires rarely lasts longer than 30 minutes. In fact, a vigorously burning building fire that lasts longer is almost a certain indication of spread beyond the compartment of origin.

Although with present construction practices intercompartmental fire spread by destruction of compartment boundaries is rare, it must not be looked on as a remote possibility. This said, the common modes of fire spread are definitely those that take place by convection and radiation.

The spread of fire by convection-radiative mechanism occasionally can be attributed to the presence of wall or ceiling cavities or to the penetration of floors or walls by plastic pipes and telephone and

*The reader is reminded that Eq. (8) and Figure 3 are applicable only if the fire load consists mainly of cellulosic materials. Fairly recent statistical data confirm, however, that the fire load is still predominantly cellulosic in residential and office buildings.

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electric cables. In most cases, however, open or burned-out doors and broken windows mark the route of fire spread. Three factors have major influence on the extent and direction of this kind of spread: (1) the potential of fire for convective spread, as quantified by the μ-factor; (2) the intensity and direction of drafts in the building prior to the outbreak of fire; and (3) the nature of the lining materials along the path of spread. The role of the μ-factor in the spread of fire was discussed in some detail in the preceding section.

Strong drafts in a building are obviously conducive to the spread of fire. As noted earlier, it is usually during the winter heating season that the strongest drafts arise, and it comes as no surprise that winter is the season of the worst fire incidents.

Fire spread tends to follow the path of air currents (see Figure 1a). If, on a calm day, fire breaks out in a compartment below the mid-height of a building, it will first enter the corridor and then, if doors are left open, tend to rise in the stairwells or elevator shafts. Equipping a building with self-closing doors on all floors below its mid-height is probably the best investment in firesafety.

In the upper floors the spread of fire will be toward the building envelope so that the use of self-closing doors may not be justified. On reaching the building envelope, flames issuing from broken windows may ignite the exterior cladding if it is combustible or may break the windows above and set a compartment on the next floor on fire. (Naturally, strong winds may modify the fire spread pattern just described.)

The nature of lining materials is an important factor in the spread of fire along corridors. Experimental studies conducted by Schaffer and Eickner (1965), McGuire (1968), Christian and Waterman (1970), and Waterman (1973) have shown a limited success in correlating the rate of spread along corridors with the results of standard tunnel tests. However, some experiments have revealed that the presence of a combustible lining is not an absolute prerequisite for fire spread. This is confirmation of the claim that the propensity of fires to spread along a corridor depends not only on the characteristics of the corridor but also, and perhaps more importantly, on conditions in the compartment that feed the fire into the corridor, as quantified by the μ-factor.

SMOKE PROBLEM

Fire statistics (Berl and Halpin 1976, Thomas 1974) reveal that more people die in burning buildings from inhalation of toxic fire gases than from heat-inflicted injuries. Even in deaths that are caused by burns, smoke is often a contributing factor; dense smoke obscures the vision of the occupants and prevents them from reaching

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safety. In fact, there are good reasons to believe that obscuration of vision is the principal threat to life safety in building fires (Friedman 1978).

The seriousness of the smoke problem depends on three factors. In order of importance, these are: (1) the extent to which materials of high smoke-producing propensity are used, (2) the intensity of the drafts in the building at the time of fire, and (3) the toxicity of the pyrolysis and combustion products of the combustible contents of the building.

A number of experimental techniques for measuring the smoke-producing propensity of materials have been reviewed by Hilado and Murphy (1979). It appears that the experimental results depend not only on the chemical composition of the material but also on such factors as the nature and amount of additives, the density and thickness of the sample material, the nature of thermal exposure, and the mode of ventilation. Representative values developed by a gravimetric technique (Hilado and Cumming 1977) are listed in Table 3 for a few common plastics.

TABLE 3 Representative Values of the Smoke Producing Characteristics of Selected Materials

Material	Percent Smoke Based on Initial Weight
Acrylic, unidentified	0.33
Linoleum	0.52
Polycarbonate	0.89-1.34
Polychloroprene rubber, filled, fire retardant	0.80
Polyester, brominated, reinforced	1.70
Polymethyl methacxrylate	0.08
Polypropylene, fire retardant	1.64
Polystyrene	4.86
Polyvinyl chloride, flooring	0.21
Polyvinyl chloride, flexible, fire retardant	2.36
Polyvinyl chloride, rigid	1.33
Wood, hard	0.05-0.13
Wood, soft	0.08-0.23
Wood, board	0.06-0.57

Source: Hilado and Cumming 1979.

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The effect of the intensity of drafts on the spread of smoke is, in a way, similar to the effect on the spread of fire. Yet, since smoke is not a combustion-carrying medium but merely an aggregate of combustion gases and airborne particles, it is much more mobile than the fire that breeds it and can disperse throughout the building in a much shorter time.

The air currents that arise in a nine-story building during the winter heating season were described earlier and illustrated in Figure 1a. Figure 1b shows how the same air currents would distribute smoke on the various levels of the building within a mere 10 to 15 minutes of the onset of a fire on the first floor. (The smoke contamination of the second floor would be the result of vertical leakage currents not mentioned in this presentation.)

There has not yet been any attempt to restrict the use of materials on the basis of their propensity to generate toxic gases. The most likely reason is that carbon monoxide, which may be produced by any material as a result of incomplete combustion, is still believed to be the only toxic gas worth considering. Accumulated data (Sumi and Tsuchiya 1975) indicate, however, that other toxic gases such as hydrogen cyanide, hydrogen chloride, nitrogen dioxide, and sulfur dioxide may be the cause of fire deaths or injuries more often than is commonly believed.

EFFECT ON ENERGY-CONSERVATION MEASURES

Airtightness of Buildings

Increased airtightness of a building is reflected by reduction of the equivalent orifice area for the outside walls and, by virtue of Eq. (1), a proportional reduction of the air infiltration. Because air currents are the vehicle for dispersion of smoke if fire occurs, an increase in the airtightness of a building is unconditionally beneficial from the point of view of the smoke problem. It may be added that if pressurization is used to combat spread of smoke, by virtue of Eq. (1) and (2), there will be a reduction in the air supply requirement as a result of increasing the airtightness of the building.

As far as the spread of fire is concerned, the effect of increasing airtightness is not necessarily beneficial. Figures 5 and 6 suggest that by cutting down on the drafts (visualized as a reduction in the apparent value of the ventilation parameter, ϕ, the potential of fire for destructive spread in the compartment of origin will tend to increase, especially if, as is usual, the fire load consists mainly of cellulosic materials. This observation, however, should not weigh

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heavily in the overall assessment of the consequences because spread by destruction of compartment boundaries is a relatively rare occurrence. More significant is the expectation that with reduction of drafts the convective spread potential will decrease for cellulosic materials (Figure 5). Furthermore, there also will be a decrease in the support the air currents provide for intercompartmental fire spread, either through corridors and shafts if the fire compartment is located below the mid-height of the building or along the building facade if the fire compartment is above mid-height.

Augmented Thermal Insulation of Building Envelope

In the normal operation of a building the effectiveness of a layer of insulation does not depend on its location in the building envelope. It is common sense to sandwich combustible insulation as far from either surface of the envelope as possible. According to the rules of sound design for fire resistance (Harmathy 1965), it may seem advantageous to place noncombustible insulation on or near the inner surface of the envelope, the one most often exposed to fire. Such practice is not recommended, however, for the following reasons: (1) according to Eq. (3), the likelihood of flashover increases if materials of low thermal inertia are used in the inner lining; (2) if there is any likelihood of flashover, according to Eq. (5) it will occur in a shorter time; and (3) the temperature of fire gases will reach higher values during the period of full fire development and, if the pyrolysis of combustibles in the compartment is sensitive to radiative thermal feedback (noncharring plastics in general), the potential of fire for destructive spread (as characterized by the normalized heat load) may increase.

If insulation is added to the envelope of an existing building, the choice of where to place it is somewhat limited. It is clear that it is unwise to attach it to the inner surface of the building envelope even if the insulation is noncombustible. Furthermore, if it is combustible, there are regulations that prohibit its application to the inner surface unless it is covered with an additional noncombustible coating.

The most common method of adding insulation to the outside walls of existing low buildings is to apply it over the external sheathing. To avoid condensation problems, it usually is recommended that a narrow ventilation cavity be left between the insulation layer and the exterior cladding. This presents no problem if the insulation is essentially noncombustible, but in recent years, combustible insulation, mainly rigid polyurethane and polystyrene foams, has become increasingly popular.

The nature of the insulation near or on the outer surface of outside walls has very little effect on the characteristics of a fire

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in the interior (i.e., on the likelihood and time of flashover and, following flashover, on the potential of fire for destructive or convective spread). As mentioned above, the typical duration of a preflashover fire is 5 to 20 minutes and that of a fully developed fire, 30 minutes. The full duration of fire is rarely so long that insulation near the outer surface of the walls can influence the temperature conditions of the building interior.

The practice of using combustible insulation over external sheathing is rather common for buildings with fewer than three floors. The problem is that any flames issuing through the windows in the event of fire may penetrate the gap between the insulation layer and the external cladding. After igniting the insulation, they can spread vertically to the upper floors. A recently completed study by Taylor (1981a), in which polyurethane and polystyrene foam boards were used as insulation, revealed that the danger of fire spread along these hidden cavities depends on the nature of the plastic foam, the thickness of the cavity, the design of the flame barriers, and the cladding material.

In Taylor's tests, a flaming heat source was applied to the insulation along a narrow horizontal slot in the cladding. The tests revealed that polyurethane and polystyrene foam behave entirely differently. This is not surprising considering the marked difference in the characteristics of the two materials. Polyurethane is a char-forming material whereas polystyrene is a thermoplastic that melts on heating before it reaches the pyrolysis temperature.

With noncombustible cladding and narrow cavities, less than 75 mm wide, the spread of fire along polyurethane foam insulation tends to stop about 2 to 3 m above the flaming heat source, irrespective of the flame spread characteristics of the foam as developd by the standard tunnel test. Beyond that height, the loss of heat, mainly through the cladding, becomes increasingly significant; because of insufficient venting, the char coating is unable to oxidize and make up for the heat loss and, therefore, pyrolysis and flaming combustion are no longer possible. If the thickness of the cavity is larger than 25 mm, however, improved venting will ensure the oxidation of char and continous fire propagation throughout the full height of the cavity. Cladding products that crack or shrink on heating (e.g., PVC siding) allow for supplementary venting and are therefore instrumental in the unrestricted propagation of fire in the wall cavities.

With polystyrene foam, the insulation boards melt to a height of about 1 m above the slot where the flames enter the cavity, and partial melting of the boards extends to a height of several meters. The melt flows down and accumulates on a flame barrier. If the barrier is below the level of the flaming heat source, the melted polystyrene will solidify and present no further problem. If, on the other hand, the barrier coincides with the location of the heat source, the melt will

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ignite and serve as added fuel, causing destruction of the foam to a higher level, possibly throughout the full height of the cavity.

Flame barriers of any kind were found to be effective in reducing fire spread, especially where the cavity thickness was larger than 25 mm. Flame barriers that allow the drainage of melted material away from the fire source offered superior results with polystyrene foam insulation.

With stud-walled buildings devoid of insulation, a frequently used technique for providing insulation is to puncture the interior lining and pump foamed plastics in a fluid state into the stud cavities. The plastics later harden into insulating slabs. Owing to its proximity to the inner boundary surfaces, the insulation may be assumed to have some effect on the history and characteristics of a fire. The same may be assumed if, by design, the insulation is applied as a coat of foam plastic to the inner surface of the walls and over it, in compliance with some building code regulations, a cover of gypsum board (13 mm thick if the building is less than 18 m high or two gypsum boards 16 mm thick if the building is taller than 18 m). In some areas in the United States, equivalents of gypsum board covers are permitted.

It may be pointed out that it is difficult to find a true substitute for gypsum board. Gypsum is the ideal fire protective material; it contains 21 percent hydrated water that is released on heating in an endothermic decomposition reaction. Until the reaction is completed, the temperature of the material is held back at a level of 100 to 180°C; after completion, a porous matrix of low thermal inertia is left behind.

The ruling that foam plastic insulation applied to inner wall surfaces is to be covered with gypsum board has been brought down on account of the peculiar behavior of foamed plastics. As discussed earlier, when ignited by large ignition sources and perhaps irradiated by other burning items, foamed plastics are capable of propagating flames at a very high rate. The primary purpose of the application of gypsum board cover is to eliminate the possibility of fast flame propagation. There are, however, other benefits. Computer-executed numerical studies have indicated that an insulating layer attached to the back of a 13-mm gypsum board cannot possibly influence the temperature on the fire-exposed side of the board for a period much longer than the usual time of flashover. This finding can be translated into the claim that the effective value of the thermal inertia to be used in Eq. (4) and (5), and possibly also in Eq. (8), is that of the gypsum board; consequently, the presence of an insulation layer behind the board has no noticable effect on either the likelihood of flashover or the time of flashover and, possibly, none on the potentials of the fire for destructive and convective spread for some time into the post-flashover phase.

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With time, possibly well into the period of full fire development, the dehydrated gypsum boards tend to shrink and fall apart, presumably owing to a transformation in the calcium sulfate matrix. The fire-resistant, so-called Type X gypsum boards manufactured with the addition of special aggregates exhibit superior resistance to disintegration. The disintegration of the protective boards has two consequences. First, the insulation layer is ignited and augments the heat evolution in the compartment and, possibly, also the evolution of smoke. However, because of the small mass of the insulation, this effect is of negligible importance. The second and more important consequence is the weakening by burning of the building envelope and the increased likelihood of destructive and convective fire spread.

Another series of experiments performed by Taylor (1981b), using a corner wall assembly (Christian et al. 1977), indicated that in fast-developing fires a single layer of 13-mm ordinary gypsum board cover is capable of delaying the penetration of flames into the interior of the construction for some 30 minutes; a single layer of 16-mm fire-resistant gypsum board delays it for 45 minutes. Neither polyurethane nor polystyrene insulation tends to ignite behind the gypsum boards so long as the boards remain attached to the surface. The gaseous pyrolysis products of polyurethane may seep into the compartment along odd joints and feed the fire. With polystyrene, the foamed material will melt at some advanced stage of the fire and accumulate at the bottom of the wall cavities.

Lie (1972) studied the performance of plastic foams sandwiched (airtight) between two layers of noncombustible materials. He found that the rate at which the foam is consumed by pyrolysis when the assembly is exposed on one side to a standard fire resistance test has no relation to the ranking of the foam with respect to surface flame spread and that the area of pyrolysis rarely extends far beyond the area of exposure to the test fire.

Insulation added to the roof is unlikely to influence noticeably the principal characteristics of a fire (e.g., the likelihood and time of flashover or its potential for destructive and convective spread once flashover has occurred) for the very reasons discussed in connection with wall insulation. It may have some influence, however, on the fire resistance of roof decks and load-bearing roof beams (i.e., on the ability of these building elements to yield satisfactory structural performance under a heat load characterizing a fire under adverse conditions in the compartment below). Stanzak and Konicek (1979) found that additional insulation at the top of the roof structure may slightly reduce its fire resistance if the heat load on the construction is very large. Luckily, the structural failure of a roof element is scarcely of any consequence from the point of view of the performance of a building as a whole.

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A popular way of increasing the thermal resistance of low buildings is by the addition of loose-fill cellulosic insulation to the roof in the attic. Loose-fill cellulose insulation is, as discussed earlier, susceptible to smoldering combustion if ignited in some uncommon way, possibly by a short circuit. Although the performance of the insulation can be substantially improved by chemical treatment, the quality of treatment is often not satisfactory (Degenkolb 1978).

Regulation of Heat Gain or Loss Through Windows

In most parts of the United States and Canada, substantial savings in the energy demand for the operation of buildings can be effected by installing larger than usual windows on the south side of the building while keeping the window size normal, usually 10 percent of the floor area of the adjacent compartments, for windows facing north. Larger window size means improved ventilation, according to eq. (4), provided that the glass pane is shattered by the fire and, thus, the whole window area is available for the inflow of air.

Eq. (3) indicates that the likelihood of flashover decreases with increased ventilation. Figures 5 and 6 suggest, furthermore, that even if flashover occurs and the fire becomes fully developed, increased ventilation will tend to lower its potential for destructive spread, as quantified by the normalized heat load. A slight reduction in its convective spread potential also can be expected if the fire load is predominantly noncharring plastics. Unfortunately, the latter two considerations are somewhat outweighed by two others. First, as Figure 5 suggests, in the most common cases where the fire load consists of cellulosic materials, the convective spread potential increases with increasing ventilation. Second, higher ventilation, even if restricted to the fire compartment, adds to the intensity of drafts and, thus, for any type of fire load will aggravate the problem of smoke dispersion throughout the building. To a lesser extent it aggravates the problem of intercompartmental fire spread.

To allay the danger of spread of fire vertically along the facade of a building the use of flame deflectors has been suggested (Harmathy 1976). As Figure 7 illustrates, they may be mounted vertically above the windows and, when activated by flames issuing from the windows, fall down to assume a horizontal position and shield the upper compartment from convected and radiated heat.

According to Eq. (4), tall windows allow better ventilation of a compartment than shallow windows of the same area. The designer therefore has a limited degree of freedom in regulating the ventilation conditions in a way that seems to be beneficial from the point of view of the problem at hand.

In some parts of the United States and Canada it is usual to restrict heat gain by equipping the south side of the building with

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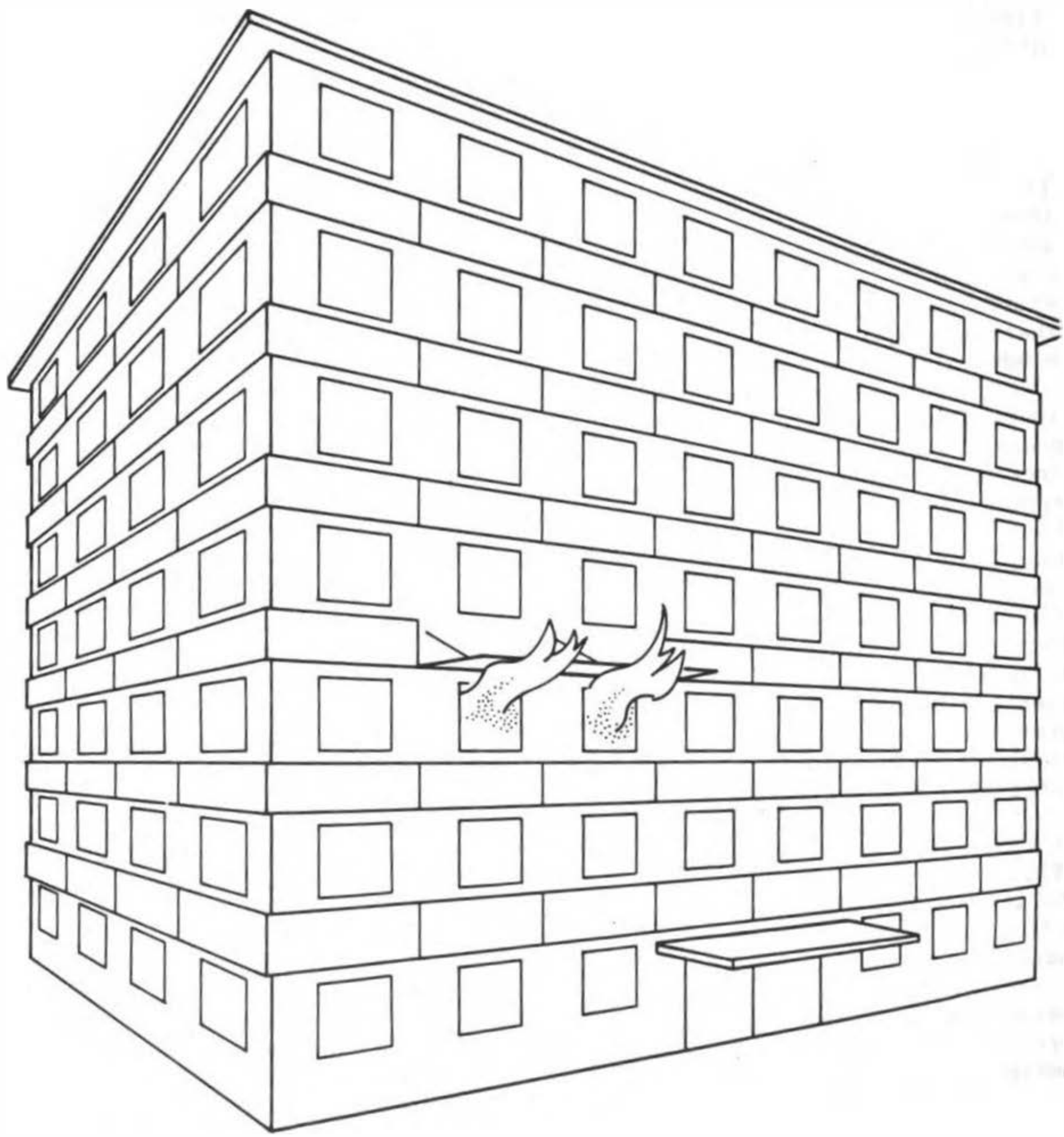

FIGURE 7 Flame Deflectors.

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direct or camouflaged fixed window shades. Horizontally projecting shades act very much like flame deflectors and are therefore useful in fire. Vertically projecting shades, on the other hand, restrict the air entrainment into the flames issuing from windows and tend to prolong the flame height; with their use, the danger of vertical spread of fire along the building facade is greatly increased.

SUMMARY

A review has been presented of the various factors that play decisive roles in the course of a building fire. Following a brief description of the preignition conditions that to some extent predetermine the main characteristics of a fire, the following phases of the fire were discussed: ignition and initial fire spread, preflashover fire growth, fully developed fire, and intercompartmental fire spread. The smoke problem that may be associated with any phase of a fire also has been outlined.

Special attention was paid to two factors: the air currents in the building that result from a temperature difference across the building envelope and have a marked influence on the nature and path of fire and smoke spread, and the thermal inertia of the construction materials that plays a more or less important role in all phases of the fire history.

The three principal ways of reducing the energy demand for a building (i.e., improving the airtightness of the building envelope, increasing its thermal resistance, and selecting the appropriate window sizes) have been examined in light of the information presented. It has been shown that these energy-conservation measures are not necessarily in conflict with the interests of firesafety. Energy-efficient buildings that are also firesafe can be built if the design is based on careful planning.

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NOMENCLATURE

A - constant.
A_F - area of floor, m^2.
A_t - total surface area of compartment, m^2.
A_V - area of ventilation opening, m^2.
B - constant.
c - specific heat, J $kg^{-1}K^{-1}$.
C - constant, 353.3 kg K m^{-3}.
E_s - total energy absorbed by unit surface area of the compartment boundaries during fire exposure, J m^{-2}.
g - gravitational acceleration, 9.8 m s^{-2}.
G - total fire load, kg.
h_B - height of building, m.
h_V - height of ventilation opening, m.
H - normalized heat load, $s^{1/2}K$.
H_m - maximum conceivable value of normalized heat load, $s^{1/2}K$.
ΔH - heat of combustion of combustibles, J kg^{-1}.
k - thermal conductivity, W $m^{-1}K^{-1}$.
n - exponent.
P - perimeter of building, m.
Q - rate of heat release by fire, W.
T_a - temperature of atmospheric air, K.
T_i - temperature of building interior, K.
V_a - rate of air infiltration, kg s^{-1}.
W_a - rate of air supply for pressurization, kg s^{-1}.
α_w - equivalent orifice area for outside walls, dimensionless.
β - orifice factor, 0.6, dimensionless.
δ - fraction of energy released by gasious pyrolysis products in compartment, dimensionless.
μ - factor characterizing potential of fire to spread by convection, dimensionless.
ρ - density, kg m^{-3}.
ρ_a - density of atmospheric air, kg m^{-3}.
τ - duration of test fire, s.
ϕ - ventilation parameter; parameter characterizing ventilation under drafty conditions, kg s^{-1}.

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The United States and Canada share the dubious distinction of having the highest fire death rates per capita in the world. The United States also has one of the highest, if not the highest, fire incident rates per capita. For one- and two-family dwellings, heating-related problems are the number one cause of these fires. The fire problem is disproportionately severe among the poor, among those living in the largest cities and those in the most rural areas, among those who are native Americans or blacks, and among those living in the North or the Southeast.

For decades the fire death rate had been declining. But in 1976 and 1977, when we had particularly severe winters as well as the energy crisis, the fire death rate went up. The struggle is on now between rising numbers of heating-related fires and "saves" from smoke detectors and other prevention approaches.

The participants in this conference are in an excellent position to do something about the fire problem and to keep it from becoming a barrier to the achievement of goals of energy conservation, reduced fuel costs, and well-being in the home. I would like to summarize for you the nature of the fire problem as it relates to your efforts and to suggest what you can do to help solve the problem.

NATURE OF THE PROBLEM

Each year over 8,000 Americans lose their lives in fires. There are also over 200,000 injuries, over $5 billion in direct property loss, and a staggering $20 billion in total cost for providing fire protection.

The vast majority of the deaths and injuries from fire--over 75 percent of them--occur in residences, usually in fires that kill or injure one or two members of a household. The big, spectacular fires such as the MGM Grand Hotel fire account for only a few percent of fire casualties.

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The fire problem is not at all homogeneous across society. The fire death rate among blacks is almost three times that of whites. Inner city areas have up to ten times the fire incident rates of the rest of the city. Rural areas have triple the fire death rate of medium-size communities, but, at the other extreme, large cities have over double the rate of medium-size ones. The problem is not homogeneous geographically either. The Southeast and Alaska have the highest fire death rates in the United States. New England has the highest fire incidence.

What is the role of heating and weatherization in these extremes? Nationally, heating-related problems are the leading cause of fires and dollar losses in residences. Heating is the second leading cause of fire deaths in the Southeast. Specifically, there are about 146,000 fires, $500 million in direct losses, and 1,200 deaths from heating-related fires in residences each year.

Heating Equipment

The heating fire problem has several dimensions. Throughout the nation, and especailly in the South, one major problem is with the use of portable space heaters and fixed room heaters. Beds or other furniture often are pushed close to space heaters at night during the occasional cold snap, clothes may be thrown near or draped over the heater, the heaters may be placed too close to curtains, they may be knocked over and their fuel spills out, and people--especially the elderly--get too close to them and their clothing ignites. Failures of the heaters themselves also are a problem, but much less so than their misuse. Portable and fixed room heaters account for 35,000 fires annually.

A second major problem with heating involves the use of fireplaces for heating or just plain enjoyment. One source of trouble is when chimneys are not kept clean, and the creosote inside them ignites. Another even more deadly problem occurs when the fireplace has not been installed or maintained properly, and the fire eventually breaks out of the chimney or fireplace and moves into the walls of the home itself igniting studs or wallboard. A third common problem with fireplaces occurs when combustibles are placed too close to them. Fireplace fires account for 27,000 fires annually with another 33,000 fires in chimneys of fireplaces and other heating equipment.

In the past few years we have seen the start of a dramatic trend toward the use of woodburning stoves and fireplaces inserts, especially in the North and Northeast. We are very concerned that there will be an epidemic of deaths, injuries, and property losses due to these woodburning stoves and inserts in winter.

One of the principal reasons for this concern is the widespread ignorance about installation of the stoves and inserts and the chimneys associated with them. Often they are placed too close to a wall

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or the hot pipes are run through flammable surfaces without adequate collars and other spacing devices. There also is some concern about how inserts perform in fireplaces that were not originally designed for that purpose. For example, they may accelerate the buildup of creosote and may stress the fireplaces with longer and more intense usage that will sooner reveal flaws in construction or maintenance. The Center for Fire Research of the National Bureau of Standards (NBS) is doing research in this area. Woodburning stoves and inserts also share a similar problem with fireplaces--namely, that combustibles are placed too close to them.*

Central heating systems are a problem primarily in one- and two-family dwellings. In apartment buildings, where the central heating systems usually are professionally maintained, they tend to be less of a problem. The fires involving central heating usually are a result of inadequate maintenance of gas heating systems (the leading problem) or flammable liquids such as cleaning fluids being placed too close to the heating equipment. Central heating systems account for 24,000 residential fires annually.

Water heaters are a leading cause of heating-related fire injuries. Again, flammables being placed too close is a leading cause. Systems in poor condition, which may explode, and misuse of the gas or liquid fuel associated with the heaters are other major problems. Water heaters account for 17,000 residential fires annually.

Thermal Insulation

Although it is one of the keys to improved heating efficiency, adding insulation presents dangers if it is not done properly. One hazard is the flammability of certain types of thermal insulation. Insulation made out of cellulosic materials that are not properly treated may provide a source of fuel for fire and increase chances for an ignition. Another less commonly known aspect of the flammability of insulation is the vapor barrier (often paper) and its adhesive (often a petroleum-based bonding agent), both of which have been found to ignite and spread fires. The Consumer Product Safety Commission (CPSC) has been monitoring such thermal insulation flammability problems.

*Because of the way the National Fire Protection Association standards for fire reporting are set up, fires involving woodburning stoves are included in the totals for fixed room heating, chimneys, and other categories. An accurate estimate is not yet available but we do know that woodburning stoves are involved in more than 10,000 fires a year and possibly many more than that. And the number is increasing sharply.

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More insidious, however, is the problem that results when thermal insulation is placed on top of lighting fixtures or certain types of electric wiring. These fixtures and wiring often require air cooling. Insulation placed on top of them can develop hot spots that can ignite wood joists or other adjacent flammables (including the thermal insulation itself if it is not fire resistant). This is a common danger especially in attics of older houses. It is aggravated when there is "over-fusing" (i.e., fuses or circuit breakers set for currents higher than the electrical wiring can handle without overheating). An overloaded circuit may start a smoldering fire that eventually breaks out and causes great damage and danger. Many in-depth investigations of fires have revealed charring along the length of a wire where it was covered by insulation and no charring beyond the edge of the insulation where the wire emerged into the air.

In a survey conducted by the NBS for the Community Services Administration, as many as one in five housefold circuits were found to be over-fused in homes selected to participate in weatherization programs. These homes are candidates for fire when insulation is added (Harwood 1979). This subject will be discussed in greater detail by other conference participants.

One part of weatherization involves making a house "tighter" with better caulking, weatherstripping, and insulation. Some people believe that this adds to the danger when there is a fire by preventing toxic gases from venting and by creating an oxygen-starved atmosphere. In the judgment of several fire experts with whom I spoke, it was felt that this was probably not true in any significant way. We did not know of any evidence and there seemed to be no reason why there should be any significant difference in risk to the occupants from fire. There could well be a difference in the nature of the burning (e.g., whether a fire remained in a smoldering stage or broke into flames), but the differences in safety were considered secondary relative to the problem of starting ignitions in the first place and other considerations discussed in this paper. In other words, one should not refrain from such things as weatherstripping, caulking, and insulating due to a fear of fire.

SOLUTIONS

One of the simplest, quickest, and cheapest approaches to getting a sharp increase in firesafety is to add a smoke detector to your home, preferably on every level. Smoke detectors protect against most types of fire. As of January 1980, almost 50 percent of the households in the United States had at least one smoke detector. However, for households with a family income below $10,000, only about 33 percent had detectors and, thus, the group that has the highest fire rate has the fewest detectors.

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To encourage the use of detectors, especially among disadvantaged families, many communities have passed ordinances requiring detectors in residences or at least when the residences change hands with the seller or landlord responsible for providing them. Another possible approach is to give detectors or credits for buying them to the most disadvantaged. (Detectors can be purchased for as little as $10.) Several communities (e.g., Wilmington, Delaware, Kansas City, Missouri, and Philadelphia, Pennsylvania) have programs to do this. Still another alternative is for major employers and civic groups in communities to arrange for discount purchases of detectors (this has been done by Fairfax County, Virginia). Where smoke detectors are installed, it is important to encourage their maintenance—especially battery replacement. Vandalism in apartments by the tenants themselves also is sometimes a problem.

You can assist in firesafety by encouraging the use of detectors and their maintenance. You also can encourage escape planning so that when there is a fire, even if there are no detectors, families will have thought out at least two ways to get out of their residence from any point.

A second major approach toward improving firesafety related to weatherization is through public education on the causes of fires and how to prevent them. The education can take place as part of visits to homes for other purposes (e.g., as counseling or aiding the elderly). Firesafety information also can be presented as part of the brochures or other media messages transmitting the weatherization information itself. In addition, you can encourage public service announcements on firesafety, especially for the disadvantaged. Reaching inner city residents and people in the rural areas are major problems in current fire prevention programs, and anything you can do to help would be important.*

Here are a few of the major points to emphasize relating to weatherization:

1. Make sure that woodburning stoves and fireplaces are properly installed. Follow manufacturer's instructions (and local codes) on required spacings exactly or with additional margins.

2. Make sure flammable objects such as furniture, paper, and firewood and flammable liquids are not placed too close to space heaters, fireplaces, furnaces, woodburning stoves, etc. Do not drape clothes over them either.

*Information on the types of public education programs and materials available can be obtained by from the Office of Planning and Education, U.S. Fire Administration, Washington, D.C. 20472.

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3. Do not put portable space heaters close to flammable objects such as drapes. Make sure they are used according to the manufacturer's instructions, and do not knock them over.

4. Thermal insulation should be installed with proper spacing around lighting fixtures as required in the National Electrical Code. Electrical circuits should be properly fused. Putting thermal insulation over wiring that is overfused or wiring that was designed for air cooling is a high risk. If in doubt, check it out.

5. Chimneys from fireplaces and woodburning stoves should be cleaned often enough to prevent creosote from building up.

However, if you can give only one single message to those with whom you work, tell them to get a smoke detector and keep it working.

There are other more innovative approaches to consider, too. In Europe, chimney sweeps are used much more than in the United States and are mandatory in some countries. The chimney sweeps are trained not only in cleaning chimneys but in checking and adjusting heating systems to be energy efficient and low polluting as well as firesafe. The chimney sweeps are highly trained by a combination of courses and apprenticeship for as long as four years. They are private entrepreneurs with essentially a local monopoly and are regulated (to various extents) by government to keep standards high. The net result is that heating-related fires are much less of a problem in Europe than in the United States even in the colder countries with similar usage of wood frame construction (e.g., Denmark and Sweden). Perhaps we can encourage improved standards and greater usage of chimney sweeps here.

Another approach is to strengthen local codes and code enforcement regarding heating systems and electrical systems. Again, in several European countries, do-it-yourself wiring is not allowed, and woodburning stoves have to be either professionally installed or tested before use.

The European approaches tend to produce major increases in safety at the cost of greater intrusion of government into the home. That choice can be made by each state and local jurisdiction. However, we probably should first try to improve the public's knowledge of the fire problem and of what an individual can do about it and to promote our simple, cheap technological fix--the smoke detector.

ACKNOWLEDGEMENTS

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PRESENTATION

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The firesafety problems created by design changes, new materials, and new systems have been consistent over the years. Most if not all of the problems are generic to classic conditions that have been core issues in our unenviable fire loss experience: large open areas, increased fire loading, concealed horizontal and vertical spaces, unprotected openings on vertical arteries, inaccessibility, and confinement (lack of ventilation). Thus, one logical approach to evaluating the impact of energy-conservation systems on firesafety would be to determine the extent to which a given energy-conservation measure contributes to creating these classic conditions.

To analyze the effect that energy-conservation systems and methods have on fire prevention and control, I have chosen some of the classic problems that have confronted fire protection specialists for years and have selected individual energy-conservation approaches and designs to illustrate the manner in which they create these problems anew. It probably would be possible to take most innovations and classify them in one of the following general categories:

1. Design changes contributing to concealed fire spread,
2. Access and egress difficulties,
3. Insulation (heat and gases, containment, increased fire load), and
4. Ignition sources (localized heating devices and passive energy systems).

DESIGN CHANGES

Design changes can create the classic physical conditions that make manual fire control difficult and that lead to fire extension and large losses. For example, some attention has been given to double wall systems for buildings. They are an adaptation of the ice block storage houses that were popular in the past. One version consists of a concrete inner wall with reflective insulation. It is separated from a cedar wall by an air gap. Heat absorbed through the outer wall and

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reflected from the inner wall causes an expansion and convection of the air to the roof. It is channelled under the roof and between the rafters to a ridge vent. Combined with other energy-conservation features (e.g., lot orientation and closed recirculating fireplaces), it is anticipated that the design will produce worthwhile energy savings.

The potential for fire spread in the concealed spaces and for involvement of the roof voids is obvious. The difficulty that firefighters have in exposing concealed fire before it extends to a point where it threatens structural stability is well known. In small residences, the property risks may be absorbed if the fire experience is low. However, past experience in ice storage houses has been sufficiently bad to cause concern should this design become attractive to architects. The number of such buildings could increase and the scale of the next step in the progression could be a return to cork or similar combustible insulation and combustibile interior surfacing, both of which would add to the fire load. It revives the problem of fire in a concealed combustibile material with sufficient oxygen to feed a spreading smoldering fire beyond the reach of firefighters. The risk to the firefighters as well as to the property increases. Although one may be inclined to doubt that this scenario could develop, past experience has shown that results such as these are likely to occur when we introduce changes into traditional building designs.

Energy conservation also can take the form of designs directed toward a reduction in electrical energy costs in the operation of a building. One actual case involves a hotel. The first floor, housing the main ballroom and several other public rooms, is serviced by an individual floor air-conditioning system. The walls of the public rooms are separated from the adjacent corridors by rated walls. There are no mechanical exhaust systems provided and no return ducts are used. The supply air is ducted to individual areas and the pressurization provided is relied on to initiate the flow of the return air to wall vents in the corner of the building where the air is removed to be recirculated or released to the outer air. To facilitate the movement of the air, openings have been cut in the rated walls. Fire dampers have not been provided because they would restrict the flow and interfere with the air-conditioning system. The ballroom is protected by an automatic sprinkler system using light-fire-hazard design criteria. The fire load will exceed 10 pounds per square foot when the area is used for trade shows. Given the storage, display, and booth arrangements common to these shows, it is not unreasonable to expect, at the very least, a heavy smoke condition should a fire occur. Where this positive-pressure air-conditioning system will push the smoke-laden air is anybody's guess. The absence of a positive exhaust system could result in the contamination of this floor, the floor above which is serviced by an open escalator, and even the nearest elevator shafts.

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If the automatic sprinkler system was overwhelmed by a fire load beyond the limits of a light-hazard water supply and the fire extended to the open ceiling space, a major problem could occur. A major involvement of the floor would severely test the skills of the firefighters and threaten the remainder of the complex with serious smoke contamination. Initial construction costs probably played a part in the development of this unfortunate design; however, the energy considerations are obvious. The elimination of exhaust fans, motors, and electrical costs are all considerations, but the unwarranted increase in risks condemns this cost-conscious approach.

A simple design that can illustrate the care that must be exercised in installing innovative energy-saving devices is the roof window. Designed to provide solar heat and illumination, it is an attractive installation but it creates several conditions that may threaten firefighters. In a smoky condition, a firefighter could step on the window, fall through the opening, and be seriously injured. On the plus side, in the event of a fire, the window could have a positive influence in limiting fire spread. If the heat were sufficient to fracture the glass, we would achieve an automatic venting action and a release of toxic gases and heat. It would increase the survival time of the people located on the upper floors and channel the fire toward the opening rather than allowing it to propagate horizontally. On the minus side, it also would create a natural draft that would deliver more oxygen to the seat of the fire and accelerate its development. The soffit around the opening at ceiling level would be a critical point. It would have to be fire resistive should the fire actually travel through the opening. If it were not, it would provide an extension point for fire travel through the space between the roof and the ceiling and, in the case of row houses, would lead to multiple building involvement. The fire control strategy and tactics would have to be implemented quickly and would have to include an appreciation of this potential extension point. Once again, design criteria must include a sensitivity to the possibilities that are created by design changes.

ACCESS AND EGRESS DIFFICULTIES

The ease of access to fire areas in buildings and other structures often determines the success of fire control operations. Losses increase in all building types when access is limited by the number of access points, heat levels, or the distances to be travelled. Windowless buildings are increasing in popularity again and are a classic example of design without an appreciation of the long-term consequences in terms of firesafety. Limited visibility and ventilation and access constraints all have been treated before. It seems improbable that anyone would design buildings with these features without including a sprinkler system; however, as the example of the hotel

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HVAC system illustrated, you cannot take a basic understanding of fire protection and sound design for granted when other objectives have higher priorities.

Another energy-saving approach is to build below grade or into the side of a hill to reduce heat loss. This may be combined with orientation of the building to expose one wall to the south to offer the greatest exposure to solar energy. This limits access to one direction or location and removes the option for vertical or cross ventilation. If the buildings involved are limited-area private residences, the consequences may not be too severe from a property loss standpoint. Even if such a building should become entirely involved in fire due to the inability to penetrate the heat barriers, the loss would not draw much attention. Firefighters will have to be cautioned, however, about the increased danger of roof collapse if there is an additional dead load created by an earthen cover for the roof. Given the increased difficulty involved in making a penetration into the building due to higher heat levels and the increased exposure of structural supports, this possibility must be considered. This raises the corollary issue of structural collapse due to prolonged burning should interior firefighting tactics be unsuccessful as well as a more rapid weakening of the structural members due to the containment of the heat and a more severe exposure of the members.

An obvious consequence of designing a building with only one exposed surface is that there is only one direction to travel when you want to leave the building. If that route is blocked by smoke or fire, you are out of options. Furthermore, the same limitation will prevent firefighters from achieving their maximum effectiveness in rescue efforts. If this design were to become fairly common, you probably could measure the increases in fatalities attributable to this type of building.

As we limit airflows due to confinement with earth berms or similar wall protection, we increase the possibility of depriving the fire of oxygen. In a limited area you may extinguish the fire by starvation; however, this will increase the risk of carbon monoxide poisoning to the occupants, a condition that will be magnified by a serious reduction in the number of egress points. An appreciable increase in the risk to life safety is obviously involved.

When large areas are involved and high temperatures are reached, oxygen-starved fires can create strong inward airstreams when an opening to the outside is made. This is followed by very rapid combustion of unburned combustible gases once they mix with the incoming oxygen that causes an explosive reaction with sufficient force to cause structural damage or injury to anyone in its path.

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INSULATION

The installation of insulating materials is the most common means of reducing energy costs. When done improperly, it can cause difficulties. In one case, an additional blanket of insulation laid in the attic over a lighting fixture deprived it of a means of shedding the heat the fixture generated. An attic fire involving the wood framing and the insulation resulted. There also is concern about combustible insulation such as polyurethane being used without a fire-resistive or noncombustible material shield. The insulation's increased susceptibility to ignition in this state, particularly when used by someone who is not acquainted with the risks involved, adds to the overall risk.

Tinted plastics used as window materials and fiberglass screens are reported to afford measurable savings in energy costs. However, effecting ventilation openings in fixed-sash windows made with these materials is difficult, which increases the potential for smoke damage, heat containment, fire extension, and injury.

A method that has been employed to increase the insulating effect of exterior walls is to increase the depth of the cavity between the exterior surface of the wall and the interior finish. One method of doing this has been to use 2-inch by 6-inch studs, 24 inches on center, instead of 2-inch by 4-inch studs. In at lease one instance, the studs were nailed directly to the wood floor joists that rested on a wooden plate, and no firestopping was provided in the space created between the studs and between the floor joists. Furthermore, the cavity was filled only partially with an insulation blanket leaving enough space for fire to travel vertically along the combustible studs. An extensive fire occurred in the cellar while this building was unoccupied; it extended to the roof space and resulted in an almost total loss. When the floor joists failed on the first floor, they disturbed the attached studs and the alignment of the exterior wall. Fortunately, no one was injured, but fire containment was impossible.

Sealants also are being used with greater frequency. The containment problem becomes a concern and some of the materials used could add to the toxicity of the gases produced if they have sulfide bases or other potentially toxic bases.

IGNITION SOURCES

Another energy-conservation approach involves the use of localized heating devices to reduce reliance on and the cost of central heating systems. Kerosene heaters are back with designs that will extinguish the flame if the heater is tilted beyond a fixed limit. Closed filling systems to avoid spillage and ignition also are provided. Zero-clearance fireplaces and woodburning stoves also are selling strongly.

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Economic survival is a strong motivation for returning to traditional, if somewhat riskier, means of heating. Candles can be expected to return too. Care will have to be taken in the installation and use of these products if the positive results intended are to be achieved. Valid testing prior to their being placed on the market, installation in accordance with instructions, use only within design constraints, and care in operation are all prerequisites to their safe usage.

Passive solar energy systems also may create problems if they are not properly designed and installed. If the removal of heat from solar energy systems is not effective, due to the malfunction of equipment or summertime conditions, elevated temperatures and critical conditions can be created. Accumulated heat in passive solar components can generate temperatures in excess of 350°F if accumulated thermal energy is not properly removed from the system. It can cause self-ignition over prolonged exposure at temperatures as low as 212°F. Temperatures for the ignition of plastics and/or insulation can be even below that of wood. The selection of materials for use in these systems requires a great deal of attention. It also is possible that insulating materials may degrade at elevated temperatures and lose their ability to protect adjacent combustible materials. Combined with the accumulation of heat, this can present a problem.

SUMMARY

It can be reasonably stated that the changes in progress or contemplated can create fire problems. The best way to avoid them would be through education that emphasizes the general as well as the specific areas of risk. To the extent that this meeting can contribute to that education, it will be worthwhile.

The problem in the past has been that the people engaged in the development of a given improvement become so immersed in their own discipline that they neglect associated issues. If that occurs, the next step must be to alert those people who will be responsible for dealing with the conditions created. This becomes somewhat more difficult because there is no central agency committed to investigating and collecting the facts prior to the advent of an emergency. Again, to the extent that we can contribute to the dissemination of information to the proper people prior to the occurrence of a series of losses, our conference will have been profitable. Let us hope that this conference at least has sensitized us to the point that we will share any unpleasant experiences that do occur with those who may not have been aware of them and thereby keep our overall losses to a minimum.

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Session II
INTERACTION OF INSULATING MATERIALS WITH FIRESAFE PERFORMANCE OF BUILDINGS

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INTRODUCTION

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Among the factors that stimulated the convening of this conference were the questions raised in magazines and newspapers about the impact of energy-conservation measures on building firesafety. Similar questions and comments have cropped up in litigation, legislative hearings, and a variety of research reports.

One of the most common energy-conservation measures is insulation; therefore, we have selected that as the topic for this session. Insulation is being used in greater thicknesses and in new areas of buildings, and new materials are being used.

Some of the questions that have been raised focus on the combustibility of the insulation. Will it ignite? Will it spread the fire? Will its placement cause overheating or problems with other building components?

Earlier we heard references to recessed light fixtures, vents, chimneys, electrical wiring, and surface-mounted light fixtures. We heard comments about the effect of insulation on fire-rated assemblies and about the oven effect (i.e., if a structure is superinsulated, heat is retained and this might cause the rate of fire growth within a space to be more rapid and could decrease the time to flashover).

Dr. Harmathy noted that lining a room with insulating materials increases the likelihood of flashover. It also needs to be remembered, however, that it is the type of room lining that has the major effect (e.g., insulation behind gypsum wallboard seems to have no direct effect on the time to flashover whereas behind sheet metal it may have a significant effect). Thus, it is the application and the total system of the structure that affects firesafety.

We also have heard comments about the impact of energy-conservation measures on smoke and toxicity in terms of the products of combustion generated by insulation materials and the effect of building tightness on the spread of smoke and gases. One very brief mention also was made of window treatments and that is one subject that concerns me because I do not think it is being considered very carefully. Older buildings with large window areas are being retrofitted with window treatments

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intended to reduce the heat loss through the windows; yet, there seems to be very little attention given to the combustion characteristics of many of those window treatments.

One of the key points to be made here is that these issues are not being ignored, and you will hear about the results of some of the work that has been done. There is more, but obviously it is not possible to discuss all of it in only a few hours. I will mention briefly now only a few of these efforts.

The National Bureau of Standards (NBS) has done considerable work on insulation flammability in its Center for Fire Research. The NBS researchers have been testing the effects of insulation on electrical wiring and other components and have been researching the smoldering characteristics of cellulosic materials. They also have been trying to find retardants that would affect smoldering characteristics. The Consumer Product Safety Commission (CPSC) also has conducted tests and statistical field studies on the effects of thermal insulation on wiring and light fixtures. The CPSC also has been one of the major sponsors of the NBS work.

The Portland Cement Association has been working on the effects of insulation on the performance of fire-rated assemblies, and, in fact, a paper on the results of some of its work was presented at the May 1981 meeting of the National Fire Protection Association in Dallas, Texas. A representative of one manufacturer of suspended ceiling materials will address you today. Other manufacturers such as Armstrong and U.S. Gypsum are doing similar work, and I wish to explain that our choice of only one manufacturer is not meant to exclude the efforts of the others. Studies have been made of the flammability characteristics and performance of insulation on pipe systems. Some of the work of which we are aware has been done by Armstrong and Factory Mutual Research Corporation. Underwriters Laboratories currently is doing some work with the Thermal Insulation Manufacturers Association. The Stevens Institute, with funding from the U.S. Department of Energy (DOE), also is investigating insulation over electrical wiring. I believe that Tennessee Tech also is doing some work for the CPSC and DOE on light fixtures.

Some time ago evaluations were made of the effect of insulation within walls and its relationship to flashover time. This was done by Owens-Corning Fiberglas with the sponsorship of the Mineral Insulation Manufacturers Association. The research confirmed what Dr. Harmathy said earlier.

A great deal of research has been devoted to the performance of foam plastics, much of it sponsored initially by the plastics industry and by the Products Research Committee established by the Federal Trade Commission in conjunction with the plastics industry. Underwriters Laboratories and Factory Mutual have conducted both large- and small-scale tests to assess the effects of foam plastic roof insulation.

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Finally, the University of California at Berkeley has done some research for the U.S. Department of Housing and Urban Development on the effects of insulation on the performance of exterior siding.

These efforts are just a sampling of the many things that have been done. You will hear more detail during the following presentations and, hopefully, at least a few answers to some of the questions that were raised during the first conference session.

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PRESENTATION
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A series of seven full-scale building fire tests have been conducted by the Jim Walter Research Corporation (JWRC). The purpose of the test program was to evaluate the performance of wood frame and metal skin buildings, metal frame and metal skin buildings, and, where present, thermal insulation in fire situations based on full-scale fire tests on unoccupied buildings.

The series of tests conducted were as follows:

- o BFT-1--1-inch Thermax Insulation Board TF-600, walls and roof, outside wood framing and inside metal skin (insulation and wood exposed).
- o BFT-2--1-inch extruded polystyrene foam board, walls and roof, outside wood framing and inside metal skin (insulation and wood exposed).
- o BFT-3--3-inch glass fiber blanket with white vinyl facing, walls and roof, outside wood framing and inside metal skin (insulation and wood exposed).
- o BFT-4--1-inch Thermax Insulation Board TF-600, walls and ceiling, inside wood framing, metal skin building (only insulation exposed).
- o BFT-5--Control, uninsulated wood frame building with metal skin.
- o BFT-6--1-inch Thermax Insulation Board TF-600, walls and roof, outside metal framing and inside metal skin (all metal building, insulation, and metal framing exposed).
- o BFT-7--3-inch glass fiber blanket with white vinyl facing, walls and ceiling, inside wood framing, metal skin building (only insulation exposed).

In planning this test series, it was realized that many potentially significant test variables could not be studied except through a program of enormous magnitude and expense. In order to maximize benefits from the limited number of tests that could be run, it was decided to utilize a standard size and type of a relatively common wood-pole agricultural building. The all-metal building was chosen to duplicate the geometry and dimensions of the wood frame building as nearly as possible. An ignition source capable of generating a large, high-intensity

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fire within a relatively short period of time would also be provided. A wood pallet type crib was chosen as an ignition source, primarily because of extensive prior fire test experience with such cribs in Factory Mutual and JWRC corner tests. The specific weight of wood in the crib, 140 pounds, was designed to provide a solid column of flame reaching up into the 12-foot-high corner of the building (similar to Factory Mutual corner test circumstances) that would generate and sustain temperatures in the 1400 to 1700°F range at the wall-roof junction above the crib. The crib was placed in the corner of the building in order to generate maximum heat buildup and the greatest opportunity for generation of a self-propagating spread of flame if the combinations of materials were susceptible to such a result. Any other positioning adjacent to one of the four walls would allow for easier heat dissipation from the crib fire and a less critical fire condition. No ridge or stack vents, windows, or skylights were used in either the walls or roof since these also would have allowed heat dissipation, especially in the case of the plastic skylights used in the roof of some farm buildings.

It was decided to leave both of the large sliding doors open for the tests primarily to facilitate an adequate supply of fresh air into the building, which would lead to a more critical fire situation. Although closed doors would have allowed more heat buildup within the building, oxygen starvation could have inhibited the type of rapid fire spread actually observed in several of the tests. Open doors also permitted easy observation of the progress of the tests and the making of movies.

TEST DESCRIPTION

Test Buildings, Auxiliary Services, and Equipment

The buildings used in the tests were constructed as follows:

1. Wood Frame and Metal Skin Building (BFT-1 through BFT-5 and 7)--This was a standard type farm building 24 feet wide by 81 feet long with an eave height of 11-1/2 feet and a peak height of 15 feet. The wall poles, spaced at 9-foot intervals, were 5-inch by 5-inch wood and were set in earth mixed with dry concrete to a depth of about 4-1/2 feet. Five rows of wooden 2-inch by 6-inch nailer strips were fixed horizontally at 3-foot intervals to the outside of the wall posts. Standard 4-in-12-pitch, 24-foot-wide wooden trusses were nailed and bolted through the tops of the wall poles. The 28-gauge, prepainted, steel wall panels were nailed to the outside of the horizontal 2-inch by 6-inch wall stringer. To form the roof, 2-inch by 4-inch wood purlins on 20-inch centers were nailed to the truss tops in the long direction of the building. Prepainted 28-gauge steel roof panels were

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nailed to the outside of the roof purlins. Three doors were included in the building: a 3-foot by 7-foot access door at the end of one 81-foot wall, an 18-foot by 11-foot sliding door centered 36 feet from the corner adjacent to the small access door, and a 12-foot by 11-foot sliding door in the 24-foot wall at the other end of the building. The two large doors were wide open during the test and the small door was closed. There were no other vents in the building and any air gap at the base of the walls was sealed with dirt fill prior to testing. The floor of the building was dirt or low-cut grass. The total weight of wood in this structure was 15,800 pounds.

2. Metal Frame and Metal Skin Building (BFT-6)--This standard metal building was 24 feet wide and 80 feet long with an eave height of 12 feet and a peak height of 16 feet. The framing of the building consisted of five sets of I-beam wall columns and 4-in-12-pitch trusses spaced 20 feet apart. The bases of the wall columns were bolted to reinforced concrete footers. Two horizontal lengths of 8-inch wall Z-girts were bolted to the outside of the wall columns at a height of 1 foot and 7 feet, 2 inches, respectively, above floor level. Two 8-inch roof Z-purlins were attached to the top of each half of each truss at distances of approximately 6 feet and 11-1/2 feet, respectively, from the eave line of the building. Prepainted 26-gauge steel panels were attached to the outside of the wall girts and roof purlins with self-tapping fasteners. The floor of the building was dirt, leveled with the tops of the concrete footers. Any air gaps at the base of the walls were sealed with dirt fill. Three doors were included in the building: a 3-foot by 7-foot access door near the end of one 80-foot wall; an 18-foot by 11-foot sliding door centered 30 feet from the corner adjacent to the small access door; and a 12-foot by 11-foot sliding door in the 24-foot wall at the other end of the building. The 12-foot by 11-foot door was wide open for the test and the small access door was closed. The half of the 18-foot sliding door nearest the access door was partially closed so that a closed 24-foot wall section resulted. The purpose of this was to approximate the 27-foot-long wall section present in the wood frame test buildings.

The insulation and method of installation was as follows:

1. Outside Wood Framing and Inside Metal Skin--This type of test utilized the building described in item 1 above. The insulation panels or blankets were held in place by nails driven through the metal skins and insulation and into the 2-inch by 6-inch wall nailers or 2-inch by 4-inch roof purlins. Both wood and insulation were thus exposed to the fire from the ignition source.

2. Inside Wood Framing--In this method of testing only the insulation was exposed, at least initially, to the ignition source fire. The basic building structure described in item 1 above was used with the addition of 2-inch by 4-inch nailer strips running in the long direction of the building and spaced 36 inches apart, nailed to the

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underside of the bottom truss chord and to the 5-inch by 5-inch wall posts. The insulation was nailed to the inside of the 2-inch by 4-inch strips, forming a box-like structure of monolithic insulation surfaces within the building. When blanket-type insulations were installed in this manner, a network of 1-inch chicken wire was stapled against the exposed side of the ceiling only to prevent the insulation from falling out during the test. The total weight of wood in this building was approximately 18,000 pounds.

3. Outside Metal Framing and Inside Metal Skin--The building described in item 2 above was used for this test. The insulation was held in place by self-tapping screw fasteners driven through the metal skin and insulation and into the wall girts or roof purlins. Both the metal framing and the insulation were thus exposed to the fire source during the test.

The wood crib ignition source for the wood frame and metal skin buildings was designed to weigh 140 pounds at controlled moisture content but actual weights varied from 135 to 150 pounds. The crib was placed in the corner of the test building, leveled on a thin sheet of plywood or hardboard, and positioned so that the sides of the crib were 10 inches away from the insulation on the adjacent walls. Ignition of the crib was accomplished by placing two flaming swab sticks, previously saturated with 500 ml of kerosene, under the crib.

The crib for the metal frame and metal skin buildings was the same as for the wood frame and metal skin buildings except that one corner of the crib was notched to accommodate the steel corner column, thus allowing the crib to be placed 10 inches from the insulation.

Temperatures were measured by placing 16 chromel-alumel, Type K thermocouples at selected locations within the test structures. The thermocouples were connected to 0 to 2400°F range temperature recorders. All wiring was external to the building with only short leads extending into the test buildings.

Sixteen millimeter color movies were taken from three locations during the test. The movies were supplemented by 35-mm color slides and color prints. Appropriate lighting was provided within the interior of the buildings. Suitable timing devices were employed for the benefit of observers and for time documentation on movies and photographs.

Procedure

After the test building and all other supporting equipment were in a state of readiness, local weather conditions were considered before initiating the test. It is difficult to specify exactly what constitutes "favorable" weather conditions, and some common sense judgment had to be exercised. Generally, however, dry weather and winds less

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than 10 mph were deemed desirable, and it was necessary to postpone tests on several occasions due to heavy rains one or two days prior to the scheduled test day.

The test was initiated by placing the flaming swab sticks under the crib. This is the zero time reference point, and all recorders and clocks were simultaneously started. Subsequent events were recorded on film and tape as previously described. One person, uninvolved in other activities, was solely responsible for issuing orders to fire department personnel standing by in readiness to terminate the test. This was to avoid confusion in the event rapid action was required. It was found, however, that in most tests a logical termination point was self-evident (i.e., either the entire building was rapidly involved in fire or the crib ignition source was exhausted with slow or minimal flame spread within the structure).

RESULTS AND DISCUSSION

BFT-1

This test involved the 1-inch Thermax Insulation Board TF-600, outside wood framing, and inside metal skin. The crib fire reached the wall-roof juncture in the corner at 2 minutes into the test. Between 2 minutes and 3 minutes, the wood began to burn and flames spread along the horizontal stringers connecting the trusses. Thermax Insulation Board mounted on the lower part of the wall near the crib also ignited. At 4 minutes 15 seconds, the fire exited the side door and material was beginning to fall to the floor. The fire increased in severity and at approximately 4 minutes 35 seconds was out the end door. All interior surfaces in the building appeared to be fully involved. The maximum temperature recorded at the wall-ceiling juncture immediately above the crib was 1730°F, which occurred at 3 minutes 30 seconds into the test. The maximum temperature recorded elsewhere in the building was 1760°F at 4 minutes 30 seconds; it occurred at the peak of truss 2. It is interesting to note that four of the thirteen eave- and peak-level thermocouple points yielded temperature curves that ascended steeply from a sharp breakpoint in the 450 to 600°F area. This temperature range roughly coincides with the auto-ignition temperature of wood. Many of the other temperature curves also exhibited abrupt changes of slope but at lower temperatures (e.g., 200 to 400°F). No similar changes in the curves could be detected in the area of 900 to 1000°F, the auto-ignition temperature of TF-600.

Figure 1 shows eave-line and roof-peak temperatures at various times throughout the test. The shaded areas, defined by 1000°F contour lines, represent an attempt to show the direction of flame spread through the building interior.

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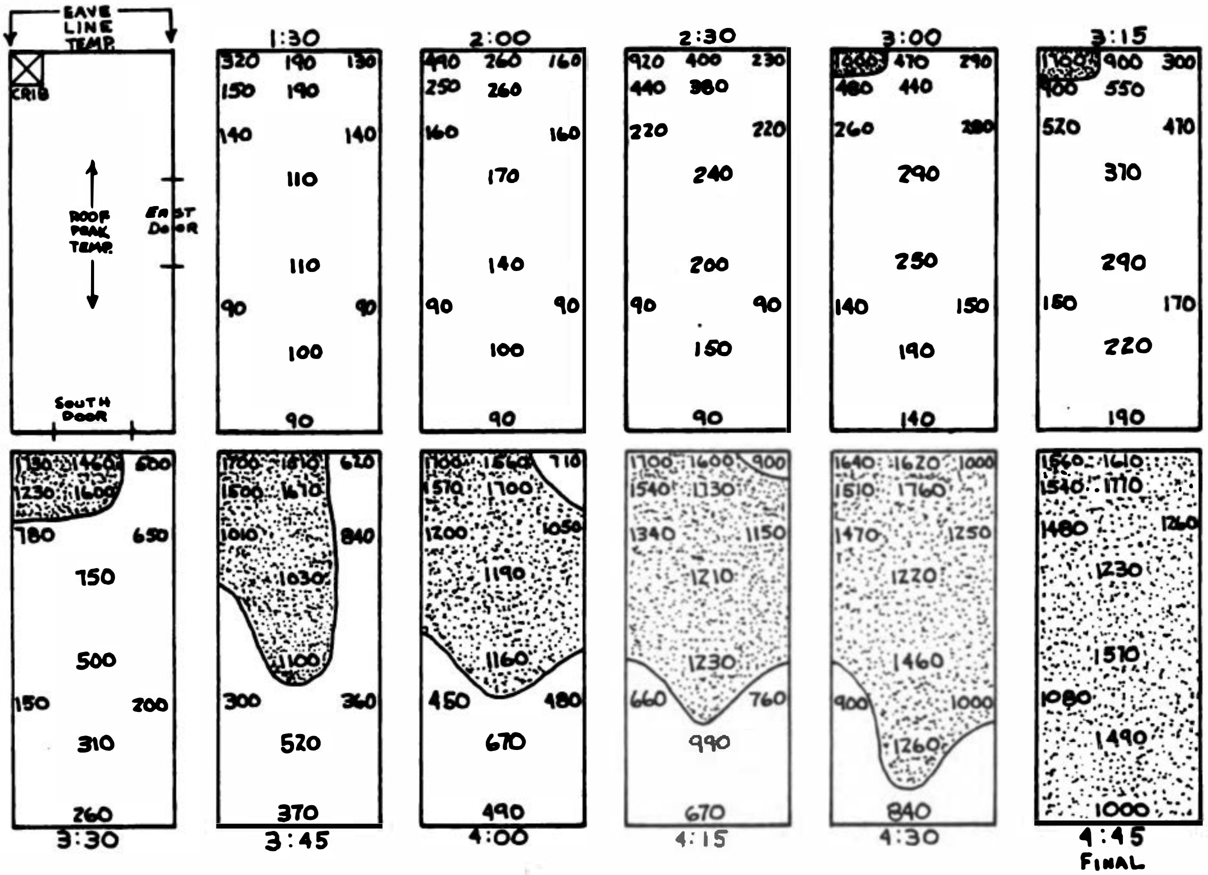

FIGURE 1 Temperature (°F) vs. total elapsed test time for BFT-1 (1-inch TF-600, outside wood framing). Shading indicates temperatures of 1000°F or greater.

The interior of the building was completely involved in fire, and damage throughout the building to both the Thermax Insulation Board and the wood framing members was highly uniform. The Thermax Insulation Board and wood framing exhibited characteristic char patterns. The building remained structurally sound.

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BFT-2

This test involved the 1-inch extruded polystyrene foam board, outside wood framing, and inside metal skin. At 2 minutes into the test, the extruded polystyrene began melting in the crib area. At 2 minutes 15 seconds, the fire had reached the wall-ceiling juncture with extruded polystyrene continuing to melt and fall to the floor. The fire began increasing and at 3 minutes was burning intensely in the corner and out to truss 2 with molten polystyrene falling from the ceiling. At 3 minutes 30 seconds, the polystyrene was flaming and dripping from the ceiling and the entire end wall was on fire. At 3 minutes 45 seconds, flaming brands were falling from the ceiling and all trusses down to truss 4 had ignited. Flames exited the side door between 4 feet 30 inches and 4 feet 45 inches and then erupted out the end door to a height of 30 to 40 feet at approximately 5 minutes. The entire interior of the building was burning violently at this point.

The maximum temperature recorded at the wall-ceiling juncture immediately above the crib was 1860°F at 3 minutes 45 seconds into the test. The maximum temperature recorded elsewhere within the test structure was 1790°F at 5 minutes; it occurred at both the peak and the east wall juncture of truss 2. Five of the thirteen eave- and peak-level temperature curves exhibited the same abrupt slope change at 450 to 600°F previously noted in the analysis of BFT-1. Figure 2 shows eave-line and roof peak temperatures at various times throughout the test. The 1000°F contour lines show the direction of flame spread within the building. The interior of the building was completely involved in flames and damage to the interior was very uniform throughout. There was no polystyrene foam board remaining in the building.

The wood inside the building had burned and charred and damage to the wood was heavy in the north end of the test structure. Trusses 2 and 3 at the north end were cracked and sagging into the interior. It was estimated that the roof in this area out to truss 4 was not structurally sound.

BFT-3

This test involved the 3-inch glass fiber blanket with white vinyl facing, outside wood framing, and inside metal skin. At 1 minute 30 seconds into the test, the horizontal wood wall members began to burn; at the same time, the faced insulation blanket close to the crib ignited but then self-extinguished within about 15 seconds. At 2 minutes, flames approached the wall-roof corner junction over the crib. The faced insulation blanket in this area and the wood corner braces also ignited at about this same time. At 2 minutes 30 seconds, the upper corner area was fully involved and a localized fireball had developed. Flames began spreading along the side wall, reaching truss 2 at 2 minutes 45 seconds. Relatively little further action occurred

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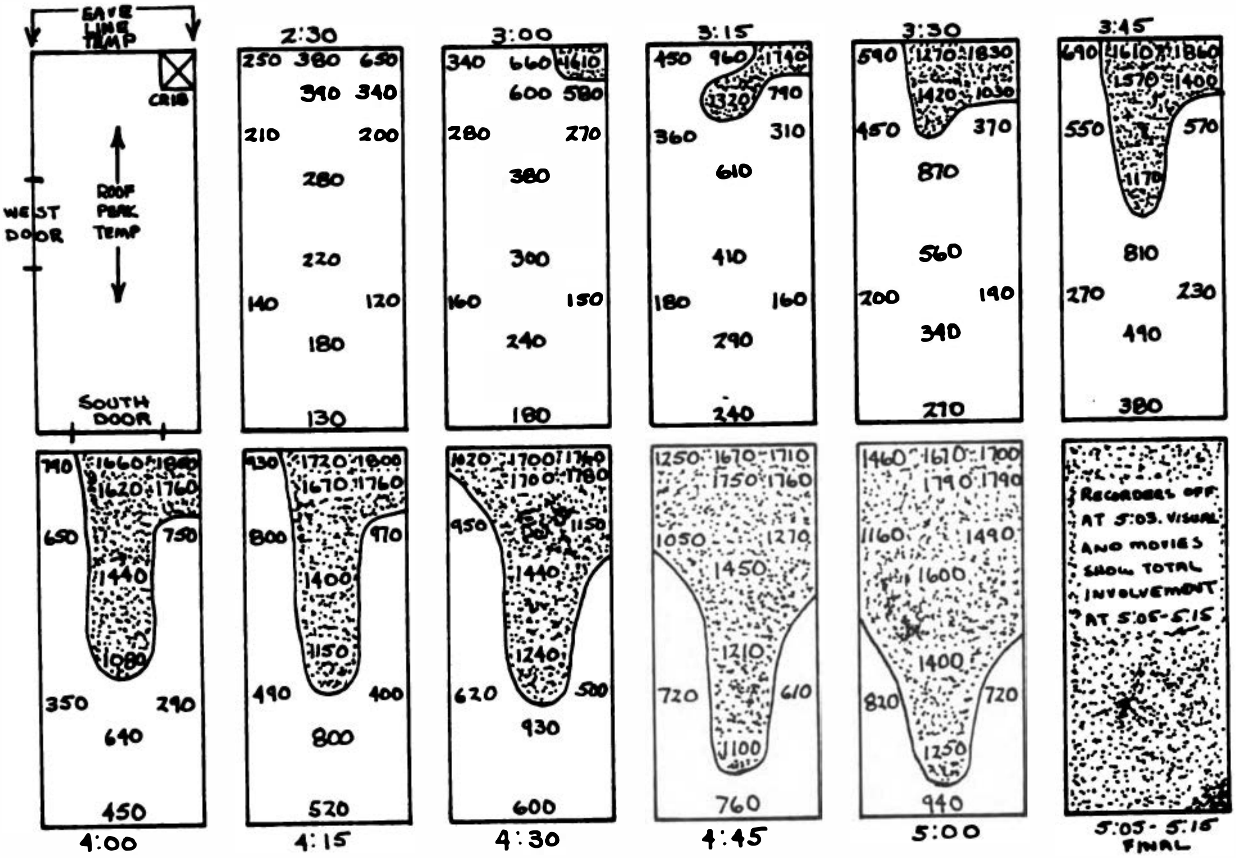

FIGURE 2 Temperature (^{o}F) vs. total elapsed test time for BFT-2 (1 inch polystyrene, outside wood framing). Shaded areas indicate temperatures of 1000^{o}F or greater.

between 2 minutes 45 seconds and about 4 minutes 15 seconds into the test as the fire spread slowly across the width of truss 2. At 4 minutes 15 seconds, most of truss 2 was burning and flames began approaching truss 3, travelling along the horizontal 2-inch by 4-inch center stringer which connected all the trusses in the 81-foot direction. The flame spread rate after 4 minutes 15 seconds became much more rapid, and at 4 minutes 30 seconds, the leading edge of the flame front had passed truss 5. Visual observations through the open side door at this point indicated clearly that the fire was spreading down the centerline of the building via the center stringer and in the roof-peak area. This initial front was followed by lateral fire spread on the trusses until the entire truss was involved.

After about 4 minuted 45 seconds, visual observations were hampered by the large volumes of white smoke pouring from both doors. Flames exited the side door at 5 minutes 20 seconds, and by 5 minutes 40

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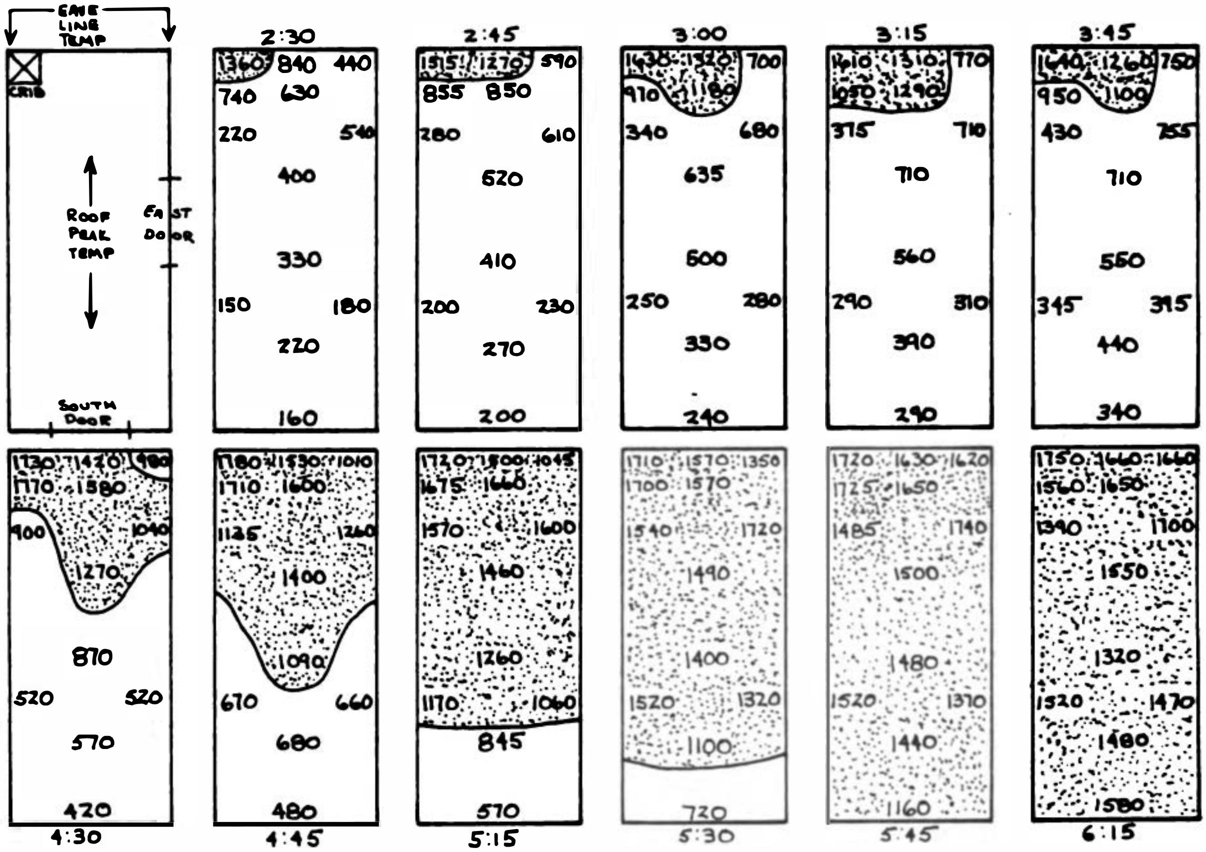

FIGURE 3 Temperature (°F) vs. total elapsed test time for BFT-3 (3 inch vinyl-faced fiberglass, outside wood framing). Shading indicates areas with temperatures above 1000°F.

seconds, flames had broken out the end door. The flame column out both doors extended about 30 feet above ground level and was accompanied by very heavy black smoke. The entire interior of the building appeared to be fully involved at this point.

Figure 3 shows roof-peak and eave-line temperatures at various times throughout the test. The shaded areas, defined by the estimated 1000°F contour lines, represent an attempt to show the manner of fire spread through the building interior.

The damage sustained by the interior of the building was remarkably uniform. All wood was charred and all the vinyl facing of the fiberglass was cracked and charred. The fiberglass had been completely destroyed over a 10- to 12-foot radius in the corner over the crib. The rest of the fiberglass was intact but was hanging in festoons from the roof. The basic building structure was intact and structurally sound.

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BFT-4

This test involved the 1-inch Thermax Insulation Board TF-600 and inside wood framing. At 2 minutes into the test, flames had reached the ceiling and the foil facer began to blacken and blister. The first sign of ignition of foam on the ceiling appeared at 3 minutes at a temperature of about 1000°F. As the crib fire intensified, black smoke evolved and the walls adjacent to the crib began to burn. The fire began to spread on the ceiling and down the wall-ceiling juncture at about 3 minutes 30 seconds. The temperature recorded by the corner thermocouple at this point was 1340°F. Concurrently, black smoke accumulated just below the Thermax Insulation Board ceiling and exited both the end and side doors. Visual observations of the degree of flame front expansion were severely hindered, but by 4 minutes to 4 minutes 15 seconds, it became apparent that fire spread had been limited and the fire receded back into the corner area. The maximum temperatures in the corner and at the side wall junction of truss 3 occurred at 4 minutes and were 600°F and 680°F, respectively. Since the flash ignition temperature of Thermax Insulation Board is approximately 900 to 1000°F, it can be concluded that no active burning occurred at these two points. Thus, flame propagation was something less than 24 feet along the junction of the end wall and ceiling and less than 18 feet along the junction of the side wall and ceiling. Following recession of this initial flame front, the crib fire remained very intense, but there was little active flaming on either walls or ceiling in the corner for the next several minutes. The test was allowed to continue for a total of 42 minutes, but unfortunately, very few visual observations could be made after about 8 minutes because the building again became filled with smoke and remained so for the duration of the test.

Temperature diagrams shown in Figures 4, 5, and 6, supplemented by the few visual observations made during the test do, however, allow a reconstruction of the progress of the fire during the remainder of the test. The temperature above the ceiling in the northeast corner began rising steeply from 420°F at 6 minutes to 1350°F at 7 minutes, indicating that, during this interval, the crib fire had broken through the Thermax Insulation Board and into the attic.

The temperature at the peak of truss 2 rose from 400°F to 1450°F between 7 minutes and 8 minutes, and the fire in the attic had reached truss 4 by 10 minutes, based on a roof-peak temperature of 1100°F at that point. In the lower portion of the building, portions of the Thermax Insulation Board mounted on the wall adjacent to the crib had been consumed and wood members behind the panels were burning. The crib collapsed at about 11 to 13 minutes into the test, and at 20 minutes, when the smoke cleared momentarily, the only fire visible in the lower part of the building was a small flame from the remains of the crib. The fire in the attic area progressed very slowly since the Thermax Insulation Board in the ceiling below remained in place and

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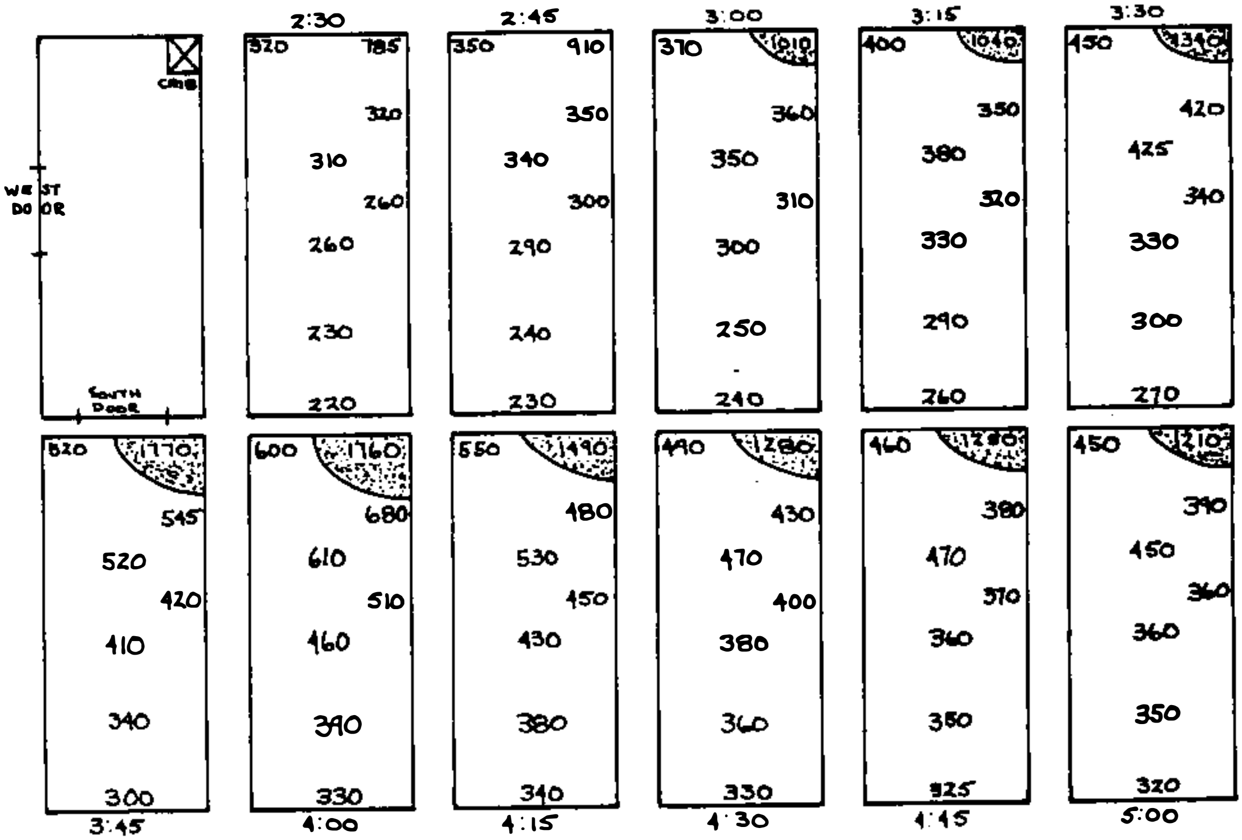

FIGURE 4 Total elapsed test time (min:sec) vs. temperature (°F) measured at points 6 inches below Thermax ceiling for BFT-4 (1-inch TF-600, inside wood framing). Shading indicates areas with temperatures above 1000°F.

restricted the oxygen supply to the fire above. Between 10 minutes and 25 minutes, the attic fire still had not progressed beyond truss 4. At 27 minutes 30 seconds, the smoke cleared somewhat and a small amount of flame exited the top of the west door. The ceiling was clearly observed to be burning slowly out to truss 6 at 30 minutes. At about 32 minutes 15 seconds, an increase in flame activity was observed through the side door; shortly thereafter, flames again exited the side door. At 32 minutes 30 seconds, a large amount of material was observed to have fallen out of the roof area and was landing and on fire just inside the side door. Closer inspection revealed this to be the remains of trusses 4 and 5 and portions of the Thermax Insulation Board from this area. The half of the metal roof in the ignition end was sagging badly by this time. Fire activity had again diminished by 34 minutes, and from then to the end of the test very little fire could be seen except for various small flames and glowing embers on the

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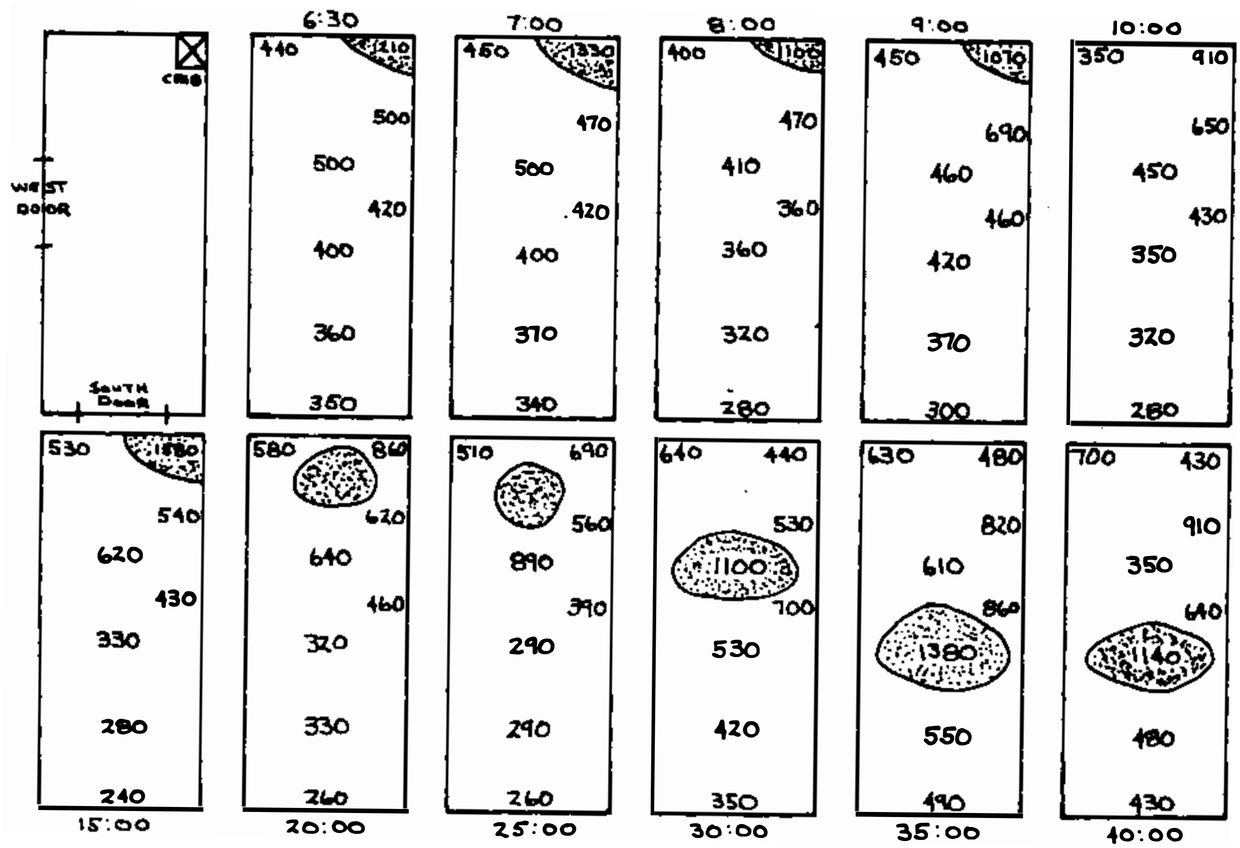

FIGURE 5 Total elapsed test time (min:sec) vs. temperature (^{o}F) measured at points 6 inches below Thermax ceiling for BFT-4 (1-inch TF-600, inside wood framing). Shading indicates areas with known or estimated temperatures above 1000^{o}F.

floor. Large quantities of gray-yellow smoke continued to issue from the eaves and door at the south end of the building. No fire was ever observed exiting the end.

Upon entering the structure after the test, the most striking feature was the substantial quantity of Thermax Insulation Board remaining. All the ceiling panels from trusses 7 to 10 were still in place, although the embossed facer had been blackened. The Thermax Insulation Boards mounted on the wall on each side of the crib were missing, but most of the other wall panels were undamaged below the 10-foot level. The metal roof on the ignition end down to truss 6 had collapsed inward, forming a V-shaped structure in the center of the lower part of the building. It appeared that, at the termination of the test, the slow-moving flame front had just barely reached the peak only of truss 8.

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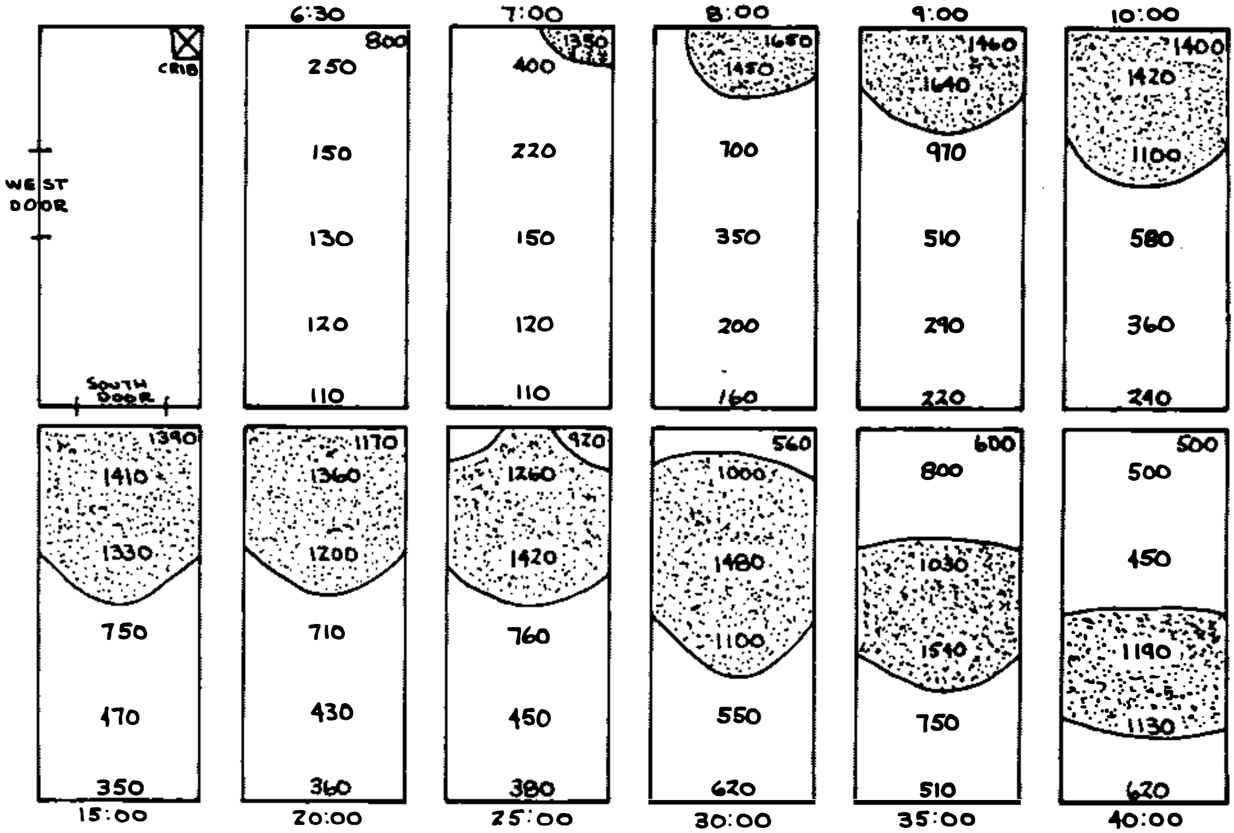

FIGURE 6 Total elapsed test time (min:sec) vs. temperature (°F) measured above Thermax ceiling for BFT-4 (1-inch TF-600, inside wood framing). Shading indicates areas with temperatures above 1000°F. Crib-corner (NE) temperature was measured several inches above technifoam; all others are roof-peak-area measurements, 2 to 3 feet above technifoam.

BFT-5

This was the control test involving the uninsulated wood frame building with metal skin. At 3 minutes into the test, flames had reached the wall-ceiling juncture, and the two lower horizontal members on the side and end walls were burning in the corner area. The fire continued to intensify, and at 3 minutes 40 seconds, the whole corner was involved with the fire moving toward truss 2. The fire continued to spread toward truss 2 at 4 minutes with appearances of the beginning of flashover activity. At 4 minutes 45 seconds, the fire reached the peak of the building at truss 2, and it began to impinge on truss 2 at the eave at 5 minutes 20 seconds. The fire remained fairly steady, burning in the corner area only, until at 6 minutes 45 seconds, truss 2 and the post supporting truss 2 ignited at the eave on the side wall.

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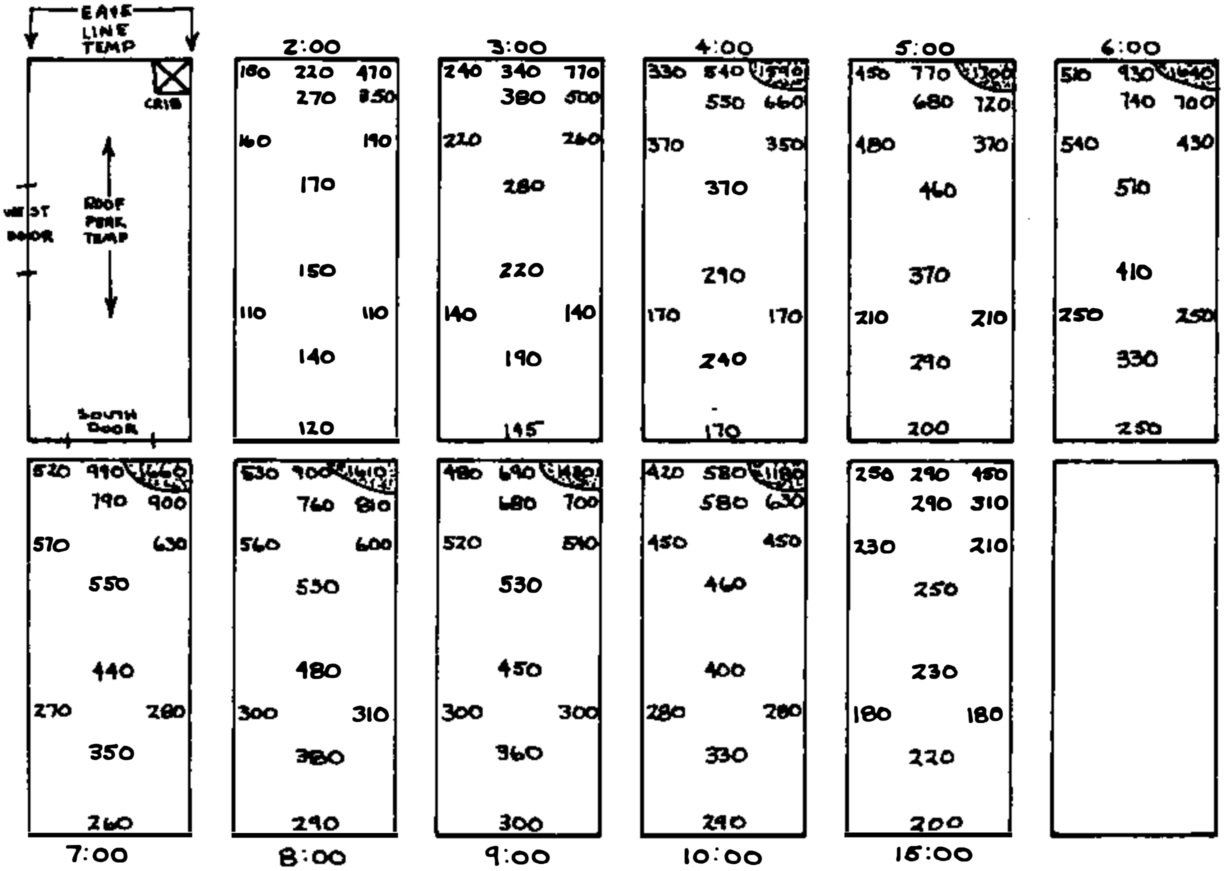

FIGURE 7 Temperature (°F) vs. total elapsed test time (min:sec) for BFT-5 (uninsulated wood frame building). Shading indicates areas with temperatures above 1000°F.

A small flame was noticed at the peak of truss 2 at 8 minutes. At 9 minutes 30 seconds, the crib fire was weakening, and the crib collapsed at 13 minutes. The fire at trusses 1 and 2 continued to diminish, and the test was terminated at 19 minutes 45 seconds.

The continuous temperature recordings taken at ridge and eave locations are shown for various times in Figure 7. The maximum temperature recorded at the wall-ceiling juncture immediately above the crib was 1710°F at 5 minutes 15 seconds into the test. The maximum temperature recorded elsewhere within the building was 990°F at 7 minutes; it occurred at the peak of truss 1. The damage sustained by the interior of the building was minimal and was confined to the corner defined by truss 2 and the peak of the building.

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BFT-7

This test involved the 3-inch fiber blanket with white vinyl facing and inside wood framing. The vinyl facing on the walls in the corner ignited at 2 minutes 15 seconds into the test but then self-extinguished at 2 minutes 45 seconds after a relatively minimal flame spread. There was no further change, except for intensification of the crib fire, between 2 minutes 45 seconds and 6 minutes 15 seconds, at which time more of the vinyl facing adjacent to the crib ignited and burned briefly. Although not visually observed, fire broke through the fiberglass ceiling at about 7 minutes since the temperature in the ignition corner above the ceiling went from 320°F at 7 minutes to 1500°F at 8 minutes. The horizontal wood wall members on the walls in the corner were burning intensely at 9 minutes 45 seconds, and even though the crib had collapsed (at 9 minutes), a solid column of flame was streaming up into the attic area. Beyond about 10 minutes, the fire progressed slowly down through the attic, and few visual observations were possible. The continuous temperature recordings shown in Figures 8 and 9 do, however, allow reconstruction of the pace of fire activity throughout the building for the duration of the 45-minute test. Arbitrarily chosen 1000°F contour lines show how the fire moved down the length of the building during the test.

At approximately 10 minutes, the fire had reached truss 3, and it approached truss 4 at 11 minutes 30 seconds (based on both temperature readings and discolored paint on the roof at the peak of truss 4). Black smoke filled the interior, but no further changes were observed until 20 minutes into the test when the fire reached truss 5. The progression of the fire was slow, reaching truss 6 at about 22 to 25 minutes and truss 7 at 27 to 28 minutes. At 29 minutes 45 seconds, the fiberglass ceiling on the ignition end of truss 6 began sagging; it then fell completely on one side but remained fastened to the eave on the other side. The ceiling remained in this position, almost completely blocking the side door, until the end of the test. By 35 minutes, the fire had passed the peak of truss 8, and the metal roof was sagging. The only visible flame throughout the latter portion of the test was that behind the fallen ceiling in the side door. The peak of truss 9 appeared to become involved at about 38 minutes, but judging from the temperatures recorded, the fire was relatively mild, perhaps due to oxygen starvation. At the time of the decision to terminate the test at 45 minutes, all recorded temperatures were less than 1000°F. No flames exited the south door at any time during the test.

Damage to the building was extensive in the ignition corner and in the attic. Most of the roof had collapsed and come to rest in a horizontal plane at eave level. Trusses 2 through 7 were almost completely consumed, and truss 8 was charred and sagging. Truss 9 was black and showed slight charring near the peak. All the 2-inch by 4-inch wood nailers on the wall below the 10-foot level were in good condition except for those in the crib corner. All three doors were operable and

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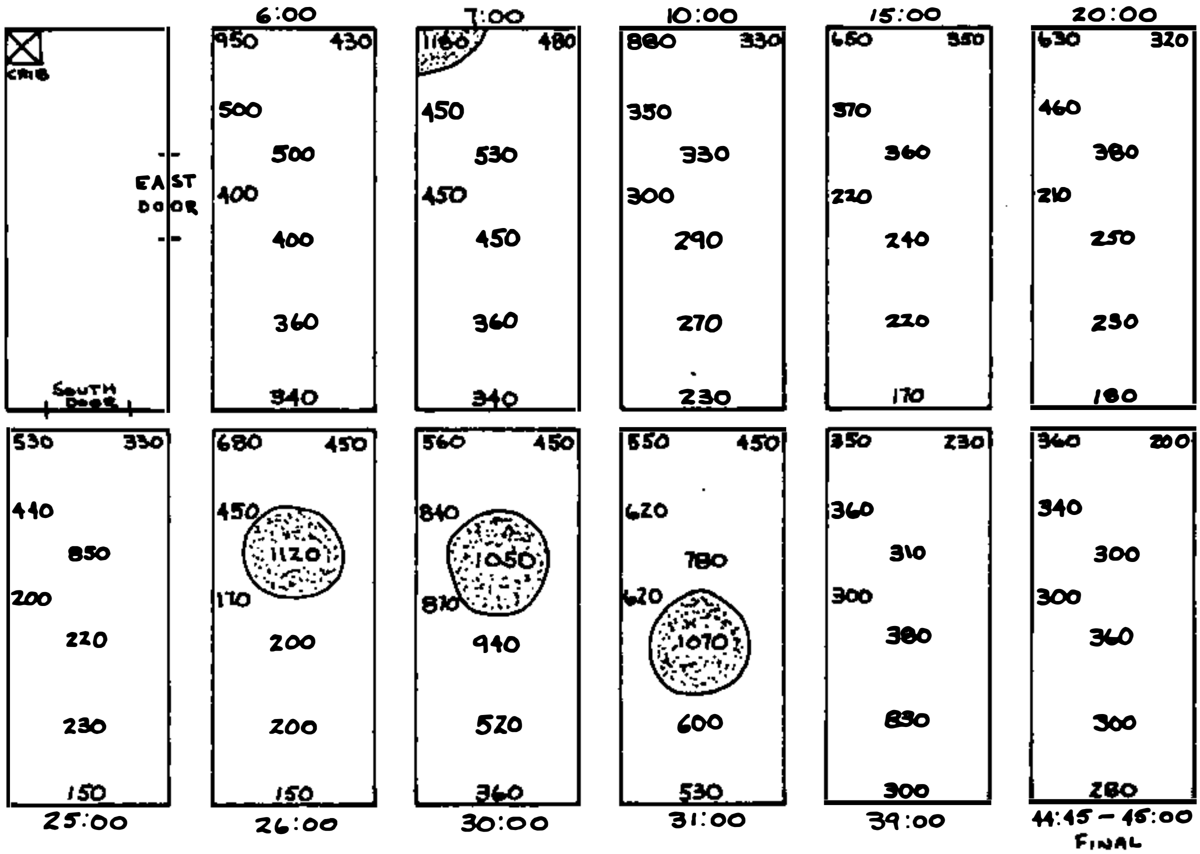

FIGURE 8 Total elapsed test time (min:sec) vs. temperature (°F) measured at points 6 inches below fiberglass ceiling for BFT-7 (3-inch vinyl-faced fiberglass, inside wood framing). Shading indicates areas with known or estimated temperatures above 1000°F.

in good condition. Most of the fiberglass insulation below the 10-foot level appeared to be unburned, but this was hard to determine because a large amount had fallen with the ceiling and the water hoses had dislodged the wall insulation in other areas. The fiberglass ceiling from truss 8 to the end door was intact with some smoke damage.

BFT-6

This test involved the 1-inch Thermax Insulation Board TF-600, outside metal framing, and inside metal skin (all metal building). At 1 minute into the test, the flame was through the top of the crib to a height of 3 feet. At 1 minute 30 seconds, the flames were approximately 9 feet above floor level and, at 2 minutes, were beginning to impinge on the wall-roof junction. The flame column was broken up to

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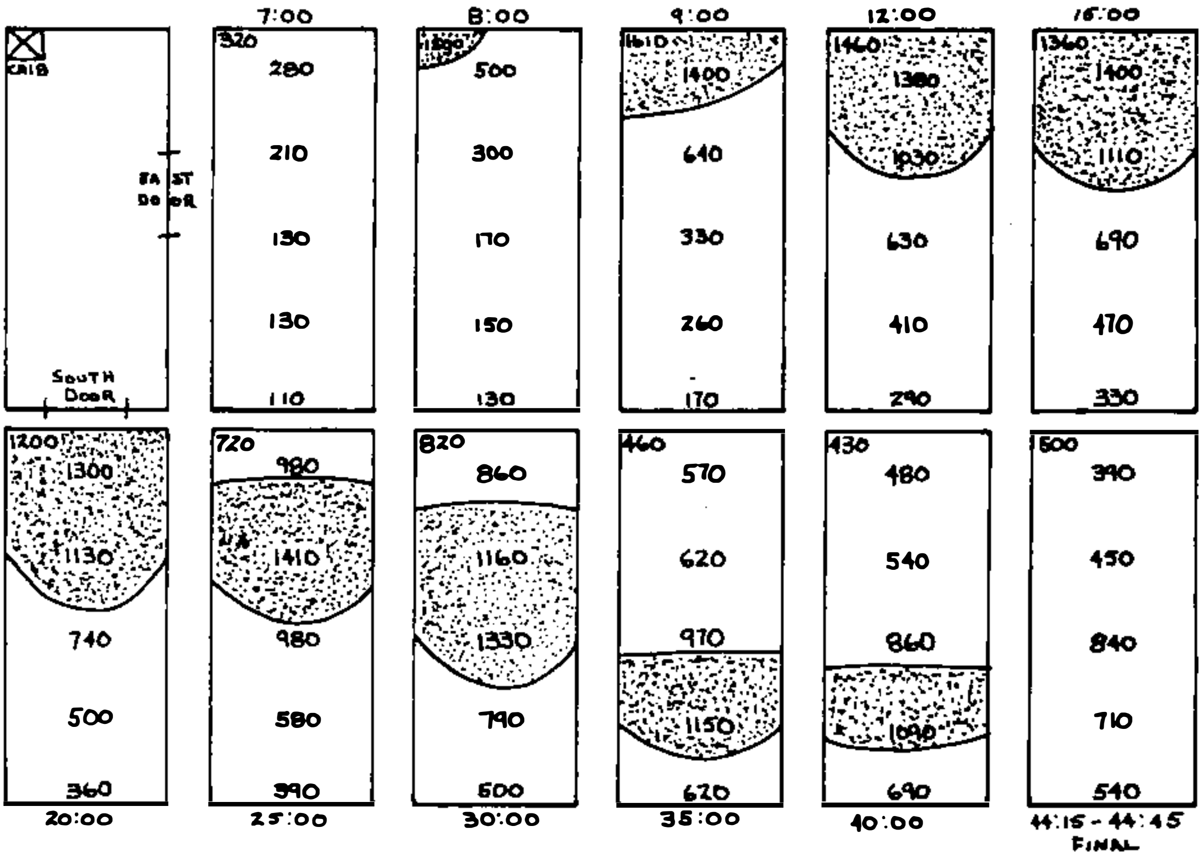

FIGURE 9 Total elapsed test time (min:sec) vs. temperature (°F) measured above fiberglass ceiling for BFT-7 (3-inch vinyl-faced fiberglass, inside wood framing). Shading indicates areas with known or estimated temperatures above 1000°F. Crib-corner (NW) temperature was measured several inches above fiberglass; all others are roof-peak-area measurements.

some degree by the wall girts and the steel column structure in the corner. At 3 minutes 40 seconds, the Thermax Insulation Board on the lower side wall ignited, but then the flames slowly receded until 5 minutes 40 seconds when the Thermax Insulation Board on the ceiling ignited. The flame front spread across the end wall laterally to a maximum distance of 8 feet and then receded. From 6 minutes to about 8 minutes, only small patches of fire were visible on the side wall and on the roof over the crib. At 11 minutes, the crib fell over against the end wall and thereafter the fire diminished steadily in intensity. Very little smoke was generated and visibility inside the building was good throughout the test.

Although some slight warpage of the corner column did occur, the building was certified to be structurally sound. The only other damage

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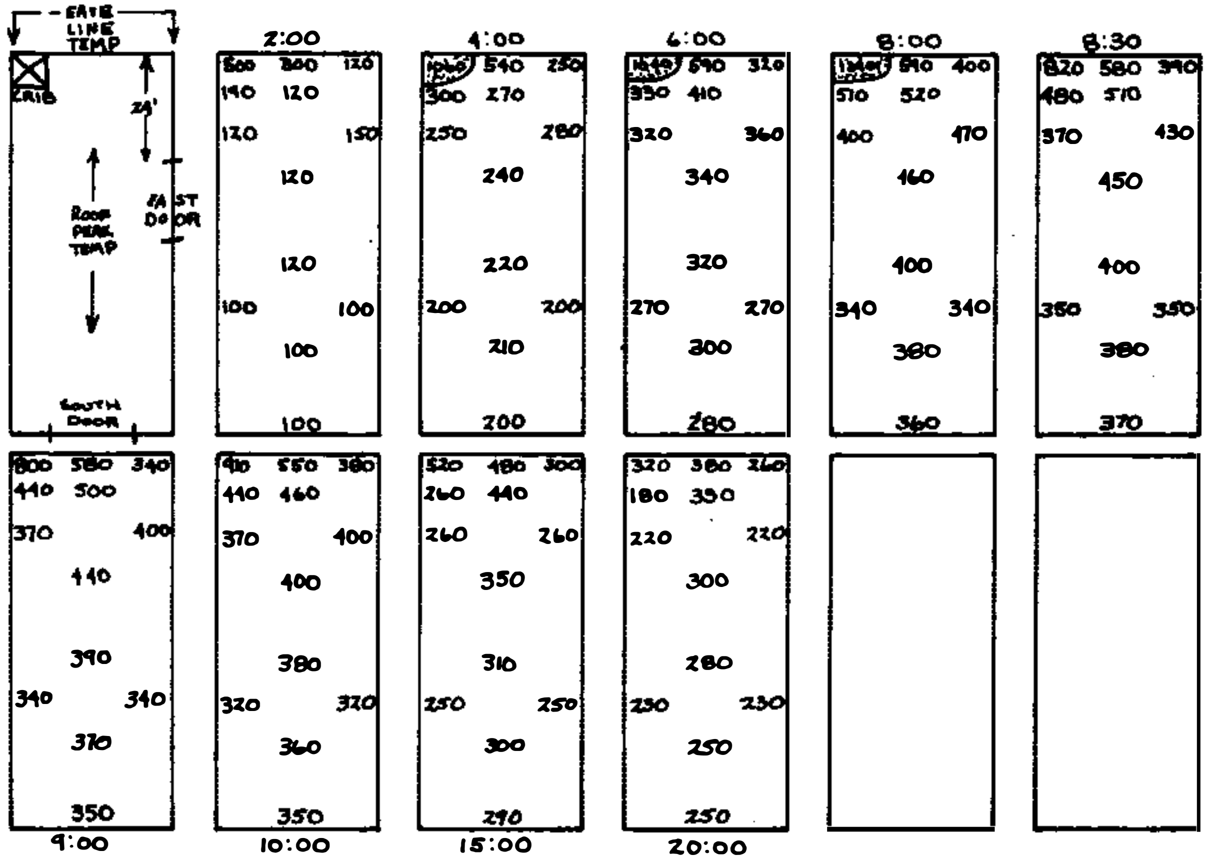

FIGURE 10 Air temperatures (^{o}F) vs. total elapsed test time (min:sec) for BFT-6 (1-inch TF-600, all-metal building).

was the characteristic flared char pattern on the Thermax Insulation Board in the corner. Approximately 250 square feet of Thermax Insulation Board was easily replaced in the repair of the building. Exterior damage was limited to a small area of paint char on each side of the northwest corner adjacent to the crib.

Figure 10 shows air temperatures attained at the ridge and eave thermocouple points and Figure 11 shows temperatures recorded by the thermocouple that had been welded to the steel beams prior to the test. The maximum air temperature recorded during the test was 1240°F at a point on the ceiling corner directly over the crib. All other temperatures were below 600°F throughout the test. The maximum steel temperature recorded was 580°F at a point halfway between the eave and the roof peak on the west side of truss 1.

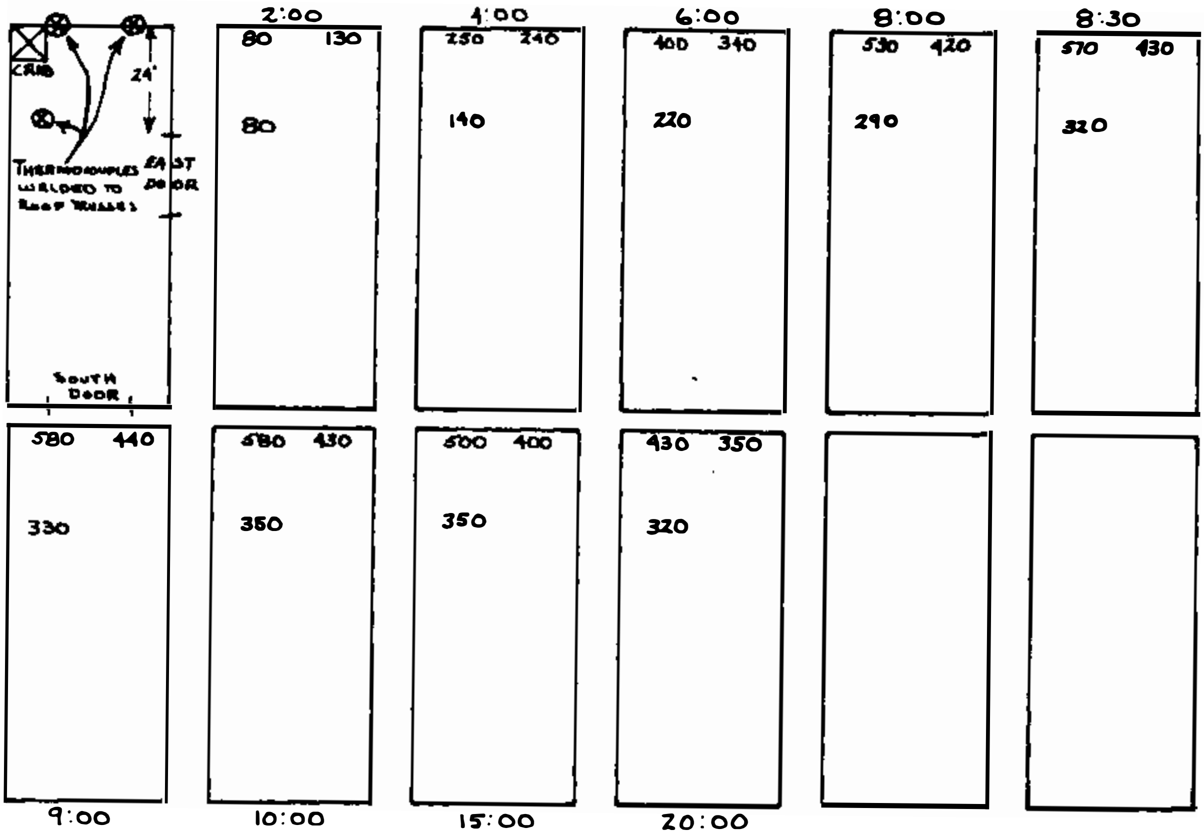

FIGURE 11 Steel temperatures (°F) vs. total elapsed test time (min:sec) for BFT-6 (1-inch TF-600, all-metal building).

CONCLUSIONS

Qualifications

The conclusions presented below apply to the performance of wood frame and metal skin buildings and metal frame and metal skin buildings in these fire situations based on full-scale unoccupied building fire tests. It must be recognized that the variables which can effect performance in an actual fire situation are infinite in number and it is virtually impossible to conduct tests, even sophisticated full-scale building fire tests, which take into consideration all of the possible variables.

These tests were designed and conducted using reasonable scientific practice to provide conclusions about the fire performance of such buildings under generally severe fire conditions involving such things as an adequate air supply and a large ignition source. The conclusions are considered valid and scientifically accurate subject to the following qualifications:

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1. The conclusions apply only to the structure itself and its major materials of construction--wood framing, metal framing, exterior metal skin, and, where present, thermal insulation.

2. The conclusions apply to a fire source inside the building.

3. The conclusions apply to such buildings where the exposed interior surface of the buildings is wood and metal, wood and thermal insulation, metal and thermal insulation, or thermal insulation only. They do not apply to other interior lining materials that might initially or subsequently be installed in the buildings.

4. The conclusions do not apply to or take into consideration certain components of any typical building such as the plumbing, electrical, and heating or air-conditioning and ventilating systems.

5. The conclusions apply to a single open fire area on the interior of the building and do not apply or take into consideration the effect of partitions.

6. The conclusions do not apply to or take into consideration the contents of such buildings.

7. The conclusions apply only to unsprinklered buildings.

8. The conclusions are based on what is considered to be a large source of ignition in relation to the size and geometry of the buildings employed. The 140-pound wood crib at peak level of fire develops a solid tunnel of flame that impinges on both the walls and the 11-1/2-foot (or 12-foot) ceiling or roof. This was specifically designed to approximate the type of large ignition source utilized in the Factory Mutual (25-foot high) corner flammability test. This type of ignition is considered capable of promoting a flashover or rapid flame spread condition in a building if the materials of construction are susceptible to such a result.

Conclusions

The conclusions regarding actual fire performance of wood frame and metal skin and metal frame and metal skin buildings based on this full-scale building fire test program are as follows:

1. The use of thermal insulation in a wood frame and metal skin building increases the susceptibility of such buildings in a severe fire situation to spread of fire and subsequent fire damage. This occurs because the insulation tends to confine heat released by the ignition source, burning wood and insulation, and direct such heat to preheat unburned wood and thermal insulation in advance of the spreading flame front, thereby making the wood and insulation susceptible to continuing ignition and fire spread.

2. The use of thermal insulation in a wood frame and metal skin building constructed so that the wood frame is exposed on the interior of the building creates a susceptibility to flashover, rapid flame spread, and early total fire involvement of the entire building interior, regardless of the fire performance characteristics of the insulation itself.

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3. In an insulated wood frame and metal skin building constructed so that the wood frame is exposed on the interior of the building, the fire performance characteristics of the thermal insulation employed can have a minor effect on the speed of flame spread and a somewhat greater effect on the heat and intensity of the fire that develops. From a practical standpoint, however, these differences are not considered significant relative to the hazard to both life and property in this fire situation.

4. An uninsulated wood frame and metal skin building constructed so that the wood frame is exposed on the interior of the building is significantly less susceptible to spread of fire and subsequent fire damage than an insulated building. The reason for this is that some of the heat generated by the ignition source and burning wood framing can dissipate through the metal skin, resulting in less preheating effect on the wood adjacent to the flame front. This should not be interpreted to mean that a building of this type will never be subject to rapid flame spread and total fire involvement since it is conceivable that much larger sources of ignition could cause such a result.

5. The use of thermal insulation in a wood frame and metal skin building constructed so that only the thermal insulation is exposed on the interior of the building prevents a susceptibility to flashover, rapid flame spread, and early total involvement provided that the insulation itself is not subject to flashover. However, such construction is subject to slow flame spread, primarily in the plenum space above the insulated ceiling. Class I flame spread rated fiberglass and Thermax Insulation Board TF-600 behave in this manner. The performance of polystyrene foam in this type of construction is not known since it has not been so tested.

6. It should be recognized that the three thermal insulations used in this test program have an Underwriters Laboratories Class I (25 maximum) flame spread rating and, as such, are not easily ignited by small sources of ignition (e.g., a match, welder's or plumber's torch, or electrical short circuit); other insulations generally lower in cost (e.g., those employing polyethylene and paper facings) are easily ignited by both large and small sources of ignition and more likely to be subject to flashover regardless of the method of installation. These latter insulations would, from a practical standpoint, constitute a significantly greater fire hazard risk.

7. It is difficult to conclude that the better performing thermal insulations, such as those employed in this program, should not be used in a wood frame and metal skin building with the wood frame exposed. It must be recognized that such construction will ignite and result in rapid flame spread only when exposed to a large source of ignition and an adequate air supply. The decision to use or not use these thermal insulations in this manner must concern itself with many factors, including cost of construction and end use of construction.

8. An insulated metal frame and metal skin building is not susceptible to flashover provided that the thermal insulation material, of and by itself, is not subject to flashover. This conclusion is

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considered valid regardless of the relative positions of the thermal insulation and metal frame (i.e., both metal frame and thermal insulation exposed on the interior or only thermal insulation exposed on the interior).

9. The use of thermal insulation in a metal frame and metal skin building may increase the susceptibility of such buildings to spread of fire and subsequent fire damage because the thermal insulation tends to confine heat released by the ignition source. Distortion of framing metal could be greater than in uninsulated buildings.

10. As a corollary to conclusion 7, the better performing insulations (i.e., those not subject to flashover) should be employed in metal frame and metal skin buildings to avoid susceptibility to flashover.

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PRESENTATION

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There are many buildings in the United States that were built 10 or 12 years ago when building owners were not concerned about the cost of fuel. Recent fuel shortages and rising energy costs, however, have caused these building owners to add insulation on the back of Conwed ceiling boards without considering what could happen to the fire ratings of the buildings. When the buildings originally were constructed, one of the reasons for fire rating was to lower the insurance rates, but by adding insulation on the back of the board, the building owners were destroying all of the fire-rated value that they were getting by having the ceiling board insulation.

Department of Energy (DOE) figures indicate that approximately 25 billion square feet of existing roof area in the United States today has no insulation or insufficient insulation. Many buildings are built today according to fire-rated design but with less than adequate insulation. The result is that building owners decide they are spending too much money for oil, gas, or electricity and put in more insulation. They save some money on fuel but lose the savings they had from the fire rating.

Several factors are considered important in assessing the effect of the introduction of additional insulation on fire ratings. Adding insulation to the back of the ceiling panels certainly will reduce the temperature transmission through the assembly, but it also will increase the temperatures on the ceiling components. Conwed had nine fire tests run on various types of ceiling material and various types and thicknesses of insulation. These tests indicated that the type and thermal resistance of the insulation and its location within the plenum space are extremely important. The basic construction of the assembly also is very important and should not be altered by the addition of the insulation.

Underwriters Laboratories (UL) ran two tests on identical constructions. In one, insulation was placed directly on the back of the ceiling board and a 45-minute time duration was achieved. In the other, insulation was placed at the roof line and the result was a

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time duration of 65 minutes. Thus, by locating the same amount of insulation in the same construction in a different position, additional minutes are obtained.

A 2-hour and a 1-hour design were tested. In the 2-hour design (UL Design P237), the restrained assembly rating, the unrestrained rating, and the beam rating are all 2 hours (Figure 1). This rating was achieved: (1) because a gypsum board ceiling was used with the insulation placed on top of it, (2) because the insulation was placed above the ceiling line and the gypsum board acted as a heat sink, and (3) because of the fire resistance of the Conwed ceramic ceiling board.

In the test of UL Design P238 (Figure 2), the insulation used was foil-faced fiberglass with a UL flame spread rating of 25 (UL will not allow the use of anything on their designs unless it does have a 25 flame spread rating or less). The insulation was placed over the top of the fixtures and on top of a ceiling board (i.e., the ceramic board). The rest of the construction was a built-up roof with 3-1/2 inches of insulation board over a 1-1/2-inch metal deck and 1/2-inch fire-rated gypsum board.

We have approval for use of both the air-handling static fixtures and the duct work and we tested them both. There are 576 square inches per duct opening per 100 square feet of ceiling area. Twenty-five percent of the 100 square feet of the ceiling area may be light-fixture opening area. The light-fixture protection material was R-19 fiberglass, the same material as was used on the back of the board.

One reason that we achieved the 2-hour duration was because of the ceramic material. We also tested many other fire-rated materials and none of them worked. When you place the insulation on the back of the board, you do impede the passage of the heat through the construction, but you also keep the heat on the surface of the material. We found that when the temperature of the ceiling board reaches approximately 1400°F, it becomes fluid and slips out of the suspension system. The reason Conwed's ceramic product works is because it has been previously fired; therefore, it remains stable.

If insulation is to be placed on the back of the board, we recommend that the plenum space be vented, which is not always possible. The reason for venting the plenum space is to allow the escape of moisture that can condense and collect in that space. Obviously, if the plenum space is vented to dissipate moisture, any heat or gases that might escape into the plenum space through the various cracks or openings created during a fire also would be vented.

UL Designs P237 and P238 provide the building owner and the acoustical contractor with a means of re-insulating an existing building. It is very possible that the existing building is not fire rated but that by installing this type of ceiling and this type of construction, two things will be gained--an R-19 insulation and a 1-hour fire rating--while maintaining the building as is. Of course, if you vent

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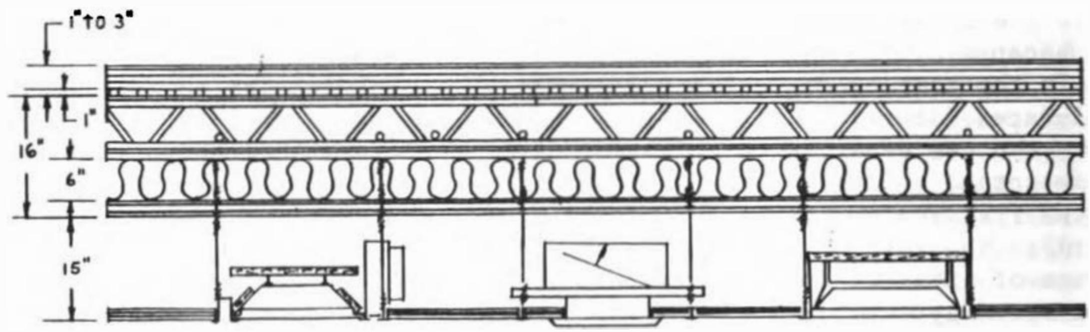

FIGURE 1 UL Design P237. The restrained assembly, unrestrained assembly, and unrestrained beam ratings are all 2 hours.

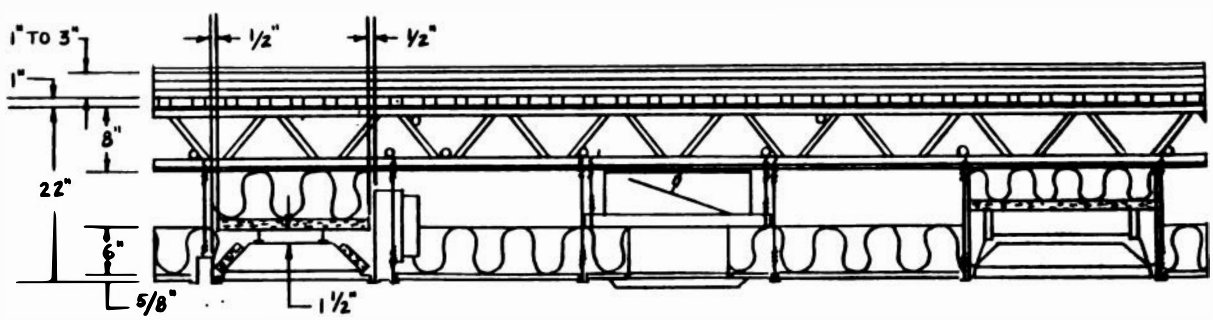

FIGURE 2 UL Design P238. The restrained assembly, unrestrained assembly, and unrestrained beam ratings are all 1 hour.

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the plenum space, you negate everything above the insulation; in other words, if you have an inch of roof insulation the value of the roof insulation is negated because the roof insulation is on the cold side of the R-19 fiberglass insulation.

The P237 double-ceiling design with the gypsum board and the ceramic board ceiling has a U-factor of 0.0445 or an R-factor of 22.46 with a vented plenum. With an unvented plenum, it has a U-factor of 0.0312 or an R-factor of 32. (As anyone that has tested at UL knows, they are not equipped to test with any type of venting because their furnaces run at a slightly negative pressure.)

Design P238 has a U-factor of 0.0473 or an R-factor of 21.14 with a vented plenum. With an unvented plenum, it has a U-factor of 0.0335 or an R-factor of 29.85. This construction gives the building owner or the architect the chance to upgrade an existing building to a 1-hour fire-rated construction.

Some of the conditions that are necessary to achieve the P237 and P238 designs are that:

1. The ceramic panel must be used (insulation placed on the back of a regular fire-rated board negates any fire rating that construction might have received);

2. All of the cross Ts must be fire-rated and hanger wire must be used at midspan of each 4-foot cross T (we found that we had to hang them at midspan because of the weight of the insulation on the back of the board); and

3. The 6-inch R-19 insulation must have a UL-approved flame spread rating.

In addition, consideration must be given to venting the plenum in order to prevent any damaging moisture buildup and that, of course, must be done on the back or cold side.

Due to the time constraint I have not given any of the dimensions or spacings. Anyone that is interested in that can contact me for them and both of these designs are listed in the UL fire-resistance directory.

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PRESENTATION

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Energy conservation has been the focal point of concern for many state and federal agencies since the cost of energy has increased drastically in the past decade. In the residential building area, builders are attempting to build homes that are energy efficient. One way to conserve energy in homes is to increase the insulation level, which is expected to reduce energy consumption and heating and cooling costs. Insulating new construction and existing homes has been the major focus of residential energy conservation.

Energy conservation has become a necessity in the 1980s; however, this does not mean that firesafety in homes should be de-emphasized when one uses energy-conservation techniques. Such federal agencies as the Consumer Product Safety Commission (CPSC), the National Bureau of Standards (NBS), and the Department of Energy (DOE) have been concerned with the relative firesafety associated with increased thermal insulation levels in an attic and the effect this has on the residential electrical wiring systems. These organizations have identified several potential hazard and problem conditions associated with thermal insulation and residential electrical systems (Gross 1978, Harwood 1978, U.S. Consumer Product Safety Commission 1980). Both NBS and CPSC researchers have performed limited laboratory tests to determine the effects of thermal insulation on electrical wiring systems and have hypothesized that thermal insulation <u>may</u> change an existing electrical deficiency into a fire hazard (Evans 1979, U.S. Consumer Product Safety Commission 1979). The CPSC (1980) has collected data on actual reported fires that identify electrical wiring systems as the source of ignition in a significantly large number of residential fires. Fire statistics also show that the greatest number of fire incidents was associated with the use of cellulosic insulation (U.S. Department of Commerce 1979, Berl and Halpen 1979). Examples of wiring problems include overloaded wiring systems, oversized fuses in circuit breakers, faulty junction boxes, and overheated recessed lighting fixtures. Data generated by the NBS (Evans 1979, Beausoliel et al. 1978) show that electrical wiring, when encased in thermal insulation and when operated

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at continuous high loads, will overheat and exceed the permitted wire temperature levels (140°F) of the National Electrical Code (National Fire Protection Association 1978).

OBJECTIVE

The concerns expressed by several federal agencies about firesafety and energy-conservation techniques are of interest to manufacturers of thermal insulation materials. A research program was established at Owens-Corning Fiberglas to generate data concerning the effect of fibrous glass insulation on electrical wiring. The purpose of the program was to measure the temperatures generated by electrical wiring when it was covered by different levels of fibrous glass insulation and the electrical wiring was operated with abnormal conditions. Abnormal operating conditions can be achieved only if the residential owner violates his electrical service safety devices (e.g., by removing the fuse or current breaker and directly wiring the circuit to the electrical service, by placing a penny behind the fuse in the fuse holder, or by using an oversized fuse instead of the proper fuse).

EXPERIMENT

Since the attic is the most commonly reported fire area in a home, it was decided to simulate the attic conditions for this fire test program. A fire test method has been proposed to the American Society of Testing and Materials (ASTM) to measure the fire performance of loose fill thermal insulation materials when subjected to a localized heat source (electrical wire or recessed light fixture). This procedure was modified to measure the temperatures associated with electrical wiring and to use batt insulation instead of loose fill insulation.

Test Apparatus—Attic Simulation

The proposed ASTM method, Localized Heat Sources and Their Effect on Loose Fill Insulation, uses a 4-foot-square simulated attic construction that is enclosed in a box with a temperature-regulated energy conservation space above the sample at a temperature of 140°F. The test box is composed of a base of 1/2-inch gypsum board with nominal 2-inch by 6-inch wood joists on 16-inch centers (Figure 1). A 14-2NM electrical wire was used as the localized heat source and was placed as shown in Figure 2. The rated current load on a 14-2NM wire is 15 amperes. An Edison base plug fuse holder was placed in series with the electrical wire before it entered the test apparatus. For the abnormal operating condition, the fuse holder was removed so that the system was

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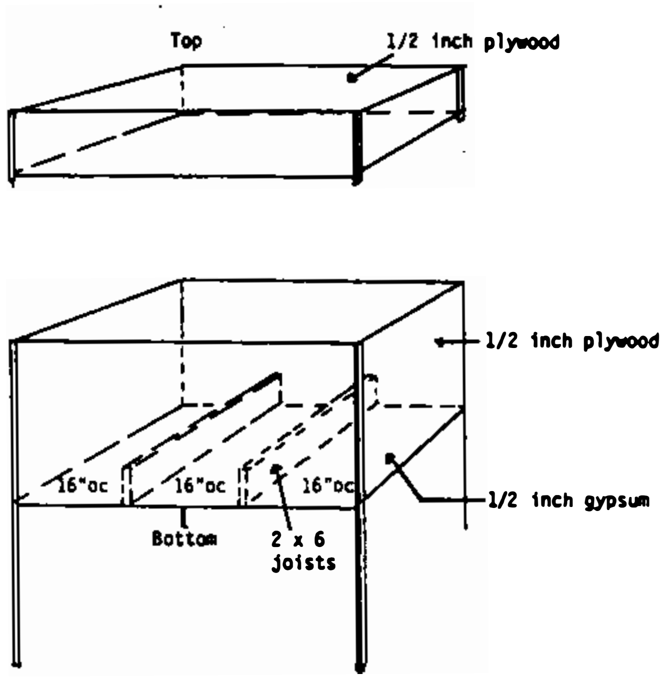

FIGURE 1 Attic simulation apparatus.

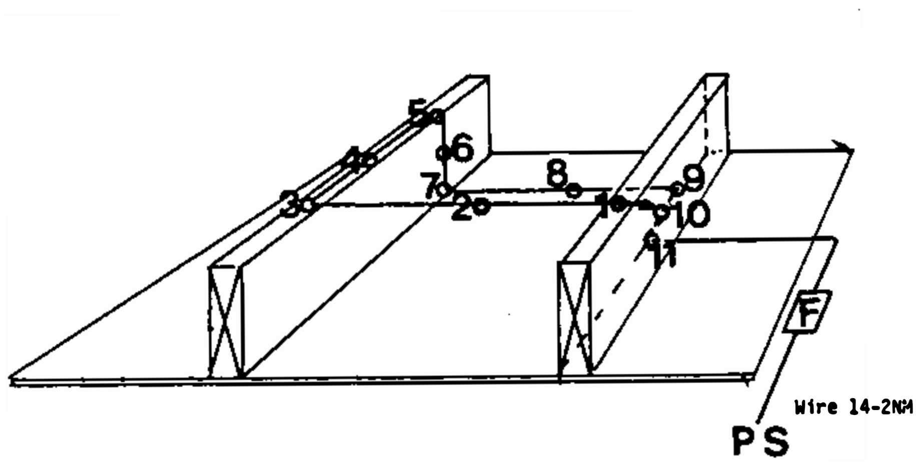

FIGURE 2 Thermocouple placement of electrical wire.

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direct-wired for test conditions A and B; for test condition C, the normal 15-ampere fuse was replaced with a 30-ampere fuse.

The current load was generated by a power system that supplied a maximum of 30 amperes of ac power to the electrical wire inside the test apparatus. The current load was monitored with a calibrated ammeter and was controlled manually with a variac every hour.

Temperature Monitoring System

A temperature monitoring system was used that consisted of 11 chromel-alumel thermocouples (28 gauge). The temperature of the electrical wire jacket was monitored as indicated in Figure 2. Three chromel-alumel thermocouples (28 gauge) also monitored the attic air temperature and the ambient temperature. An Accurex Autodata-9 data scanner was used to record the temperatures on a variable time cycle (every minute or every 30 minutes).

Sample Description

The thermal insulation used during the test program was Owens-Corning Fiberglas insulation. The insulation was kraft-faced R-19 (6 inches thick) fibrous glass insulation, 15 inches wide. Two levels of R-19 insulation were used to obtain a R-38 level (12 inches). The vapor barrier was removed from the second level of insulation for R-38 levels.

Test Conditions

A series of tests was performed in the attic simulation apparatus to study the temperature rise associated with the electrical wire (14-2NM) when loaded to the rated capacity of 15 amperes and to twice the rated capacity (30 amperes). Tests were performed at each load to measure the temperature of the electrical wire with and without insulation. Two levels of insulation were used, R-19 (6 inches) and R-38 (12 inches). The test conditions and levels of insulation are summarized in Table 1. The test conditions listed in this table are for abnormal operating conditions under laboratory conditions. As noted above, to achieve these conditions the residential owner would have to violate his electrical service safety devices.

Test Results

The maximum temperatures were measured for each test condition. These values are listed in Table 2 for condition A, in Table 3 for condition B and in Table 4 for condition C. Figures 3, 4, and 5 show typical temperature versus time curves for thermocouples 2, 4, 8, and 9 for test condition A. Figures 6, 7, and 8 show typical temperatures versus time curves for thermocouples 2, 4, 8, and 9 for test condition B.

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TABLE 1 Test Conditions, Electrical Wiring, Attic Simulation Tests

Test Condition	Ampere Load (amp)	Fuse (amp)	Insulation Level
A	15	a	None
	15	a	R-19 (6 inches)
	15	a	R-38 (12 inches)
B	30	a	None
	30	a	R-19 (6 inches)
	30	a	R-38 (12 inches)
C	30	30	None
	30	30	R-19 (6 inches)
	30	30	R-38 (12 inches)

[a] The electrical circuit was direct-wired to the power supply.

TABLE 2 Maximum Temperatures for Test Condition A (15-ampere load on a 15-ampere circuit, 14-2NM wire, no fused circuit, direct-wired)

Thermocouple Number and Position (Time Maximum Reached)	Maximum Temperature (°F) No Insulation (3-1/2 hr)	R-19 Insulation (6-1/2 hr)	R-38 Insulation (18-1/2 hr)
1. Top of joist	129	140	185
2. Air space between joists	129	135	203
3. 90 deg. bend, top of joist	129	140	192
4. Straight run, top of joist	125	140	205
5. 90 deg. bend, top of joist	130	140	180
6. Side of joist	126	140	172
7. 90 deg. bend, bottom of joist	125	125	146
8. On gypsum board	126	133	133
9. 90 deg. bend, botton of joist	125	131	128
10. Straight run, bottom of joist	121	136	122
11. 90 deg. bend, botton of joist	121	136	122
Test period (hr)	25	33	50

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TABLE 3 Maximum Temperatures for Test Condition B (30-ampere load on a 15-ampere circuit, 14-2NM wire, no fused circuit, direct-wired)

Thermocouple Number and Position	Maximum Temperature (°F) No Insulation	R-19 Insulation	R-38 Insulation
1. Top of joist	183	202	365
2. Air space between joist	171	208	460
3. 90 deg. bend, top of joist	131	214	453
4. Straight run, top of joist	143	220	465
5. 90 deg. bend, top of joist	140	234	383
6. Side of joist	112	272	332
7. 90 deg. bend, bottom of joist	171	240	262
8. On gypsum board	174	271	283
9. 90 deg. bend, botton of joist	159	262	268
10. Straight run, bottom of joist	123	287	288
11. 90 deg. bend, botton of joist	183	263	247
Test period (hr)	30	44	48
Time maximum reached (hr)	5	11	11

TABLE 4 Maximum Temperatures for Test Condition C (30-ampere load on a 15-ampere circuit, 14-2NM wire, 30 ampere fuse circuit)

Thermocouple Number and Position	Maximum Temperature (°F) No Insulation	R-19 Insulation	R-38 Insulation
1. Top of joist	174	190	249
2. Air space between joist	165	195	306
3. 90 deg. bend, top of joist	158	196	283
4. Straight run, top of joist	161	200	283
5. 90 deg. bend, top of joist	169	104	259
6. Side of joist	142	230	239
7. 90 deg. bend, bottom of joist	165	187	187
8. On gypsum board	152	205	202
9. 90 deg. bend, botton of joist	153	198	180
10. Straight run, bottom of joist	153	222	205
11. 90 deg. bend, botton of joist	170	230	214
Test period (hr)	0.63	0.55	0.48
Test period range (hr)	0.25 to 0.63	0.27 to 0.55	0.35 to 0.70

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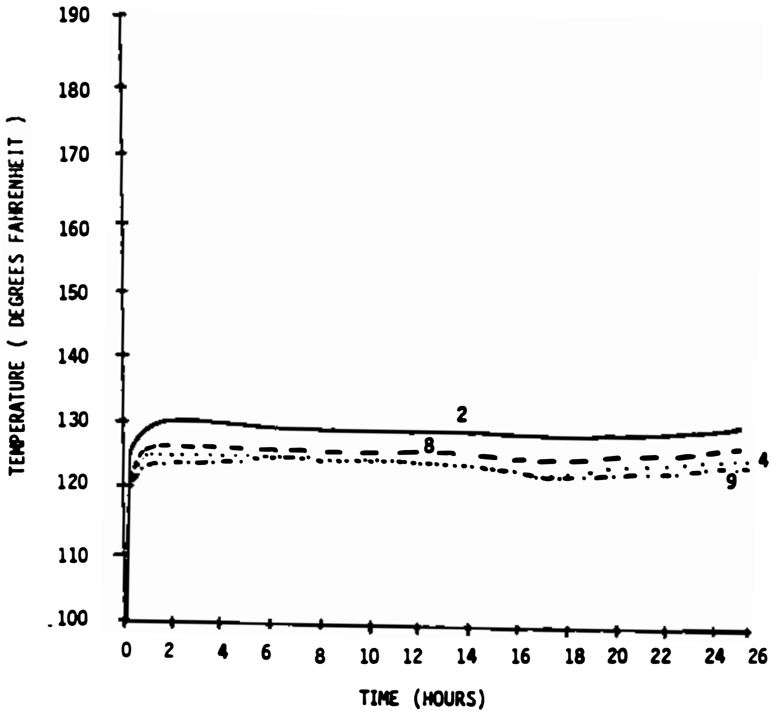

FIGURE 3 Temperature vs. time curves for 15-ampere, no insulation test.

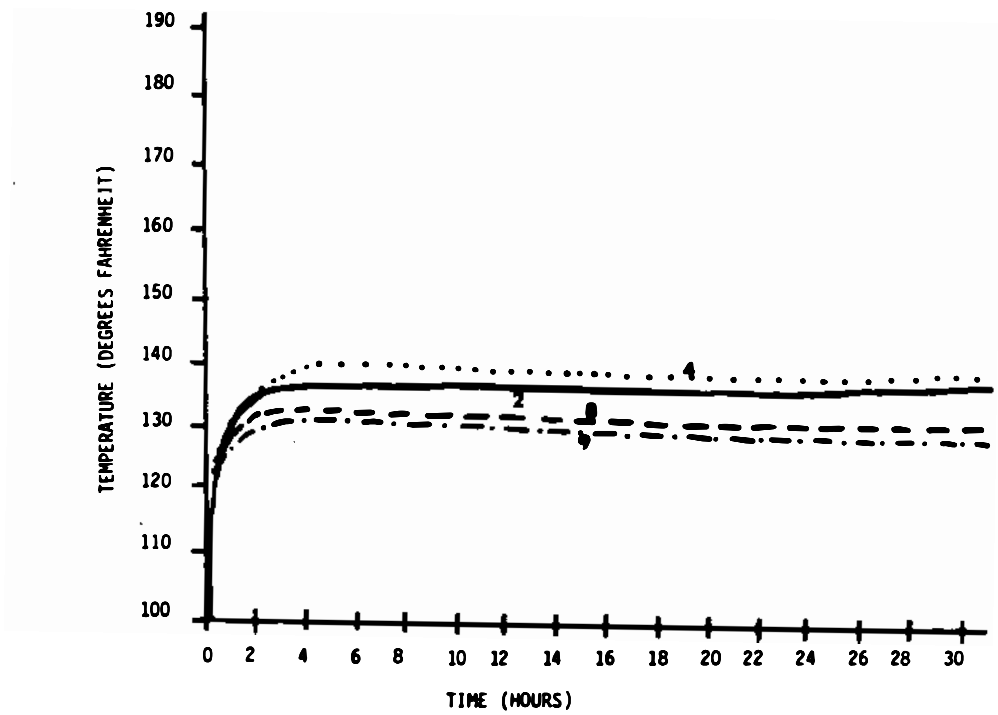

FIGURE 4 Temperature vs. time curves for 15-ampere, R-19 test.

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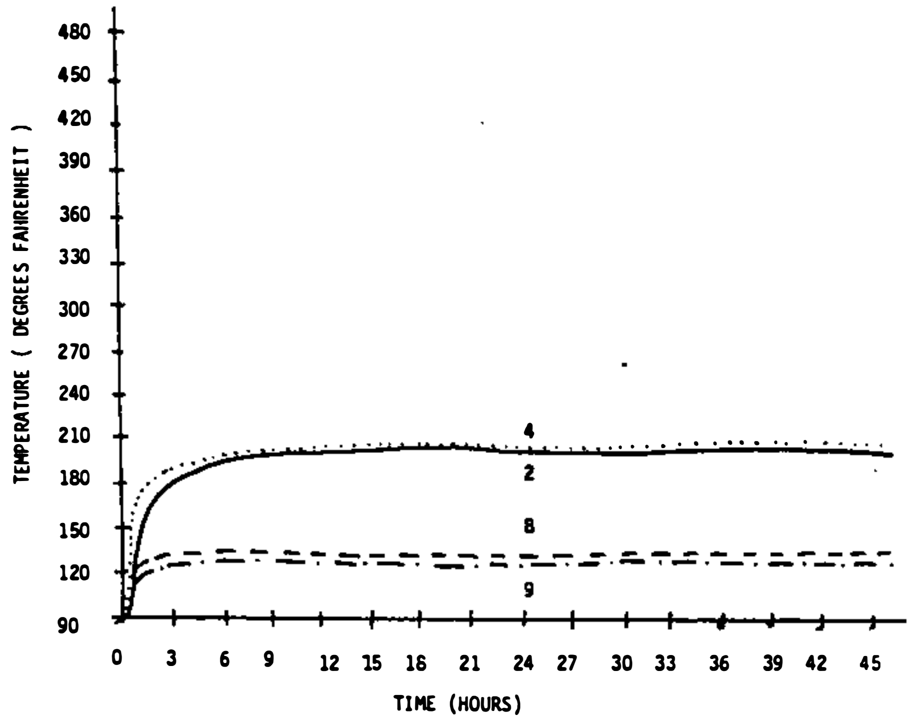

FIGURE 5 Temperature vs. time curves for 15-ampere R-38 test.

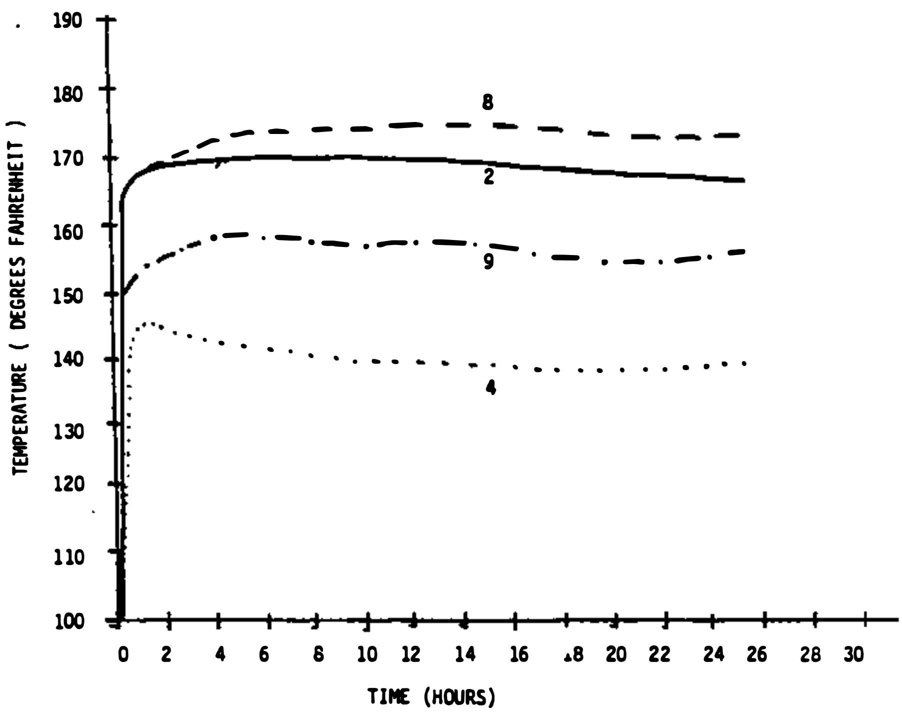

FIGURE 6 Temperature vs. time curves for 30-ampere, no insulation test.

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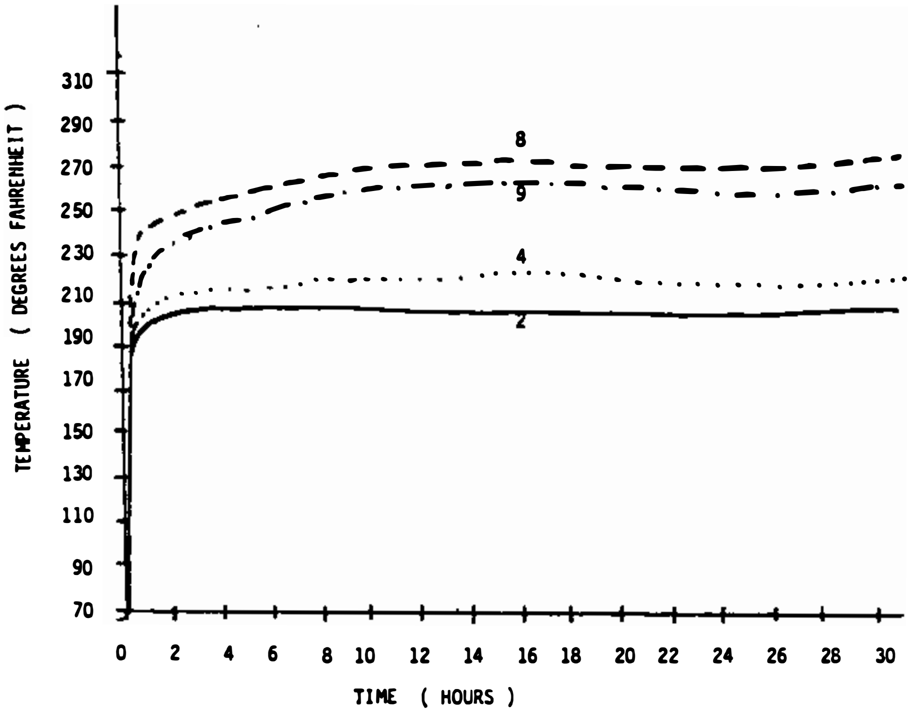

FIGURE 7 Temperature vs. time curves for 30-ampere, R-19 test.

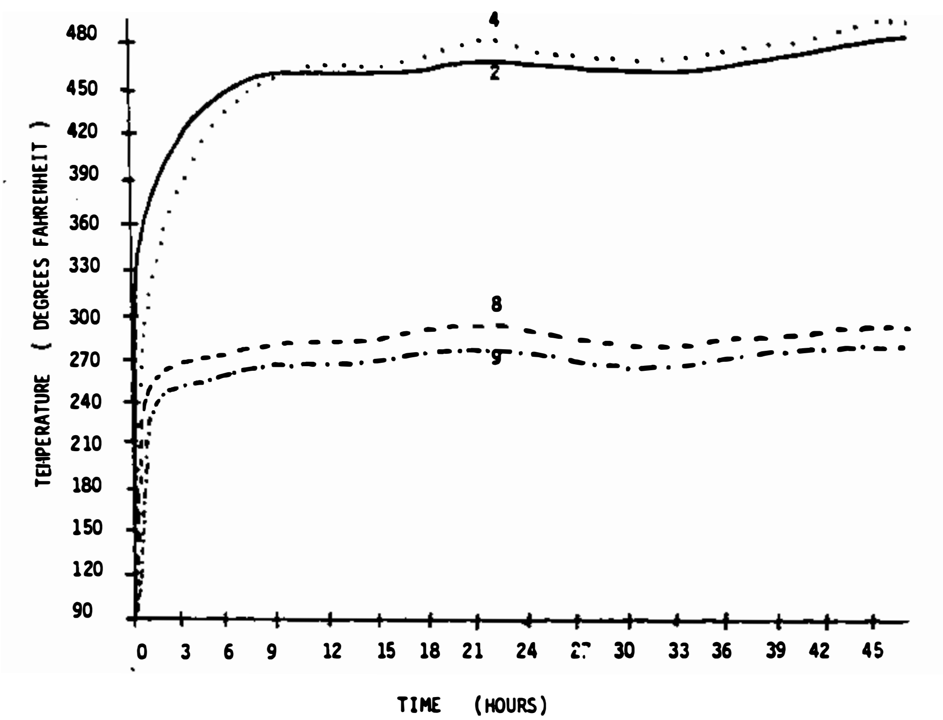

FIGURE 8 Temperature vs. time curves for 30-ampere, R-38 test.

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DISCUSSION

Test Condition A

When a 15-ampere load was placed on the 14-2NM wire without a fuse in the circuit (direct-wired) and without insulation surrounding the wiring, the maximum wire temperature was 130°F. This temperature is below the National Electrical Code limit of 140°F. When R-19 fibrous glass insulation was placed in the test apparatus, the maximum temperature was 140°F. The electrical wire jacket did not crack, char, or become brittle. When R-38 fibrous glass insulation was placed in the test apparatus, the maximum temperature was 205°F. This temperature is above the recommended National Electrical Code wire temperature; however, the wire jacket did not char, crack, or become brittle. When the electrical wire was surrounded by the insulation or by the wood joists (positions 1 through 5), the wire jacket material was slightly deformed. This test lasted for 50 hours. No fires were observed.

Test Condition B

When a 30-ampere load was placed on the 14-2NM wire without a fuse in the circuit (direct-wired) and without insulation in contact with the wire, the maximum wire temperature was 183°F. The plastic insulating wire jacket did not char, crack, or become brittle. The wire temperature exceeded the National Electrical Code specifications of 140°F. The maximum temperature was 287°F for the tests when R-19 fibrous glass insulation was in contact with the wire. These temperatures were above the recommended National Electrical Code wire temperature; however, the wire jacket did not char, crack, or become brittle. Again when the wire was in contact with the insulation and the wood joists (positions 7 through 11), the wire jacket material was slightly deformed.

The maximum wire temperature for the tests with R-38 fibrous glass insulation was 465°F. The wire jacket was pyrolyzed and the copper wire was exposed in spots. The wood joist was charred about 1/4 inch deep over the length contacted by the wire. The portion of the wire in contact with the gypsum board was not charred but only slightly deformed. Even though the wood in contact with the wire was charred, a fire was not observed during the test period, which lasted for 48 hours.

Test Condition C

A 30-ampere load was placed on the 15-ampere circuit which used a 14-2NM wire and a 30-ampere fuse. Tests were run without insulation surrounding the wire. The 30-ampere fuse operated within 15 to 38 minutes. The maximum temperatures reached on the electrical wire

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jacket ranged from 140 to 174°F. When the tests were repeated with R-19 fibrous glass insulation in contact with the wire, the fuse operated within 16 to 33 minutes. The maximum temperatures reached on the wire jacket were in the range from 190 to 224°F. The highest wire temperatures were recorded for the tests when R-38 fibrous glass insulation was in contact with the wire. The fuse operated between 21 and 42 minutes; however, the maximum temperatures ranged from 187 to 306°F.

In test C the wire temperatures were in excess of the recommended National Electrical Code maximum temperature of 140°F. Even though an oversized fuse was used in the 15-ampere circuit, the fuse did operate within time periods of less than 45 minutes. The wire jacket was not damaged. The overheated electrical wire did not ignite the insulation or the wood joists before the fuse operated.

CONCLUSIONS

The attic simulation tests on electrical wiring indicated that the wire temperature increased as the current was raised from 15 to 30 amperes with the same insulation level. The addition of insulation had a greater effect when it encased the electrical wire. This result is as expected from a heat-transfer viewpoint. When the electrical wire was in contact with the gypsum board, the heat was dispersed quite well even with R-38 insulation above. Although relatively high temperatures were recorded for the electrical wire covered by insulation, the fibrous glass insulation did not ignite even when the temperatures were high enough to destroy the electrical wire jacket and char wooden structural members (test condition B). These temperatures were obtained only after the electrical circuit safety devices were violated by direct wiring of the electrical circuit to the power supply or by placing an oversized fuse in the fuse holder.

The addition of fibrous glass thermal insulation in the attic increased the operating temperatures of electrical wire when the wire was exposed to an overload condition. The fibrous glass insulation did not increase the apparent fire hazard since no fires were observed under laboratory test conditions.

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PRESENTATION

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Fire resistance is a fundamental part of building codes and other firesafety regulations. Energy conservation has been highlighted recently in codes, and there is concern about its effect on construction assemblies that have fire resistance established without insulation. Insulation in both combustible and noncombustible constructions may have an effect on fire resistance. Data available from two studies by the American Iron and Steel Institute (AISI)--one on load-bearing steel stud walls and the other on steel C-joist and metal deck roof constructions--permit evaluation of its effects.

WALL TESTS

The study of load-bearing steel stud walls was conducted at Underwriters Laboratories (UL) using Type X gypsum wallboard as the surface protection (Figure 1). The assembly was tested with load cells under each of the six steel studs to monitor the loads in each stud throughout the test.

Temperature measurements were taken at the midheight of the steel studs and on the unexposed side of the wall face. In order to monitor wall deflections continuously up to the point of load failure, transducers were located on the unexposed side of the wall assembly at midheight.

Nine walls were tested with and without insulation. The wall construction included 3-1/2-inch, 18-gauge steel studs with punchouts in the web. Studs varying from those with many punchouts to those with almost a solid web were used. The studs were spaced 24 inches on center.

The walls were surfaced with either one or two layers of 5/8-inch Type X gypsum wallboard or three layers of 1/2-inch Type X gypsum wallboard. The test assemblies in the test program were instrumented to provide maximum data and a basis for analytically assigning fire-resistance ratings. The load, the stud cavity insulation, and the

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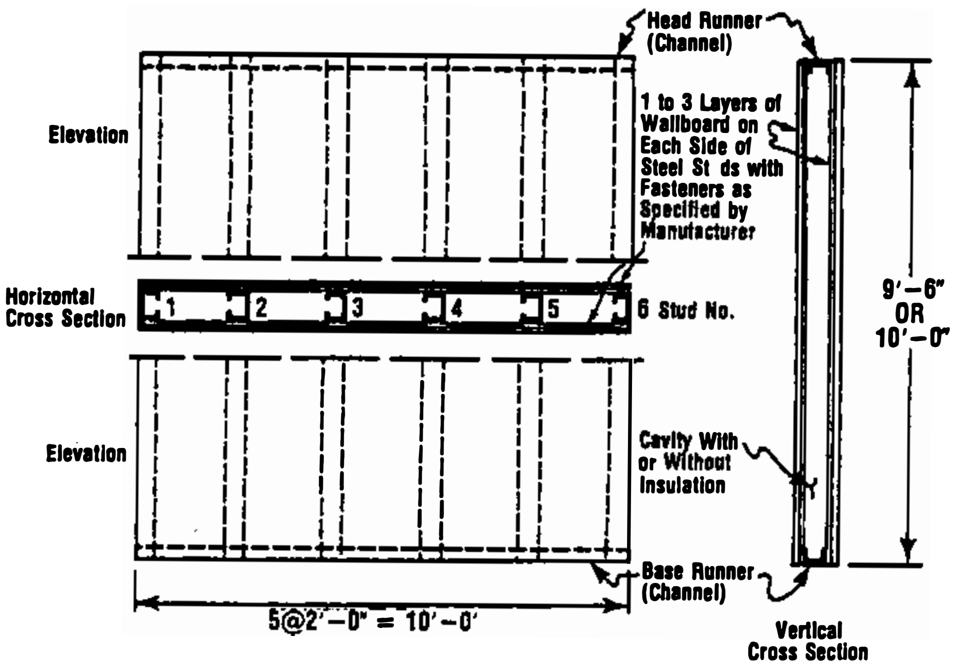

FIGURE 1 Typical wall assembly for fire test.

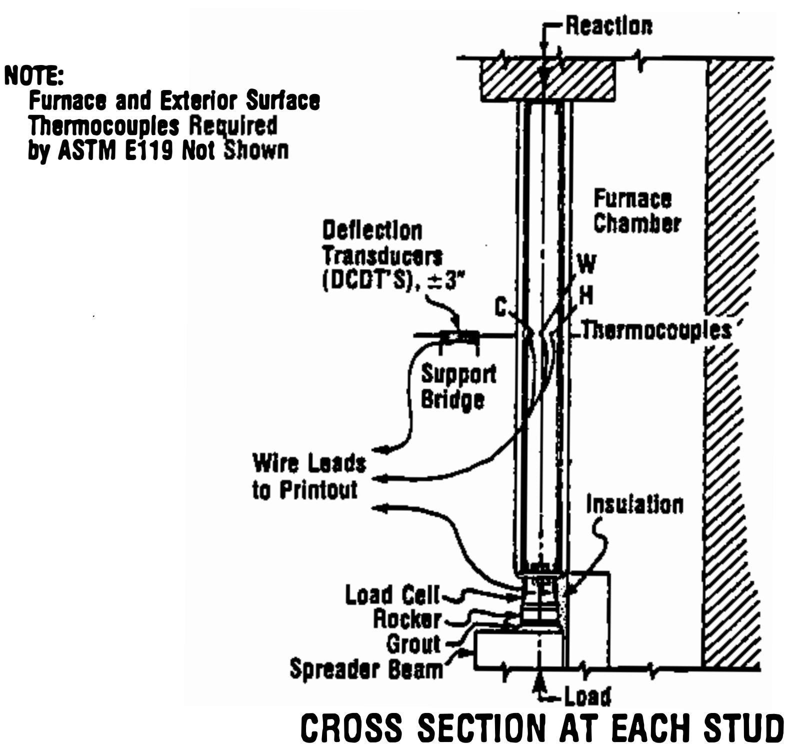

FIGURE 2 Test instrumentation; cross section at each stud.

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gypsum wallboard surfacing on each face of the wall were primary factors in wall performance. The instruments were extremely important in the analysis of the effect of each of these factors.

Figure 2 shows the load cells (located under each stud in the wall and on top of a header beam) that were used to transfer the load from the hydraulic jacks to the studs. It also shows the location of the thermocouples on the steel studs as well as on the unexposed side of the wall as required in ASTM E119, Standard Methods of Fire Tests of Building Construction and Materials (American Society for Testing and Materials 1980). Test walls 1 through 7 had only selected studs thermocoupled whereas test walls 8 and 9 had each stud thermocoupled at midheight.

After the test, visual inspection of the test assemblies provided information to confirm the recorded test data (Figure 3). The wallboard was removed so that the deformation of the studs could be studied.

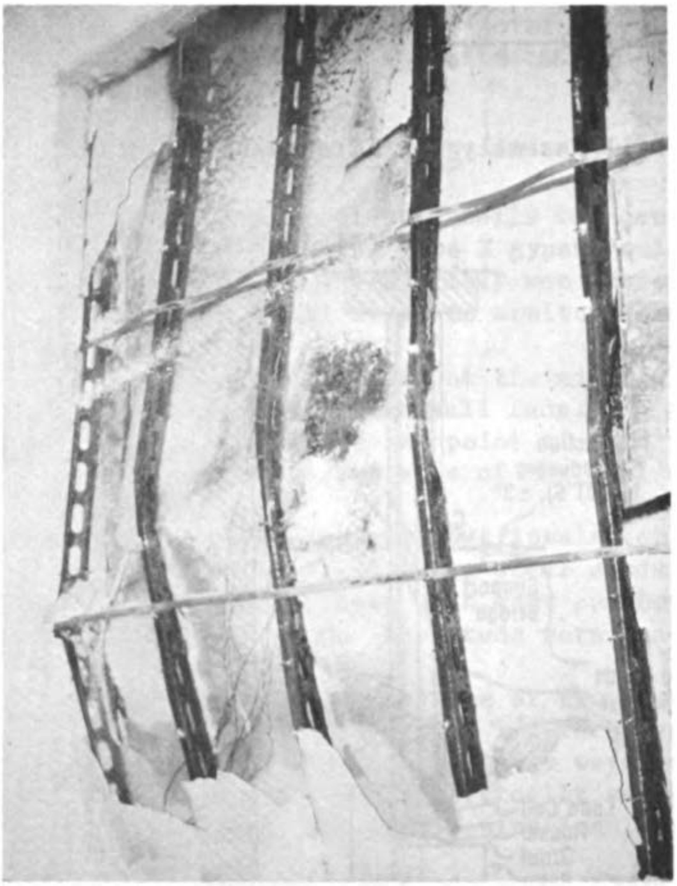

FIGURE 3 Visual inspection following test confirms deformation of wall studs recorded in test data.

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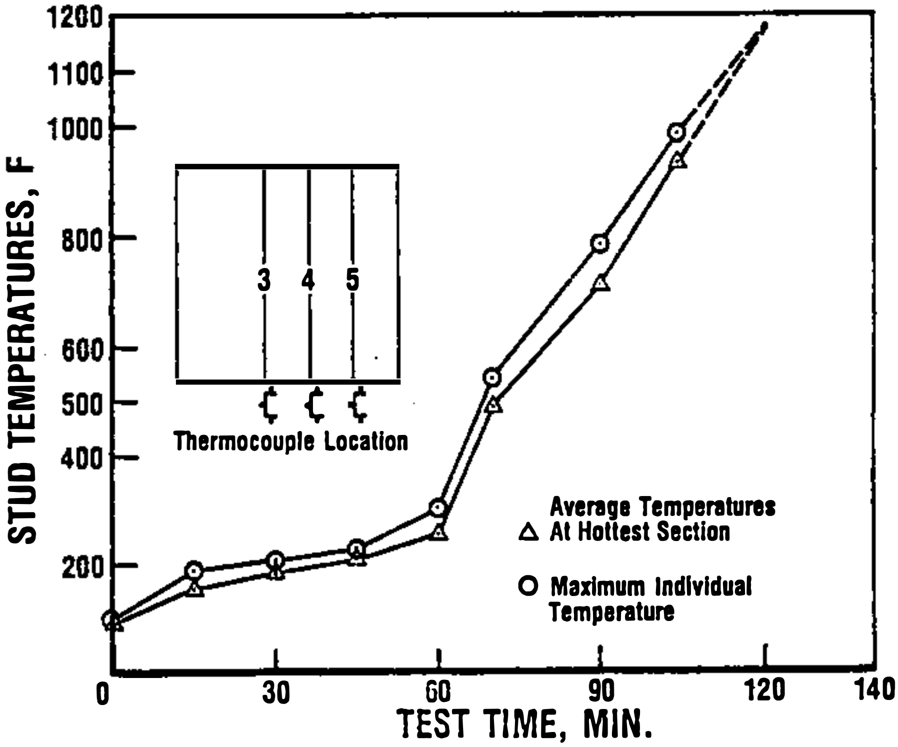

FIGURE 4 Temperature vs. time (°F) for test wall 6.

The data presented in Figure 4 are for test wall 6 with two layers of 5/8-inch wallboard and no insulation and show the temperatures on the studs. The hottest stud temperatures occurred near the middle of the wall at midheight. At 120 minutes, the temperature had not yet reached 1200°F.

Test wall 9 also had two layers of 5/8-inch-thick gypsum wallboard with insulation but the temperatures on the studs were slightly different (Figure 5). Stud 4, which was very close to the middle of the wall, showed a temperature at 120 minutes well beyond the 1200°F but no load failure occurred. Thus, insulation does make a difference on the temperature of the structural elements in a wall, but if the wall is properly designed, the load-bearing characteristics are not affected.

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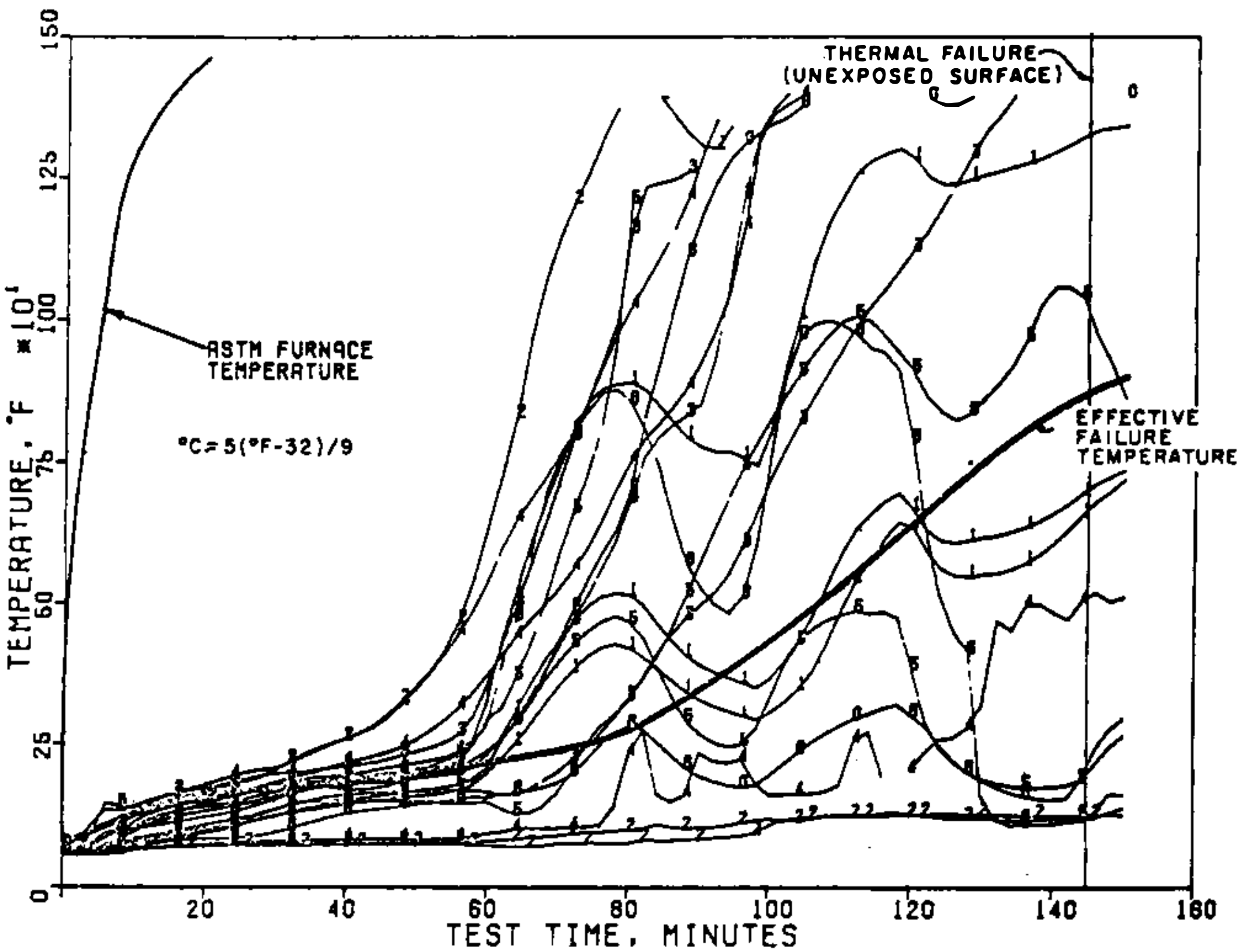

FIGURE 5 Temperature vs. time for test wall 9.

Looking at temperature versus time, test wall 8 consisted of one layer of 5/8-inch-thick gypsum wallboard and no insulation and Figure 6 shows the temperature spread on the studs throughout the wall. In this particular test, each stud was instrumented with thermocouples on the web and flanges. The studs nearest the edge of the wall, affected by their location to the concrete test frame, generally were cooler. The unexposed surface temperature was reached at slightly over 60 minutes. The load capability of wall 8 continued and there was no load failure; the test was terminated at 90 minutes.

Figure 7 examines the deflection of load-bearing steel members as influenced by insulation. The data are for wall 8 (one layer of 5/8-inch gypsum wallboard, no insulation) and show that the deflection was fairly uniform and minor throughout the period during which the load was maintained (up to 90 minutes).

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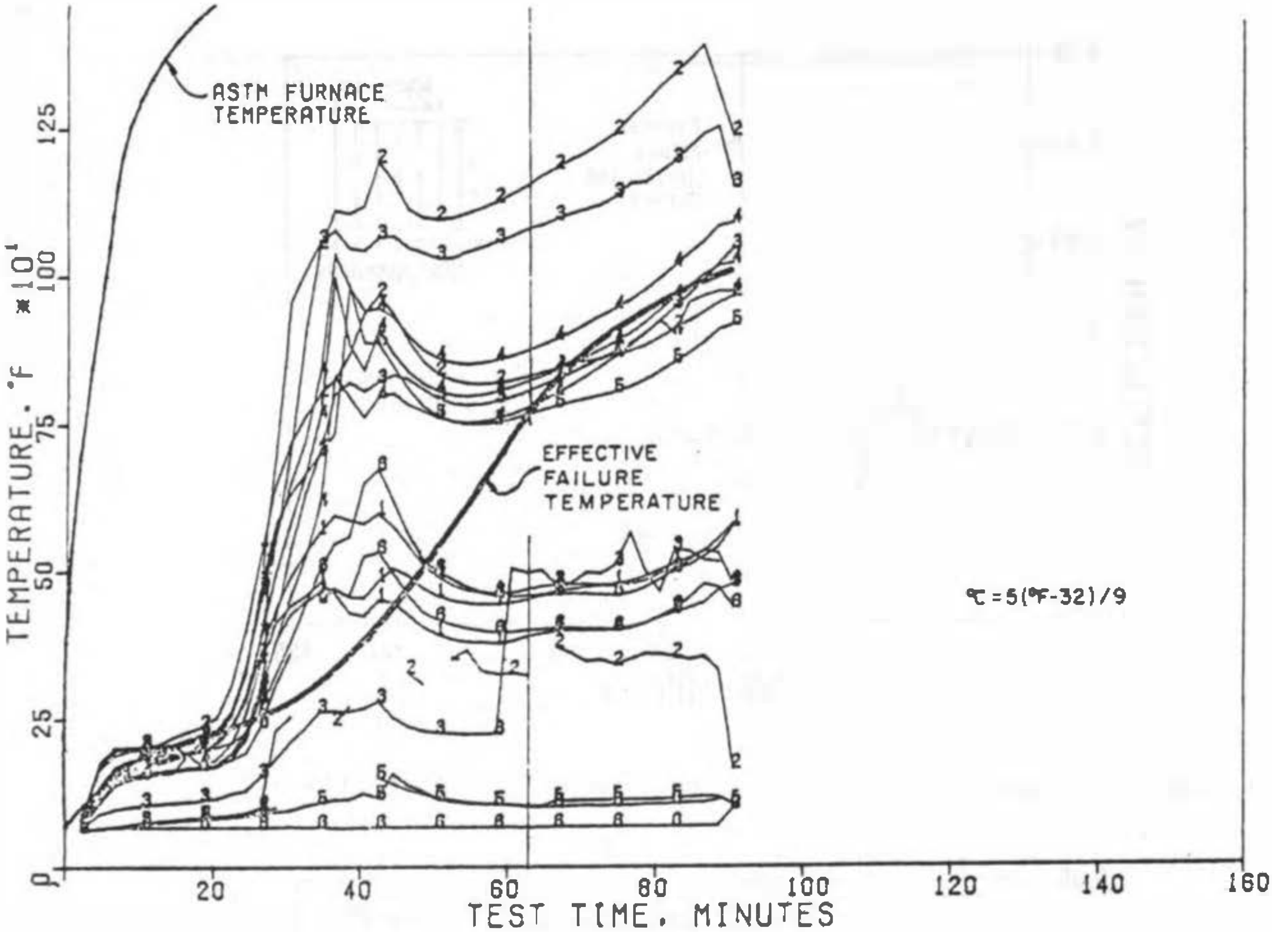

FIGURE 6 Temperature vs. time for test wall 8.

Figure 8 presents similar data for test wall 9 (two layers of 5/8-inch gypsum wallboard with insulation). The deflection of the wall, although quite large at the center, did not result in load failure, and the test was stopped at approximately 140 minutes.

The most interesting data, for load versus time, are presented in Figure 9 for test wall 8. It provides an interesting examination of tests for load-bearing walls under ASTM E119, which states that the applied load is to be maintained throughout the test period. As Figure 9 indicates, the steel studs were heated unevenly and, therefore, expanded unevenly. Some studs developed an increase in load, and this has an important bearing on the deflection curves in Figure 8. Figure 9 shows that the average load varied in the test from slightly more than 3000 pounds per stud to approximately 5000 pounds per stud.

Figure 10 shows that with an insulated wall cavity (test wall 9) the individual studs also expanded and the load on each stud varied.

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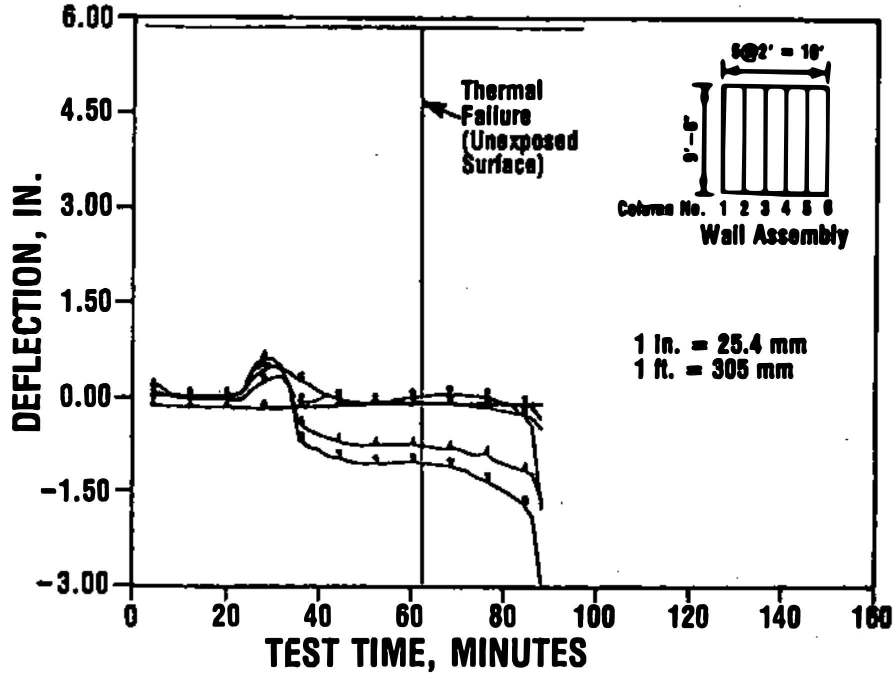

FIGURE 7 Deflection vs. time for test wall 8 (no insulation).

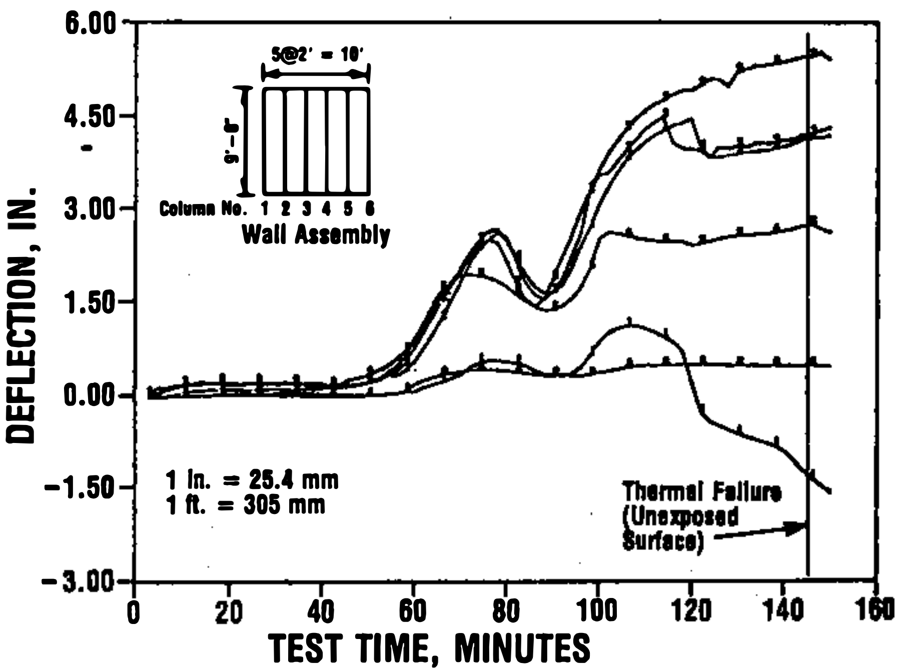

FIGURE 8 Deflection vs. time for test wall 9 (insulation in cavity).

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For example, stud 5 varied from the initial load of approximately 3.5 kips to more than 12 kips throughout the test as the studs were heated, grew, and then deflected.

The data from these tests suggest that the effective failure deflection versus time curve (Figure 11) could be affected by the applied load, the amount of cladding, and/or the presence of insulating materials between studs. However, until more data are available, the quadratic curve prepared by Klippstein (1979) is considered to account for these effects conservatively.

Further, the ASTM E119 fire test methods need more specific test criteria to ensure the structural-thermal duplication of test conditions for all components in successive tests.

Figure 12 represents the load ratio (LR) versus failure time relationship for all investigated panels, with or without insulation. LR equals the failure load at elevated test temperatures divided by the failure load at room temperature. The horizontal line is shown at LR = 12/23. This line represents the inverse of the safety factor incorporated in the usual room-temperature design of studs.

Fire endurance is determined from Figure 12 by using the vertical scale on the right, which is a design load ratio. Where that band curve crosses that horizontal line at 100 percent of the design load, the wall will have the rating--load failure will occur--in minutes along the bottom. A wall constructed with three layers of 1/2-inch-thick Type X gypsum wallboard at 100 percent of the design load, with or without insulation in the cavity, will have a 2-hour rating. In the case of two layers of 5/8-inch Type X gypsum wallboard, with or without insulation in the cavity, 100 percent of the design load will not result in a 2-hour rating unless the percentage of the design load is reduced to 8 percent of the maximum design load permitted on that wall.

The data collected during the nine tests conducted at AISI and three others conducted by an AISI member company permitted the above analysis and UL published fire resistance ratings for load-bearing steel studs, with or without insulation, as shown in the UL Fire Resistance Directory as Design U425 (Figure 13).

The interesting thing is that the interior wall ratings also can be used for exterior wall ratings, provided the same number of layers and thickness of fire-rated gypsum sheathing board are applied on the exterior face of the wall. If an exterior wall rating is needed only from the interior of the wall, then on the exterior face use a 1/2-inch layer of regular gypsum sheating, metal siding, stucco, or other finish with the cavity insulated and on the interior wall surface use the number of layers of wallboard shown in UL Design U425 for an exterior wall rating. For example, three layers of the 1/2-inch gypsum wallboard with 100 percent of the design load will have a 2-hour rating.

On the other hand, if brick veneer is used on the outside and two layers of 5/8-inch Type X gypsum wallboard are used on the inside and a single layer of 1/2-inch regular gypsum sheathing is used on the outside, the wall will have a rating from both sides of 2-hours.

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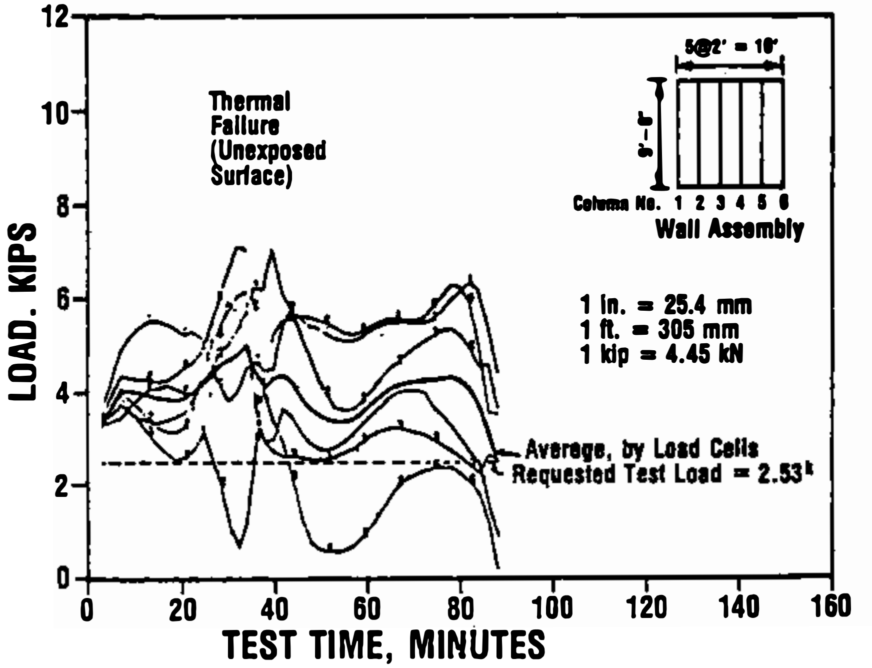

FIGURE 9 Load vs. time for test wall 8 (no insulation).

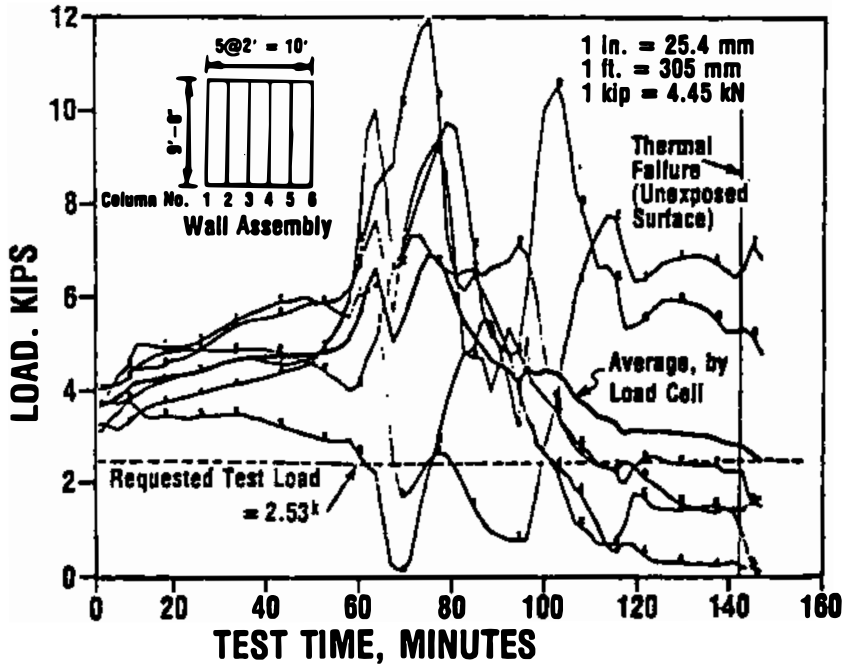

FIGURE 10 Load vs. time for test wall 9 (insulated wall cavity).

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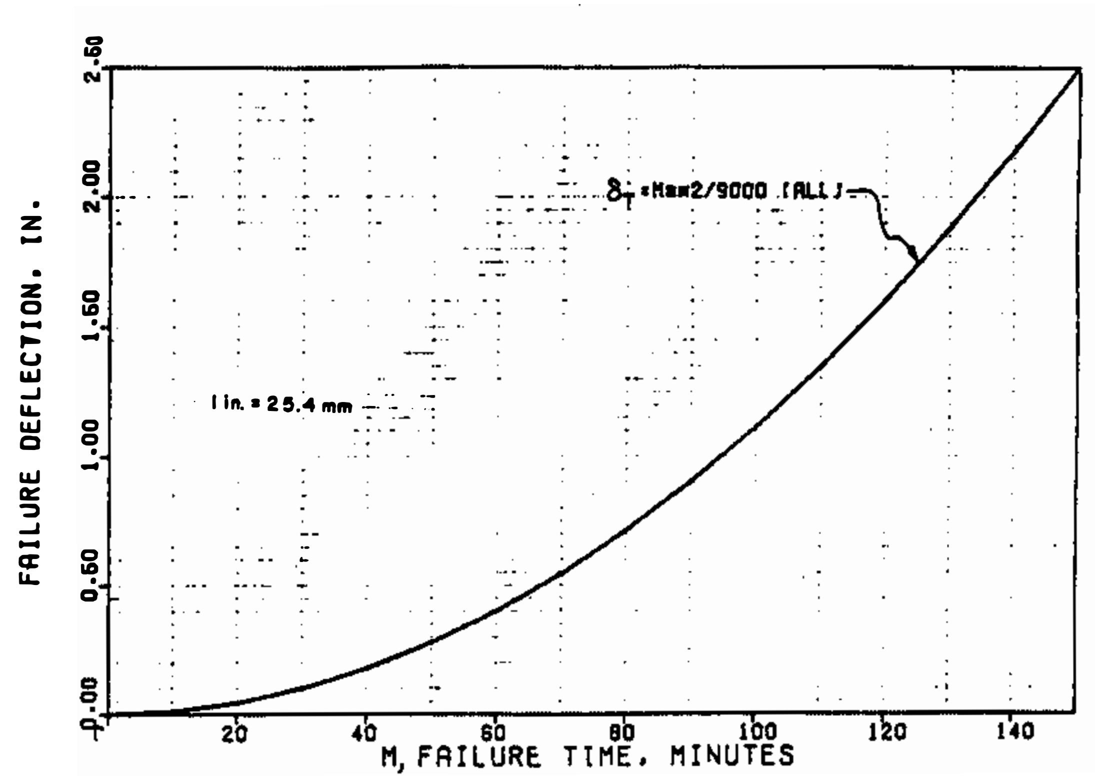

FIGURE 11 Effective failure deflection vs. time (Klippstein 1979).

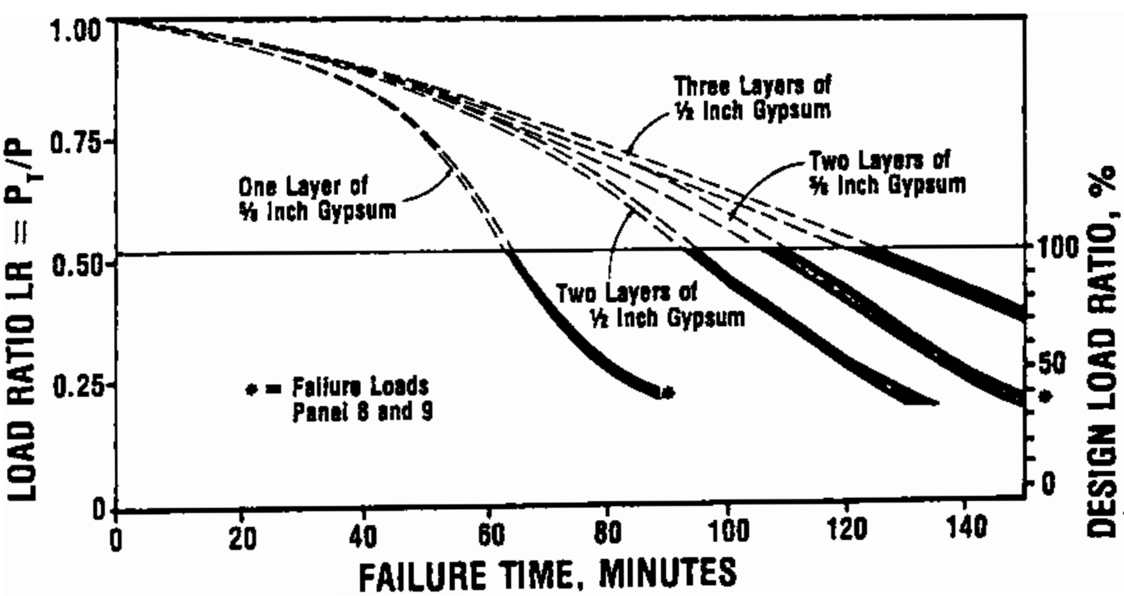

FIGURE 12 Load vs. time relationship for walls with steel studs.

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LOCATION	RATINGS (HOURS)	WALLBOARD	INSULATION	PERCENT OF DESIGN LOAD
Interior Walls*	2	2 layers — ⅝″	With or without	80%
Ratings either face of wall	2	3 layers — ½″	With or without	180%
	1½	2 layers — ½″	With or without	100%
	1	1 layer — ⅝″	With or without	100%
	¾	1 layer — ½″	With or without	100%
Exterior Walls	2	3 layers — ½″**	With	100%
Ratings for inside only	1½	2 layers — ⅝″**	With	100%
	1	2 layers — ½″**	With	100%
	1	1 layer — ⅝″***	With	100%

*Wallboards for each face of the wall assembly.
**Interior face of wall assembly is covered as shown; the exterior face is covered with a single layer of ½-inch-thick regular gypsum sheathing and a choice of exterior facings.
***Exterior face covered with a single layer of ⅝-inch-thick fire resistive gypsum sheathing and a choice of exterior facings; Ratings for either face of wall.

FIGURE 13 Fire Ratings for UL Design U425.

ROOF TESTS

The second series of tests conducted by AISI at UL were on an insulated steel roof deck supported on 18-gauge C joists 7-1/4 inches deep. The price of wood goes up or down and, depending on how the price fluctuates, wood sometimes is more difficult to obtain than steel. For example, several years ago the Perl Mac Company in Denver, Colorado, built about 6000 homes in that area. The price of wood fluctuated so much that about half the houses used light-gauge steel framing. The steel industry was and is extremely interested in this and other commercial markets; however, test data were needed to determine the effect of insulation on a roof system where a fire resistance rating was required.

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Figure 14 illustrates the construction tested. It consisted of two layers (2-7/16 inches each) of Owens-Corning fiber glass insulation on steel deck with 1/2-inch-thick gypsum sheathing board, all supported

FIGURE 14 UL Design P512; the unrestrained assembly rating--is 1 hour.

by 7-1/4-inch, 18-gauge, steel C joists, 24 inches on center. The ceiling protection was two layers of 1/2-inch gypsum wallboard (any UL classified type).

The assembly, UL Design P512, received a 1-hour fire resistance rating. But more important, UL agreed to analyze a small 3-foot-square specimen of this roof to see if it was possible to substitute other types of roof insulation for that used in the test.

Several small-scale fire tests were conducted to determine the temperature or thermal gradient through the assembly. Using this temperature data as a reference, small-scale tests may be run with substitute insulation for acceptance in UL Design P512.

Figure 15 illustrates that temperatures were recorded at various points. UL has stated that for alternate insulating materials to be acceptable, the results of the small-scale fire test should be as follows:

1. The test assembly must meet the conditions of acceptance discribed in UL 263 (ASTM E119);

2. The average temperature of the steel roof deck units during the 60-minute fire test must be similar to the average temperature of the roof deck units shown for the small-scale test samples; and

3. At 60 minutes the average temperature of the steel roof deck units must be equal to or less that 525°F.

Table 1 presents the temperatures at the midheight of the plenum. Table 2 gives the steel roof deck temperatures on the underside of the deck in the plenum area; at 60 minutes they were 515°F and 510°F. Keep in mind UL says that the trend of temperatures throughout the 60-minute test must be similar to the temperatures and the final temperature in Table 2. Thus, Table 2 is a key temperature chart for anyone seeking to substitute insulation materials in this tested assembly.

Table 3 shows the temperature change from start to finish on the unexposed surface of the second layer of insulation underneath the built-up roof covering. The change in temperature is small indicating that more insulation should not adversely affect the 1-hour rating for this construction.

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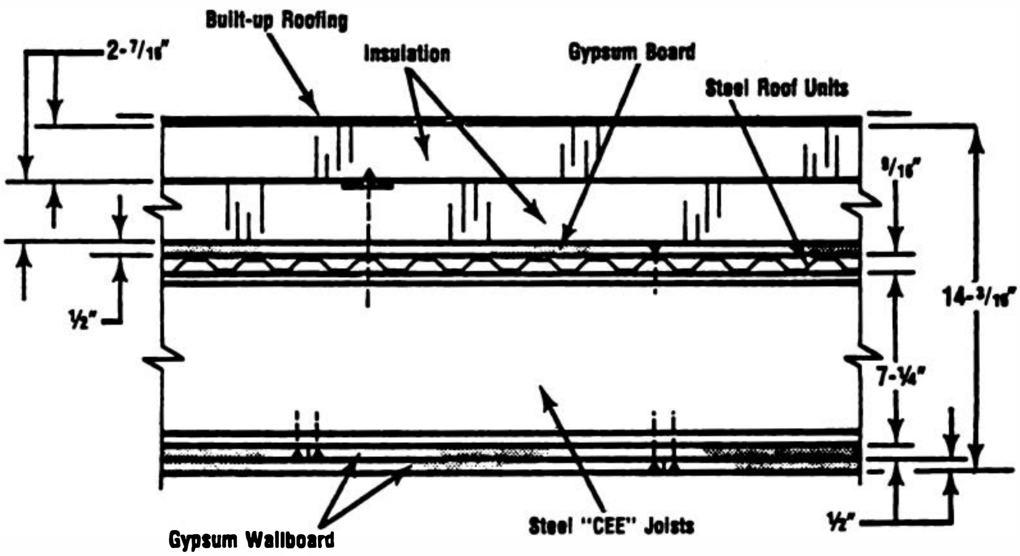

FIGURE 14 UL Design P512; the unrestrained assembly raling--is 1 hour.

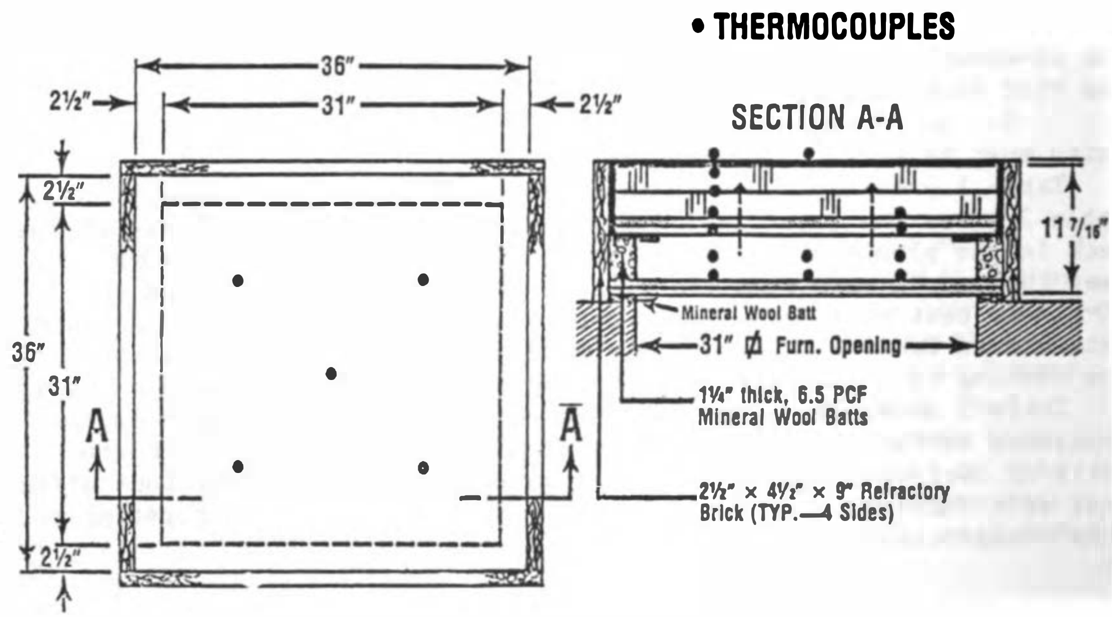

FIGURE 15 Location of thermocouples.

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TABLE 1 Average Temperatures (^{o}F) at Mid-Height of Plenum

Time (min)	Full-Scale Test	Small-Scale Test 1	Small-Scale Test 2
5	120	110	108
10	170	143	192
15	180	161	165
20	195	175	170
25	210	195	195
30	220	205	215
25	228	215	220
40	270	225	233
45	462	278	327
50	-	445	466
55	-	543	547
60	-	642	615

TABLE 2 Average Temperatures (^{o}F) of Steel Roof Deck Units

Time (min)	Full-Scale Test	Small-Scale Test 1	Small-Scale Test 2
5	110	95	100
10	165	130	130
15	175	150	150
20	190	163	165
25	200	170	175
30	205	175	185
35	205	180	190
40	210	185	195
45	307	215	218
50	-	323	340
55	-	428	440
60	-	515	510

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TABLE 3 Average Temperatures (°F) of Unexposed Surface of Second Layer Insulation

Time (min)	Full-Scale Test	Small-Scale Test 1	Small-Scale Test 2
5	72	80	82
10	72	80	85
15	72	80	83
20	72	80	85
25	72	80	85
30	72	82	83
35	72	83	83
40	72	85	83
45	73	85	85
50	-	85	83
55	-	85	83
60	-	85	83

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MULTISTORY FIRE EVALUATION PROGRAM

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Energy conservation has become an important factor in building design. In order to make exterior walls more energy-efficient and especially to reduce the high construction costs of exterior walls, foam plastic insulation currently is being used in exterior nonload-bearing wall systems, predominantly in single-story buildings, throughout the United States. These systems basically consist of a sandwich panel with steel or metal facings on both sides and some type of foam plastic insulation in the core; insulation thickness depends on the geographic location of the construction. Typically, the foam plastic insulation is either urethane or isocyanurate rigid foam.

Due to their increased energy efficiency and their lower construction costs, these wall systems now are being considered for use in multistory applications. However, code officials throughout the United States have required that the panel manufacturers demonstrate that the use of this type of exterior wall system does not pose a significant increase in fire hazard in multistory constructions. The major questions about the use of these wall systems in multistory construction are:

1. Would the combustible foam insulation provide a vehicle for rapid flame spread from compartment of fire origin to a vertical adjacent space?
2. Would the wall panels warp and buckle in such a manner as to provide an avenue for heat and flame transmission through the openings protected by the firesafe material?
3. Would there be a significant vertical spread of fire along the exterior face of the panels, predominantly along the seams?
4. Would there be a vertical spread of fire along the interior face of the panels into the second story?
5. Would the panels warp and buckle away from the fire-rated or permanent walls of adjacent spaces on the same floor to provide an avenue through which the flames and the heat would be transmitted into the adjacent compartments?

In order to answer these questions, a broad-based industry group, the Exterior Nonbearing Wall Task Group, was formed under the auspices

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of the Society of the Plastics Industry (SPI). This task group was charged to address the concerns of the code officials and to show that this type of wall construction would not pose an increased fire hazard in multistory applications. In order to accomplish this task, the group contracted with the Southwest Research Institute (SWRI) to help in the design and the performance of a multistory fire evaluation program.

The objective of this program was to determine the performance characteristics of foam plastic insulated wall panels in a multistory application based on full-scale test configurations. The primary panel performance characteristics of concern in this program were:

1. The capability of the panels to resist vertical spread of flame within the core of the panel from one story to the next,
2. The capability of the panels to resist significant flame propagation over the exterior face of the panels,
3. The capability of the panels to resist vertical spread of flame over the interior face of the panels from one story to the next, and
4. The capability of the panels to resist significant lateral spread of flame from the compartment of fire origin to adjacent space.

In order to perform the program objective and to evaluate the performance characteristics, a test protocol was developed using inputs from the SPI task group members, from the technical directors of the three model building code groups, and from various code officials and fire consultants throughout the United States. The test protocol was finalized and the major elements of this protocol consisted of the following:

1. Test Structure--This was to be a permanent two-story building constructed so that the test wall systems would form two intersecting walls and, thus, provide a corner configuration. The first floor would be the room of fire origin.
2. Ventilation--One of the test walls would contain a window opening. This window opening not only would satisfy fire ventilation requirements but also would have relationship to the energy-conservation requirements of the codes.
3. Fuel Source--Initial discussion involved a fire load similar to that permitted by the codes in the types of multistory structure for which these tests were being conducted. This fire load would have resulted in a wood crib of approximately 5000 pounds. This, of course, would almost certainly destroy any fixture that might be constructed. It also was suggested that a wood crib was preferable to a gas-fired source because of the need to include radiant energy. The final approach was to design a wood crib that would reproduce the ASTM E119 time and temperature conditions for the room of fire origin for the test duration.
4. Test Duration--The test period was initially set at 15 minutes. However, due to the nature of this nonstandard test, the test duration was extended to 30 minutes in order to assess more fully the performance of the wall systems under pessimistic conditions.

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5. Benchmark Test—As a point of comparison, the performance of the wall systems tested should be viewed relative to the performance of a noncombustible, code-acceptable wall system. In this program, a fiberglass-insulated steel panel wall system was selected as the benchmark to establish a performance level based on the finalized test protocol.

A permanent two-story test fixture was constructed at the SWRI. This fixture consisted of a building, two stories in height, with the floor-to-ceiling height of each floor being 12 feet. The interior rooms with the test walls in place were 15 feet by 15 feet. The permanent walls of the test structure were of concrete block construction and the floors and ceilings were of concrete slab construction. Prior to the test, all interior walls, floors and ceilings, spandrel beams, and columns were fireproofed in order to protect the test structure.

As noted above, the test walls intersected to form a corner configuration. The east test wall was constructed without any openings. The north test wall was constructed with a window opening centered with respect to the room of fire origin. The window opening was 8 feet wide by 4 feet high with a sill height of 3 feet. The wall systems extended beyond the permanent concrete block walls in order to simulate adjacent lateral spaces.

The wood crib used was of Douglas fir and was basically 8 feet long, 4 feet deep, and approximately 2-1/2 feet high. It was constructed of 2-inch by 4-inch boards so that the longitudinal rows were made up of seven 8-foot lengths and the transverse rows, of fourteen 4-foot lengths. The crib was raised above the floor in order to provide adequate ventilation during the test. In order to ignite the crib, approximately 1 gallon of kerosene was divided among eight pans placed underneath the crib. These pans were interconnected with kerosene-soaked rags and approximately 2 pints of kerosene were poured over the crib just prior to the test. In order to initiate the test, the kerosene-soaked rags were ignited and fire spread rapidly through the kerosene, providing an immediate increase in temperature in the room of fire origin and also igniting the wood crib.

Instrumentation in the test program consisted primarily of temperature measurements. Approximately 100 thermocouples were placed at various locations in the room of fire origin to monitor the progress of the fire and along the exterior face of the wall panels, both the north and the east walls. Thermocouples also were placed across the window openings to monitor the temperature of the flames exiting from the window and at various locations in the core of the wall systems to monitor the temperature inside the cavity of the system. The in-cavity temperature measurements were used to determine whether or not there was a spread of fire into the adjacent space through the core insulation material.

The test program consisted of a total of six tests; however, only the first four will be discussed. These were:

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1. Wall System A, Gypsum Board Walls—This test was conducted to determine the performance of the wood crib (i.e., to verify that it would meet the time and temperature requirements that were imposed on it).

2. Wall System B, The Benchmark Test--This was a test of the code-acceptable, noncombustible wall. This system consisted of metal panels with 4-1/2 inches of fiberglass insulation in the cavities.

3. Wall System C—This wall system consisted of commercially available steel-clad urethane foam insulated wall panels with a thermal barrier. The facings were of 22-gauge steel and the core was of 2 inches of urethane foam insulation. A thermal barrier consisting of one layer of 1/2-inch Type X gypsum wallboard was placed on the interior face of the wall system. This is a normal construction technique currently used in response to the requirements of code officials.

4. Wall System D--This wall system was similar to wall system C, a commercally available steel-clad urethane foam insulated wall panel system; however, no thermal barrier was applied to the interior surfaces of the wall system.

Basic fire properties of all the wall systems evaluated in this program were that the test panels had a flame spread rating of less than or equal to 25, a smoke development rating of less than or equal to 450, and the potential heat of the foam plastic insulation was less that or equal to 6000 Btu per square foot.

The U-values of the wall systems tested also were obtained. Wall system A, the gypsum board wall, had a U-value of 0.263, a much higher value than the other systems because no insulation was used. The U-values of wall system B (0.062), C (0.064), and D (0.062) were kept very similar so that any differences in the performance of the wall systems would not be related to either an increase or a decrease in the insulation value of the systems.

Test 1 (wall system A) was performed to verify that the crib would meet the time and temperature requirements as specified in the test protocol. The walls that were used in this test were gypsum board construction without insulation materials. At approximately 10 minutes into the test flames began to exit from the window openings up to an elevation of approximately 11 to 12 feet and continued to do so throughout the entire test period. It was noted that at approximately 35 minutes into the test period the smoke emerging from the room of fire origin changed color from the grey that it had been to a very dense black. This was due to the ventilation-controlled situation of the fire, but it also showed that black smoke, normally associated with burning plastics, can be produced by only burning wood materials.

Figure 1 is a plot of the temperatures obtained in the room of fire origin during the test. These data show that the time and temperature curve obtained during the test very closely followed the ASTM E119 time and temperature curve. In the time frame of approximately 35 to 45 minutes, a marked increase in temperature due to intensification of the fire was noted. This time coincides with the emergence of the black

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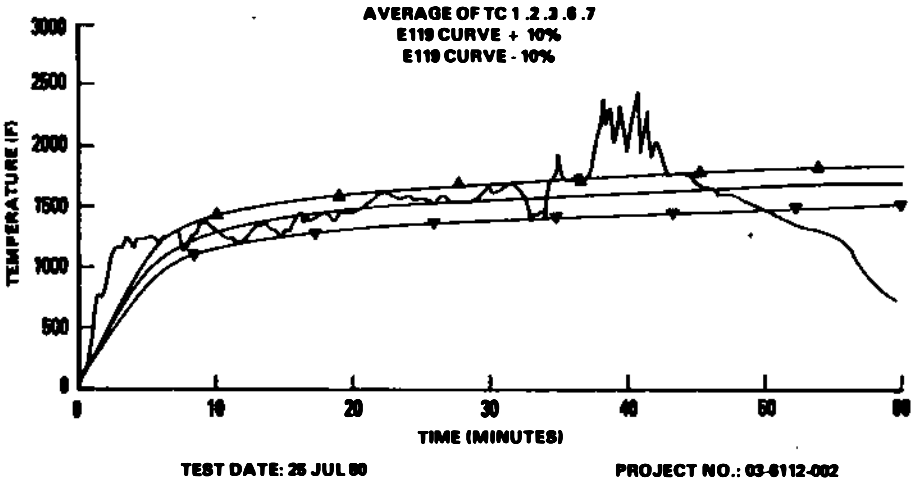

FIGURE 1 Temperatures obtained in the room of fire origin during the test of wall system A.

smoke from the window. It also should be noted that in tests of wall systems B, C and D, this fire intensification period occurred significantly earlier at approximately 25 to 30 minutes into the test period. This probably was due to the reflectiveness of the metal panels (re-radiating the heat back to the wood crib and intensifying the fire) and/or to the increased insulation of the wall systems tested in systems B, C and D (retaining the heat in the room of fire origin and thereby reintensifying the burning of the crib).

Test 2 (wall system B) was conducted as the benchmark test using the code-acceptable, noncombustible wall system. The wall system was constructed of 22-gauge steel panels on both faces and the cavity contained 4-1/2 inches of fiberglass insulation. At the end of the test, the test panels were dismantled and an evaluation was made of the damage to the core insulation materials. On the north wall, the insulation immediately adjacent to the room of fire origin was completely destroyed for the full width of the test wall and vertically to a horizontal fire stop at the second floor line. There was some damage of the fiberglass insulation above this horizontal fire stop on the panels directly above the window opening up to a height of approximately 1 to 2 feet above the second floor line. There also was smoke discoloration of the fiberglass insulation all the way up to the 26-foot mark. On the east wall, the fiberglass insulation immediately adjacent to the room of fire origin was completely destroyed, and in the corner area, destruction of the insulation extended above the second floor line approximately 1 to 1-1/2 feet.

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Test 3 (wall system C) was performed using a commercially available steel-clad sandwich panel consisting of 22-gauge steel on each face and 2 inches of urethane foam in the core. In this test, one layer of 1/2-inch Type X gypsum wallboard was installed on the interior face of the wall panels. It should be noted that in tests using panels of this type, there was intermittent flaming along the exterior seams because the seams expanded and warped, thereby exposing the urethane foam which ignites. Smoke also emerged through the seams that opened up due to heat expansion during the test period. The core insulation of the north wall was completely destroyed up to the second floor line, and full-depth char extended approximately another 1-1/2 feet to 2 feet above the second floor line in the three panels directly above the window opening. On the east wall, complete foam degradation was noted in the areas of the wall adjacent to the room of fire origin; however, this charring did not extend above the second floor line. The corner panel had full-depth char extending approximately 1-1/2 feet above the second floor line.

Test 4 (wall system D) was performed on a wall system very similar to wall system C except that the thermal barrier was not installed on the interior surface of the wall panels. Damage to the core insulation was such that full-depth char extended approximately 2 feet above the second floor line in the three panels directly above the window opening. There was total destruction of the core insulation immediately adjacent to the area of fire origin in the north wall. In the east wall, the core insulation immediately adjacent to the room of fire origin was totally destroyed with full-depth char extending up to the second floor line; however, no char was noted above the second floor line on the east wall.

Several conclusions were drawn based on this test series:

1. The crib used in the program does provide a fire intensity similar to the ASTM E119 time and temperature conditions for a period of 30 minutes.

2. In all tests there was no flame penetration into the second floor area during the 30-minute test period.

3. In all tests there was no significant flame propagation over the exterior face of the wall panels.

4. In all tests there was total destruction of the core insulation in both the east and north walls to an elevation of approximately 11-1/2 to 12 feet.

5. In all tests there was heat damage to the core insulation above the second floor line on the wall with the window opening.

6. In tests 3 and 4, there was no lateral spread of flame from the compartment of fire origin to adjacent spaces during the 30-minute test exposure. In test 2, the fiberglass insulation was damaged for the full width of the wall system.

7. During all tests smoke was observed in the second floor room during the 30-minute test period.

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In summary, a test protocol has been developed and tests have been performed to evaluate the fire performance characteristics of exterior nonload-bearing wall systems for use in multistory applications. These test results have been submitted to various code officials throughout the United States and acceptance of the wall systems has been granted by many of the code bodies. For anyone requiring further information concerning these tests, the final report of this program is available from the headquarters of the Society of the Plastics Industry in New York, New York.

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PRESENTATION
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The changing economics of energy utilization have resulted in the increased use of thermal insulating materials in all forms of building construction. Cellulose fiber insulation is one such material. A major use of cellulose fiber insulation is as attic joist cavity fill insulation in residential and light commercial-industrial construction.

The increased use of cellulose insulation materials has raised some questions: What are the fire characteristics of concern for these materials? How can these fire characteristics be measured? What is the relationship of performance both between various test methods as well as between test methods and actual installation situations? What is the impact of recessed light fixtures and electrical wiring on such installations.

These questions and others were the subject of in-house studies and sponsored research recently undertaken at Underwriters Laboratories. One project of special interest was undertaken under the sponsorship of the Department of Energy (through Oak Ridge National Laboratories). The program was intended to develop data for the evaluation of the fire performance characteristics of building insulation materials used in wood frame attics.

FIRE TEST STUDIES

Full-scale and standarized laboratory fire tests were used to evaluate the fire performance characteristics of several insulation materials. The degree of fire retardance produced in cellulosic materials by commonly used treating methods and the relationship between laboratory tests and full-scale performance were explored in the investigations.

Full-Scale Fire Tests

The full-scale attic burns involved both flaming and nonflaming ignition sources and were conducted in simulated attic constructions such as that shown in Figure 1. Flaming ignition sources included a

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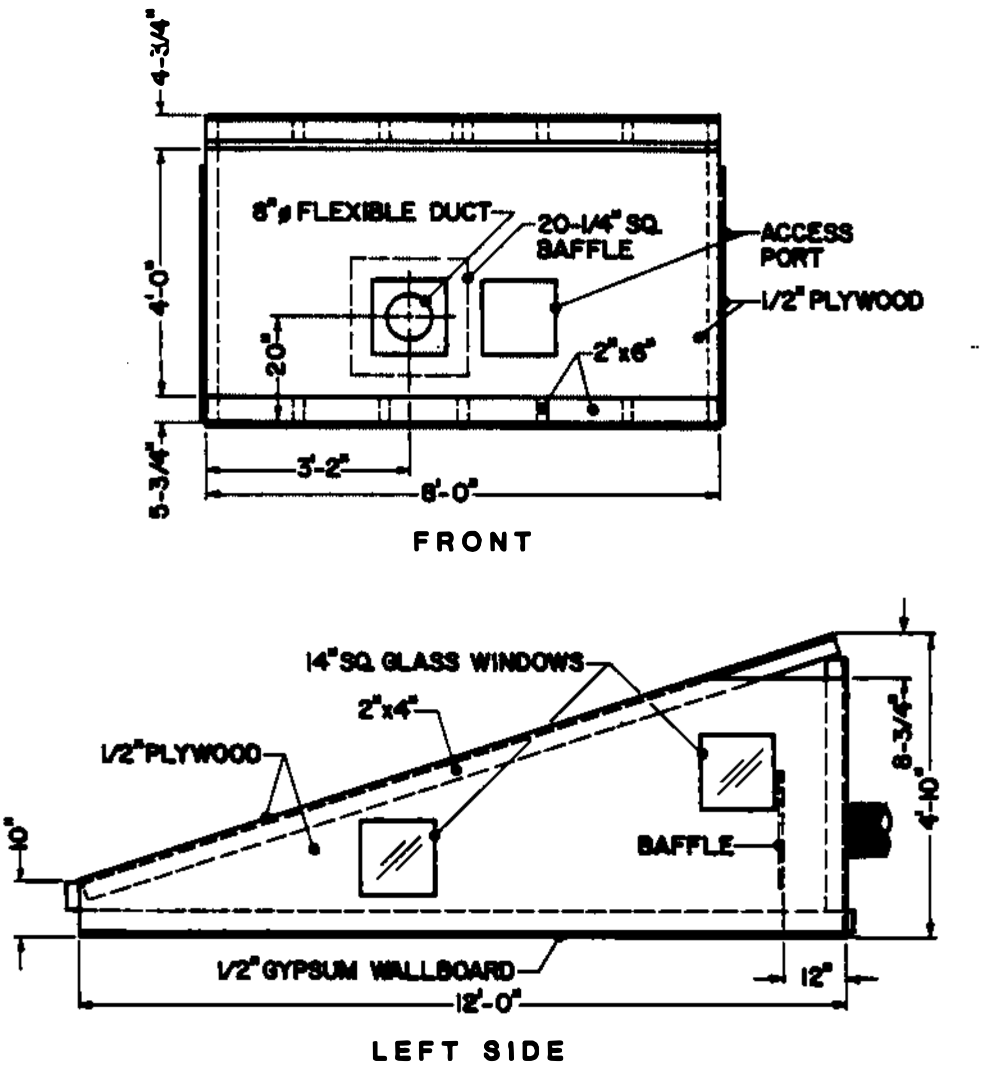

FIGURE 1 Full-Scale Simulated Attic.

butane torch applied to the surface of the insulation material and a flammable liquid spill (alcohol) poured on the insulation material and then ignited. Only one ignition source, applied at one ignition location, was used in any particular experiment in order to remove the possibility of interaction between two ignition conditions. This was done to maximize information from the study with regard to the effect of each ignition condition individually.

The nonflaming ignition sources included a recessed lighting fixture, an electrically energized wire, and a smoldering cigarette. The light fixture was used with a 60-watt incandescent light bulb specified

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as the maximum size for use with the particular light fixture as well as with an overlamped condition of a 150-watt incandescent bulb.

Full-scale tests were conducted with an 8-foot by 12-foot plan attic enclosure with a sloping roof. The attic had nominal 2-inch by 6-inch wood joists, nominal 2-inch by 4-inch wood rafters, plywood sheating over the rafters, and a 1/2-inch gypsum wallboard ceiling nailed to the underside of the joists as would occur in typical construction. The attic was provided with insulation over the top surface of the exterior sheathing in order to facilitate temperature rise within the attic construction. The insulation material for each experiment was blown into the space between the joists to provide a simulation of exposed insulation as would occur in a typical, open attic, wood frame residential dwelling.

All of the experiments in the attic were conducted with elevated ambient temperatures representative of those that would occur on a hot, sunny day in summer. The ambient temperature in the attic was 150°F. The temperature was achieved using two different heating methods: a convective heating method using a hot air heater to blow hot air into a duct that led into the attic cavity, and a radiant energy source consisting of two electric radiant heaters located within the attic. In each case, the heating was continued for about 5 hours until temperature equilibrium had occurred in the attic and insulation.

Laboratory Tests

The laboratory test phase of the investigation included two tests methods. First of these was the 25-foot tunnel test (ASTM E84, UL 723, Tests for Surface Burning Characteristics of Building Materials). The test develops a value for flame spread and smoke development for material under specified test conditions with respect to a reference material of red oak lumber classified as 100 and a noncombustible asbestos-cement board as 0 on the classification scale. The second test method used was the attic floor radiant panel test presently specified as one of the flammability tests contained in the Consumer Products Safety Commission Interim Safety Standard and the General Services Administration Federal Specification HH-I-515D for cellulosic loose fill insulation materials.

Materials Evaluated

Cellulosic, glass fiber, and mineral wool "loose fill" insulation products were included in the investigation. Two groups of cellulosic insulation materials were included in these studies. One set of cellulosic samples was manufactured using a specific chemical formulation fire-retardant treatment but with varying chemical "add-on" rates. The chemical add-on rates were designed so that a range of flame spread values, as determined by the tunnel test method, of approximately 25, 35, 45, 55, and 65 would be exhibited.

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These materials were used in a series of attic experiments to bracket the value of flame spread corresponding to the full fire involvement in the simulated attic. The range of flame spread values was selected to show a range of performance in the simulated attic.

The second set of cellulosic samples was treated with four different chemical treatment systems, each of differing chemical composition. These materials were intended to be representative of the spectrum of chemical treatment systems commercially in use. These were obtained with varying treatment levels to produce a range of performance in fire testing.

EXAMINATION OF RESULTS

Fire testing in the full-scale simulated attic construction was first conducted using cellulosic materials treated at various levels with a single chemical treatment system. In full-scale simulated attic tests with cellulosic insulation having a flame spread value of approximately 35, the fire tended to extinguish of its own accord in the immediate vicinity of the ignition source. Propagation occurred for a distance of several inches with little vigor but extinguished before extending more than a few inches beyond the immediate ignition area.

Cellulosic material with flame spread values greater than approximately 45, as determined by the tunnel test method, supported combustion and led to full or near full attic involvement. In tests in full-scale simulated attics with higher flame spread materials, flame propagation extended over the top surface of the cellulosic material, and a char developed that extended approximately 1/4 to 1/2 inch into the material. Beneath the char layer, the cellulose material was unchanged in appearance.

Once testing was completed with cellulosic material with various levels of a single chemical treatment system, the next step was to conduct tests with cellulosic materials treated with four different chemical treatment systems representing a spectrum of commercially used chemical treatment systems. This was intended to examine whether performance characteristics in full-scale simulated attics applied only to a single treatment formulation or to other kinds of chemical treatements as well.

Again, where the material had higher flame spread values, propagating fires were produced. Materials with flame spread values of approximately 35 or less burned only in the immediate location of the ignition source.

Similar results were acquired with other materials--shredded glass fiber and mineral wool insulation. The composition of these materials was such that all samples exhibited flame spread values in the range of 25 or less. These materials, consistent with the performance of low flame spread, cellulosic materials, did not support propagating fires where flaming ignition sources were used.

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Smoldering Fire Testing

To investigate smoldering conditions, tests were conducted in attics in which the insulation material was installed into the cavity in the blown-in condition. Smoldering ignition conditions incorporated in these studies included a smoldering (lit) cigarette, a recessed electric lighting fixture, and an electrically energized copper wire. In experiments that utilized the cigarette ignition source, the insulation material was blown into the joist cavities and a small, round-tipped rod was insertes into the insulation material to create a small cavity. A lit cigarette was then inserted in the cavity with the lit end up. The burning of the cigarette and the smoldering of the cellulose insulation that ensued was permitted to continue for not less than 4 hours. The rate of smoldering in inches per hour was recorded for each material.

All cellulosic materials included in these studies exhibited continuing smoldering combustion after placement of the lit cigarette. Smoldering combustion did not lead to flaming combustion in tests with any of the cellulose materials. The rate of smoldering combustion propagation ranged from 3.25 inches per hour for cellulose loose fill material having a flame spread of approximately 25 to 6.6 inches per hour for untreated cellulose material.

Experiments conducted with the recessed light fixture using the maximum specified 60-watt incandescent bulb resulted in no change in the appearance or color of the cellulosic insulation material after 5 hours of exposure regardless of the treatment type or level of treatment. There was some temperature rise in the insulation material adjacent to the fixture, but it was not sufficient to cause any apparent degradation of the material after the system reached temperature equilibrium. With the fixture improperly overlamped with a 150-watt incandescent bulb, higher system temperatures were recorded, and smoldering occurred. Smoldering combustion propagation rates were similar to those which occurred when smoldering combustion was initiated by the cigarette ignition source.

Experiments with the building wire were conducted with the wire embedded in the cellulose insulation. The wire was a No. 14 gauge copper wire stripped of its insulation. The circuit was energized at 115 volts ac provided through a load bank to develop approximately 48 amperes in the system. The current was applied for 8 hours after steady state temperatures were developed. The maximum temperature measured adjacent to the wire was 320°F. No discoloration or other change in the appearance of the cellulose insulation was noted. Smoldering combustion did not occur.

Comparison of Laboratory Test Methods

Flame spread values for various cellulosic materials, as determined by the tunnel test, are shown in Figure 2 in relation to the add-on rate

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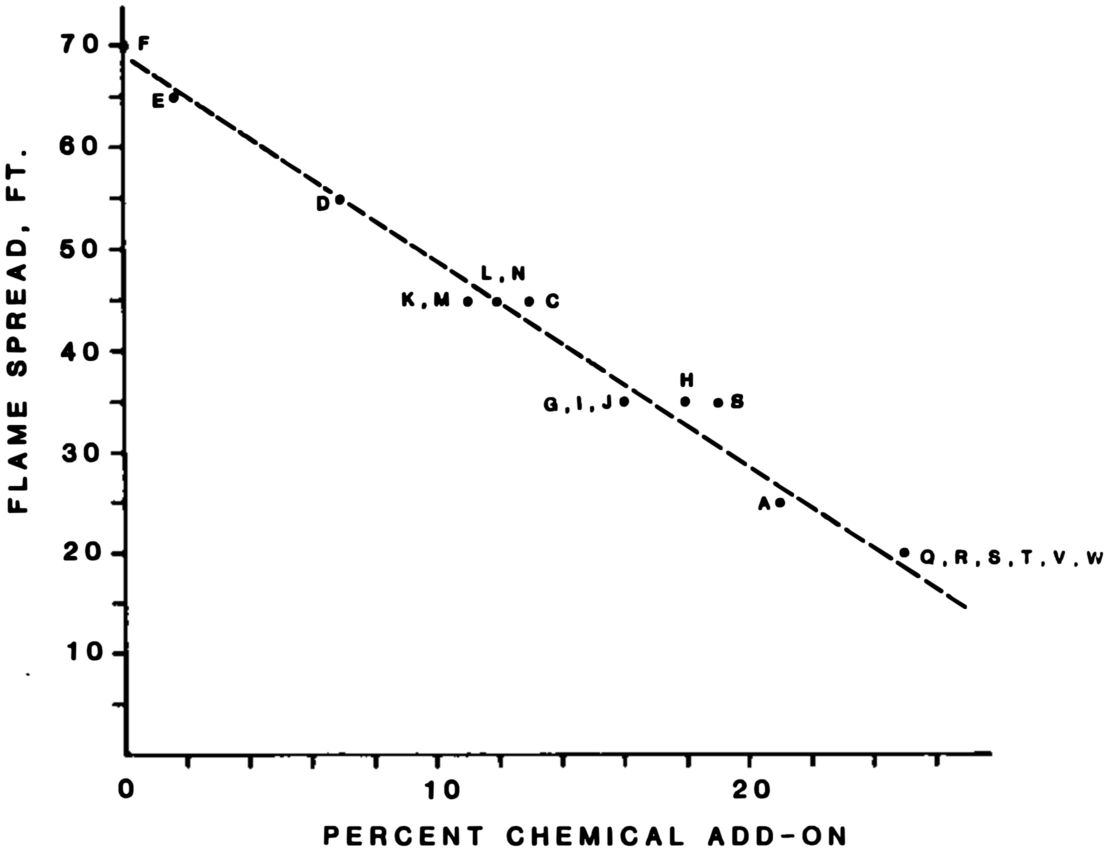

FIGURE 2 Flame spread vs. percent chemical add-on.

of chemical flame-retardant treatments. Critical radiant flux as determined for the same materials using the radiant panel is shown in Figure 3. As is evident, the variation in full-scale performance reported for cellulosic materials of various flame spread is consistent with variation in treatment levels. Thus, the tunnel furnace method is able to provide discernment of material performance that relates to the actual attic involvement. Conversely, the inability of the radiant panel method to assess critical radiant flux values above 0.10 W/cm^2 results in an inability to compare results of the respective methods. The discernment of performance characteristics provided by the tunnel furnace method is not provided by the radiant panel test method.

FINDINGS

A complete report of these fire test studies currently is being prepared for inclusion in the final report of this investigation. Certain preliminary findings can be summarized as follows:

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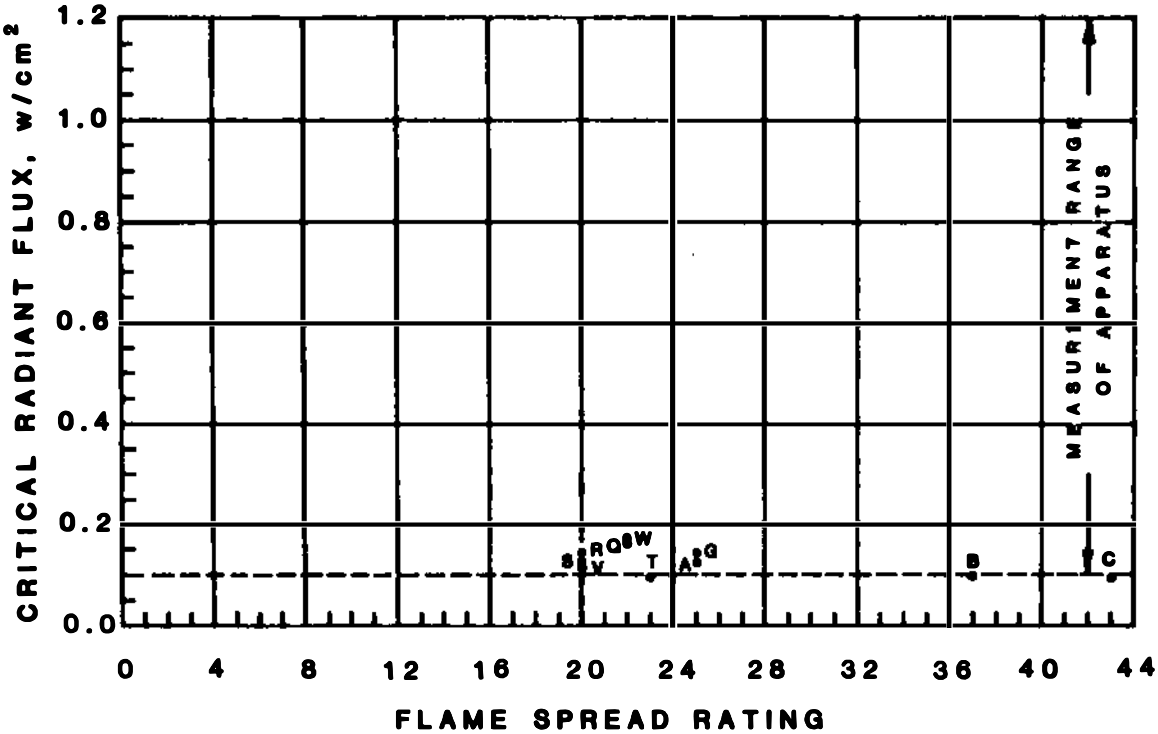

FIGURE 3 Flame spread vs. critical radiant flux.

1. Under smoldering and flaming combustion conditions, both the attic floor radiant panel and the 25 foot tunnel test method provide data that correlates to, varying with flame propagation, characteristics of the same materials in simulated full-scale attics. The attic floor radiant panel provides essentially a "pass-fail" judgment mode. The 25 foot test method provides a means of ranking or grading performance, including the ability to provide indication of performance in both high ambient temperature and normal ambient temperature attic conditions.

2. Materials having a 25 foot tunnel flame spread value of 25 generally developed a critical radiant flux value of 0.12 W/cm^2 as determined by the attic floor radiant panel method. Materials having flame spread values of approximately 30 to 35 exhibited critical radiant flux values less than 0.10 W/cm^2. The end of the test specimen in the critical radiant flux method coincides with a critical radiant flux of 0.10 W/cm^2. As long as the specimen does not propagate the full length of the specimen in the attic floor radiant panel test method, a correlation with 25 flame spread value materials can be shown. This performance level coincides with the likelihood of little propensity for total fire involvement in attic enclosures. However, materials that have marginally higher flame propagating characteristics

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are beyond the capability of the attic floor radiant panel to provide indication of likely performance of materials in the full-scale attic enclosure.

3. Loose fill materials placed in joist cavities in attic floors demonstrate a greater propensity for smoldering and flaming combustion when the attic ambient temperatures are elevated. In experiments conducted in simulated attics at ambient temperatures of approximately 150°F, loose fill material having E84 flame spread values of 45 or greater supported both smoldering and flaming combustion. Flaming combustion of loose fill materials having flame spread values of 45 or greater generally led to full fire involvement. Loose fill materials having flame spread values of 35 or less generally failed to support flaming combustion or sustain combustion at all; accordingly, they did not lead to full attic involvement. Those materials having approximately a 35 flame spread tended to exhibit some amount of propagating flame in the immediate region of ignition but generally tended to cease burning prior to full involvement of the material in the attic space.

4. The fact that materials will meet either the critical radiant flux acceptance requirement of the attic floor radiant panel or the 25 flame spread requirement of the tunnel method does not necessarily indicate that smoldering combustion will not occur. There appears to be a need to evaluate smoldering characteristics apart from these methods. Smoldering combustion was not produced when various cellulosic materials were exposed to the recessed light fixture in a rated lamp condition regardless of the tunnel flame spread value. In other words, temperatures with the bulb in the fixture at its rated level did not rise high enough to produce a degradation of the material. However, when the fixture was overlamped, the temperatures developed led to degradation of the cellulosic material. It is important to adhere to the bulb requirement specified for a fixture. It should be noted that the National Electrical Code prohibits the placement of insulation adjacent to a fixture. Temperatures monitored during the overheated electrical wire experiment resulted in temperatures within the insulation of a maximum of approximately 320°F after 8 hours exposure with a 48 ampere load. This condition did not lead to the onset of ignition during the 8 hour exposure period.

These findings are preliminary in nature. This paper is intended primarily to provide an indication of the nature of fire research work that UL is carrying out with loose fill insulation material in full-scale simulated attics. The full findings of this work will be included in a final report to the sponsor.

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Session III

HOW TO PROVIDE ENERGY-EFFICIENT AND FIRESAFE BUILDINGS

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INTRODUCTION

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During this session of the conference, eight experts will describe what they are doing with respect to the conflict between energy conservation and firesafety in buildings. They also will explain what might be done in the future.

The experts have been selected to cover as broad a range of interests as possible. One speaker represents the Department of Energy and another, the Department of Housing and Urban Development. One speaker represents the building code community, specifically the model building codes. One speaker represents the American Institute of Architects, another is a professional engineer representing the air-conditioning field, and another is a practicing fire protection engineer. The remaining two speakers represent building owners, contractors, and developers.

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PRESENTATION

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Before discussing problems associated with the fire properties of insulation materials, let me review a broader picture: America's energy goals and the energy-efficient society we all are working to create. Our national energy goals are clear; we must move our economy away from its reliance on oil and toward new, diversified energy sources. It is important to remember that we are in a transition from an oil-dependent economy to an energy-diversified economy. This transition has reflected itself in several crises, beginning with the oil embargo in 1973.

When we talk about oil, we are talking about the single most important element affecting our national security, our economy, our standard of living, our social and political freedom, and the kinds of lives our children and grandchildren will be living. Oil expenditures already have more to do with our inflation rate, the value of the dollar, and our balance of payments deficit than any other economic factor.

Energy is a truly pervasive issue that affects every American. Right now, the people of the United States are sending $10 million abroad to feed our oil appetites--and that happens every hour of every day and every night at present oil prices. At current levels of imports, America will spend about $90 billion this year for foreign oil.

The basic objective of our energy policy is to cut our imports in half by 1990. In the meantime, we must not increase our imports beyond what they were in 1977. This policy must be developed and enforced with concern for inflation, unemployment, and other economic issues. It also has to be developed within the framework of international cooperation.

Reduced energy consumption is the cornerstone of re-establishing our energy balance in the immediate future. The key is energy-efficient utilization. This means doing things a little better--or a lot better--than they have been done in the past and getting more use out of our resources. Energy efficiency is productivity. Too much of

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the energy we use today is wasted through inefficient home construction and inefficient appliances. It does not contribute to productivity and it does nothing to improve or maintain our standard of living. It is simply wasted.

For the past 10 years, the main thrust for energy savings from the use of thermal insulation came from applications in residential housing. Much has been done and yet a great deal still needs to be done with new and existing buildings.

There are three major performance characteristics that should be considered in assessing the effects of adding insulation materials in building construction with respect to fire development. These characteristics are: (1) flammability or flame spread, (2) combustibility, and (3) the influence of insulation on the hourly fire-resistance rating of building structure elements previously tested and classified without insulation.

The flammability characteristics of building materials generally are measured by means of flame spread tests conducted in accordance with the standard for tests of surface burning characteristics of building materials (ANSI/ASTM E84, NFPA 255, and UL 723). This test method provides information regarding the flame spreading characteristics over the surface of materials, temperatures developed by their combustion, and the standard fire test exposure.

"Combustible" is generally taken to mean "capable of undergoing combustion in air at pressures and temperatures that might occur during a fire in a building or in a more severe environment when specified." Combustible materials are considered contributory to the severity of the fire environment whereas materials that are not readily combustible are generally not contributory to fire development. Materials of limited combustibility will ignite and burn to some degree when exposed to fire environments conducive to such combustion but generally are considered as not contributing significantly to the severity of the energy environment. In general, a material that is not readily combustible can be considered to be one that will not ignite, burn, support combustion, or release flammable vapors when subjected to fire or heat.

Building codes regulate and limit the use of combustible materials with respect to building construction type. Therefore, the combustibility characteristics of certain types of insulation may need to be determined depending on applicable building code requirements and the types of building construction involved.

Fire properties of insulation materials are extremely complex problem areas that have numerous aspects (e.g., ease of ignition, transition from smoldering to flaming combustion, rate of spread of combustion, rate of heat release, ease of spread to other materials, rate of smoke generation, and toxicity of combustion products). Quantitative measures of each of these aspects are dependent not only on the nature of the insulation but also on how it is used. This implies a need for new test methods that reflect the real usage conditions of current insulation materials.

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The currently most pressing concerns about fire properties fall in a limited number of catagories; these are defined by the frequency of present usage and the available fire statistics. In large part, these involve loose fill cellulosic insulation; however, the increasing usage of cellular plastics and pressed wood products in wall structures merits attention as do similar potential problems with other insulations that I will mention.

As you may know, loose fill cellulosic insulation is now required to pass the attic floor radiant panel test and a cigarette-based smoldering ignition test. This is the first step in effectively addressing the combustibility of these materials. The former test simulates a realistic flaming ignition and spread situation in a residential attic; the latter is less realistic but certainly provides some measure of smoldering ignition. Resistance to smoldering ignition and spread appears difficult to achieve with current retardants so the next point in the sequence must be examined, transition from smoldering into flaming; no test currently exists but one is needed. Basic studies on smoldering mechanisms are needed to assure a scientific basis for such testing and to guide the development of more smolder-resistant products. It is not clear whether the radiant panel test provides a proper measure of the flaming that follows smoldering, especially with regard to the tendency to involve other materials. This implies a need for more exploratory work on the flaming characteristics of this insulation.

Environmental cycling effects and permanency of combustion retardants in cellulosic insulation currently are under investigation at the Oak Ridge National Laboratory and the National Bureau of Standards. These are serious concerns; their impact would be measured appropriately with an improved smoldering ignition test.

Other insulation materials with an appreciable organic content (in bulk or as a facing) share unique fire properties, notably a propensity for rapid flame spread. Recommended practice precludes their exposure to building interiors; however, it is unclear to what extent such materials may aggravate smoldering or flaming susceptibility of wall structures to internal ignition sources such as electrical failures. Continuing research is needed to identify effective ways to measure and suppress the combustibility of such insulation materials in these types of applications. At present, there are no test methods that measure this type of hazard; it is not clear whether performance in the E84 tunnel test bears on this question.

Tests for rate of heat release, heat contribution, smoke formation, and toxicity of combustion products are under active development for general application to building materials and structures. Their applicability to the evaluation of the firesafety of insulating materials must be reviewed, and appropriate investigations and recommendations must be made when the need is indicated. These items should be developed jointly by the public and private sectors with opportunity for all

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to participate and/or review the results of the work. Organizations such as the Advisory Board on the Built Environment, the National Institute of Building Sciences, the American Society of Heating, Refrigerating and Air Conditioning Engineers, the American Society for Testing and Materials, and the International Standards Organization should be actively solicited for input. New or revised standards and codes should be rapidly developed and implemented.

In summary, the application of energy-efficient materials to existing or new buildings will never totally be without risk of hazard to the occupant of the building or to the structure itself. However, I believe these risks can be minimized through the use of quality materials designed and tested to respond to the rigors of the environment in which they are placed. If we can commit ourselves to that, our country can look forward to a secure and safe energy future.

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PRESENTATION

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I would like to approach this talk on the use of the systems approach not mainly from the mobile home aspect, but rather from an all-residential housing view with emphasis on building technology research.

In the early 1970s, the Department of Housing and Urban Development's (HUD's) building technology research focus concentrated on demonstrating the use of factory-built housing to meet the needs of all income groups. In Operation Breakthrough, we also attempted to advance the state of the art in residential firesafety by the development of mini-fire ratings and test procedures with which to judge quite innovative building materials. Using the systems approach, Breakthrough explored the capabilities of many kinds of buildings--from single-family plastic dwellings to 25-story modular concrete apartment buildings (in which the modules themselves provided their own support without any columnar assistance).

The energy crisis and its aftermath confronted HUD with a problem: how to save energy without appreciably raising the cost per square foot of building. The consequent inflation after 1973 has impacted HUD's time-honored goal of providing "decent safe and affordable housing for each American." As inflation increased, we have adapted our research to concentrate on reducing building costs, using the systems approach to assure that the final research delivered is timely and realistic.

In my opinion, the only way that this conference can achieve an answer to questions concerning the successful marriage of energy conservation and firesafety is through the systems approach. I recognize that the term, "systems approach," is much maligned, but properly used, it can provide surprisingly successful results to difficult problems. Let me share with you a few examples.

Consider the energy-consumption level of America's one- and two-family homes. To find out if it was practical to reach much lower U-values and become energy-efficient, we entered into a joint venture with the National Association of Home Builders Research Foundation. Two homes were conceived, designed, and built incorporating very innovative structural envelope and HVAC features that could substantively

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reduce the occupant's fuel consumption. These homes were built by a typical builder and their performance was scientifically compared to adjacent homes of similar but conventional construction in order to determine cost-effectiveness. In addition, the trade-off between firesafety and advanced energy-conservation design was systematically made.

Another example of the rigorous use of the systems approach are our "OVE" homes that were designed to reduce labor and building material costs through improved engineering design. Here we tied together other HUD-sponsored research results, such as the use of comply wood studs (which are composed of lumber mill scrap combined with isocyanate resins to form a very dependable, dimensionally stable board). In our very large solar demonstration project, HUD researchers scrupulously used the systems approach to select and judge the potential of hundreds of proposed solar collector, storage, and distribution systems to provide optimum energy performance, to be firesafe, to meet durability requirements, and to be cost-effective.

Another example was our assistance to the Department of Energy in its very substantive effort to develop Building Energy Performance Standards (BEPS). The use of a systems approach was vital in order to address the enormous amount of information and choices available to the technical and economic professionals assembled from industry, academia, and government. Here, too, firesafety was a highly important factor. In our Modular Integrated Utility System (MIUS) program, we sponsored residential power plants to demonstrate a MIUS system for burning a community's wastes and recovering the energy for reuse.

In a different area, we have sponsored extensive research and then demonstrated the use of electric flat-conductor cable (FCC). FCC has the potential to revolutionize the expensive electrical rehabilitation methods used in older urban residences since the FCC wiring is not installed in wall or ceiling cavities. Rather it is simply placed directly under the carpet or linoleum, resulting in minimum tear-down efforts and installation time. To assure its firesafety performance, we have sponsored extensive electrical firesafety testing with the National Bureau of Standards (NBS) and Underwriters Laboratories (UL) and the results have been good. It appears that the use of FCC also could improve life-cycle energy performance (by removing the insulation compression and connecting paths often caused by conventional wiring in wall cavities) as well as reduce overall rehabilitation first costs. Interestingly, we understand that Western Electric was so impressed that it now is using FCC in many of its office buildings.

To further narrow our focus, let us turn to research on trade-offs between firesafety and energy. Take, for example, factory-built housing. As you are aware, expensive, full-scale testing generally is required before a manufacturer can obtain building code approval to construct and sell a dwelling containing innovative material (e.g., foam plastic) that might affect the home's firesafety performance. To reduce testing costs, we sponsored research with NBS to experiment with

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1/8- and 1/4-scale testing modules in order to develop a reliable, reusable, economic, small-scale test method. Its use could economically benefit modular, mobile, and panelized systems manufacturers in their search for safe, high-thermal-performance materials and render obsolete the more expensive full-scale testing.

In an earlier effort, we sponsored the development of a specialized full-scale fire test with the Illinois Institute of Technology Research Institute so as to judge the firesafety performance of the rigid foam used as thermal insulation in ceiling and wall cavities. Electrical receptacle fires were generated to determine in-the-wall reactions in order to develop criteria for pass-fail testing.

Even smoke detector performance has been examined in conjunction with the manufactured home's energy system to note if the operation of the home's HVAC system would suck the smoke away from the detector and thereby prevent the detector from warning the occupants of danger. Earlier tests had implied this, but the subsequent research, systematically pursued, proved that the detectors were effective in most locations under furnace and air-conditioning "on" conditions.

In conclusion, you may judge from these examples that we have been using the systems approach in our efforts to generate residential energy improvements and to identify any adverse side-effects on firesafety. If there are trade-offs, these can be measured and evaluated. The end result can provide cost-effective and safe homes for our citizens.

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PRESENTATION

Charles O. Everly
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City of Alexandria, Virginia

I do not pretend to be an energy expert, and I suspect, given what I have heard at this conference, that there are no real energy experts here. Most of our concerns are with firesafety rather than with energy. However, I have observed that many changes in building codes over the past two years were brought about as a direct result of the energy crisis.

For the most part, these changes are practical solutions to known problems, and that is what building codes deal with. We really represent the front line, and I think of the building code as the aperture of a funnel through which everything else passes and eventually gets down to the user. Research projects are great, but until their results are transmitted in some form to the fellow with the hammer and the saw, they are not going to have any great impact on building construction.

To begin, I think we need to consider what a building code is and, in a very broad sense, what its approach to the two basically unrelated subjects of energy efficiency and firesafety really is. Energy efficiency in terms of the building code is a brand new topic. No one was concerned with that problem prior to 1973 when the oil embargo occurred.

To the extent possible, codes over the years have been written in performance language, but they still must be simple enough for the people in the field to understand. In the minds of many of us involved with codes in the mid-1970s, energy conservation or energy efficiency was really not a performance criterion. Building codes for years had allowed the builder to balance how much insulation he put in the wall against how much would be spent for fuel (i.e., you could spend your money on a capital investment or pay more for operating expenses). The decision between the two was economic and it could be analyzed by economic methods; it had nothing to do with codes. However, in the brief time since the first embargo, energy efficiency has become a part of all of the major model codes, either by inclusion in the body of the code or by direct adoption of the model code for energy conservation.

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On the other hand, firesafety always has been one of the three major topics of modern building codes (along with health and environment and structural safety). In terms of the personnel time that is devoted to the subject, unquestionably firesafety ranks number one.

To some extent, this conference was stimulated by concern that energy considerations occasionally have compromised accepted fire protection criteria. Characteristics of new materials generated the need for new test methods and new test methods never gain unqualified overnight acceptance. We still have considerable argument at code hearings about the requirements for various materials, primarily due to the questionable nature of many of the tests.

The Board for Coordination of Model Codes has been considering how to balance the requirements of the three model codes regarding foam plastics. We had barely began discussing the subject when the National Bureau of Standards (NBS) sent us a letter questioning the validity of tests that were performed and proposed by the Society of the Plastics Industry. Given the lack of anything else, we probably will refer to those tests in spite of the NBS. Give us something better and we will use it.

It should be kept in mind, particularly by those of us who make the rules, that firesafety is a very subjective term. It cannot be measured on a numbered scale; it has no absolute value. To be sure, there are statistics, but there is little correlation between those statistics and the actual acts that we perform with a building.

Adding an inch of a specific kind of insulation will produce predictable change in the energy consumption of a building, but its specific effect on firesafety probably will never be known. Its effect on a fire system will be known, but I doubt very seriously whether anybody will ever quantify its effect on people in the building.

Our system of regulating building construction has evolved over many years. Building codes are a catchall; they pull together the thinking of diverse and isolated sources and attempt to make them all mesh. Firesafety, health, energy, security, structural safety, and other considerations are important in solving a problem in one area but they often create a problem somewhere else. There is a constant striving for balance by the people who write the building codes.

The fact that energy conservation is a newcomer to the list does not mean that it should not also be balanced with the others. Energy efficiency really boils down to a pure engineering problem. Once you eliminate the economic questions, your empirical decision is made by code as to how much energy consumption you are going to allow and the engineer can, from that point on, determine the required insulating properties of the envelope. In many instances, this insulation requirement will be greater than what was traditionally supplied at the time of many of our older fire tests; therefore, if you are dealing with an envelope that must have fire-resistant properties, the added insulation cannot be allowed to reduce those properties below the minimum.

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It is difficult to add insulation to an assembly without affecting the fire rating of that assembly, frequently in an adverse manner. I say frequently because obviously if a system fails by heat transmission all the way through and if temperatures of the individual components within reach the maximum, perhaps the addition of a little insulation to the top side will change the mode of failure; it may even improve the system but that is highly doubtful. The only exception I can think of would be the addition of insulation to the fire-exposed side of an assembly, and, as Dr. Harmathy pointed out yesterday, the problem would be one of increasing the flashover problem inside of a space.

Determining the need for rated construction, however, is not an exact science. I am speaking now in terms of retrofit. The construction type tables and codes jump, in most cases, in 1-hour increments. One must wonder what magic has transpired, for example, when a 19,000-square-foot business building does not need any rating on the roof but a 20,000-square-foot building must have a 1-hour rating. The heights and areas charts of the building codes are, to some extent, a matrix representing points on a curve and it is not improper for a building official, if he chooses, to exercise judgment with that in mind.

I will now use my 19,000- and 20,000-square-foot example again. If you are dealing with an existing situation, you might be inclined to make your evaluation with those parameters in mind. As a building official, I personally might be more inclined to worry about the effects of insulation on a roof rating if a building had a taller, closeby neighbor than I would if there was ample fire separation and the roof obviously had no effect on its surroundings.

If I am to judge by the case reports in the various journals, I think that the problem of compromised fire-rated assemblies may be more theoretical than actual although I admit there is still a lot of experience to be gained. A factor of demonstrable importance, however, is that of highly combustible insulation materials used in exposed locations. The use of foam plastics caused considerable public concern a few years ago until that matter was addressed by the codes. The codes now limit the quantity that can be used and require protection of the material with at least a 15-minute barrier or, to put it in very practical terms as the code is sometimes inclined to do, a minimum of 1/2 inch of gypsum board.

An article in a recent issue of the Fire Journal discusses reflective insulation, and the severity of the fires involving it that have been reported is something I would not have predicted. The material involved is an aluminum foil with a paper backing and the problem, I think, is that the ASTM E84 tunnel test probably was not valid for the material. However, I must reserve my judgment on this until more complete information is available. I am sure that if such insulation proves to be a widespread problem and more people have difficulty with it, someone most likely will sponsor a practical solution to it in the code.

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In any case, the flame spread characteristics and combustibility characteristics of insulation materials always should be carefully checked for compliance with the code. Buildings are not always required to be fire resistant; however, building codes always have a requirement regarding the insulation of a building.

I recently participated in a project to examine the particular problems of solar energy utilization and to develop guidelines for building officials that would help encourage the development and use of solar energy. We identified a number of firesafety problems that solar equipment and methods might create and also a number of problems that the codes create for solar. A report that perhaps some of you have seen and I hope gets wide distribution was prepared for the Department of Energy as a guide for the building official concerning solar energy; it is not written to be a code, but it does address code problems and the potential solutions to those problems. I will touch on a few of the points made in that report.

The amount of solar energy that is available is directly related to the area of a particular site. On small sites, every square foot can count if you are going to use solar heat in a building. Since codes presently permit street projections, like awnings over a street, we call attention in the document to the fact that this space also could be made available to collect solar energy.

On the other hand, open space sometimes is specifically required around a building for fire separation. You are allowed to build a bigger building under the building codes if you have open area all the way around it. One of the purposes of this space is to provide access for firefighters. The space, therefore, should be kept clear, and solar components should not be placed there. Collectors on roofs also create a problem that had not occurred to most of us. Many roof surfaces are required to be classified as to their fire-resistance characteristics--Class A, B, or C roofing. The ASTM E108 test rightly assumes that the roof surface will be exposed to the sky; however, the presence of solar collectors, or any other equipment for that matter, seriously alters the characteristics of a burning brand and can serve to concentrate the effects of flames on the roof surface, causing failure. Where the surface characteristics of a roof are important, care must be exercised. Collectors either should be mounted right against the roof surface or the space beneath them should be closed to prevent the intrusion of burning brands or flames. If such equipment is mounted a considerable distance above the roof, the problem is not significant, but the exact clearance that should be required has yet to be demonstrated by test.

Collectors mounted as much as 2 feet above the roof did not seem to interfere with the rating. Obviously, it is not a huge problem for a small installation such as solar heating for residential hot water. Air-conditioning units and similar things currently are placed on the roof and I know of no problem that has been generated by that particular practice; therefore, small solar collectors should not be of

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concern. Heating an entire building, however, will require covering, perhaps, acres of roof area and that becomes a very significant problem.

Techniques for the utilization of solar energy also often make use of natural convective forces, particularly in passive designs. Such techniques run headlong into the very serious fire hazard generated by concealed spaces. Codes have for many years required firestopping at the floor line in such concealed spaces to prevent the vertical spread of fire by the same forces that solar techniques seek to utilize. To my knowledge, there is no commercially available equipment that solves the problem easily because all of the systems are largely experimental and have not been standarized. However, smoke-detector technology is available and firesafety absolutely demands that firestopping be maintained in those spaces by some kind of a Rube Goldberg rig that is smoke-detector-activated and that will operate in the fail-safe mode.

There are other ways in which smoke detection devices might be used as an alternative to the firesafety systems required by building codes. In many areas of the country the temperature a short distance beneath the ground surface remains fairly constant and temperate all year. Energy conservation pioneers have buried buildings beneath the ground to take advantage of this natural climate control. Mr. Hagan showed a cross section of one such building earlier. Below-ground dwellings, however, conflict with the exit provisions of the building codes. All codes require a secondary means of exiting a bedroom. This normally is provided by a window with certain minimum dimensions. Codes, incidentally, are not consistent in this area because a window obviously does not serve as a second means of exit if it is on the top floor of a 15-story high-rise. For this reason, those of us who were discussing it in terms of the document we were preparing suggested that an alternative would be to provide two exit paths from the bedroom door. That is what the high-rise building has in that when one exits an apartment, there are two ways to travel. These exit paths should be monitored by a smoke-detector system and a smoke detector should be placed in the bedroom. The unique characteristic of that particular code requirement is that it addresses a second exit from the bedroom.

The code does not actually require a smoke detector in the bedroom; it requires one in the corridor space in the vicinity of the bedroom, intending to notify people that are in the bedroom of a fire in another part of the house so that they can get out before it blocks their exit. If the smoke detector was in the bedroom, the occupants would be awakened if a fire occurred and then could take advantage of the two means of egress. In my judgment, that is a safe system.

While we are talking about windows, another code change that was brought about by energy conservation considerations comes to mind. The National Association of Home Builders sponsored this change a number of years ago and it concerns the requirement for natural light and ventilation. The 10 percent of the floor area requirement for light

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has been reduced by 20 percent and only 8 percent is required at this point. Window glass has very poor insulating qualities and, even in multiple layers, is very inefficient.

Improper use of woodburning appliances, in my judgment, has been the greatest fire hazard that has been generated by the energy crisis. Mr. Schaenman dwelt on it in his statistical presentation. Improper installation and maintenance both are responsible for a dramatic increase in fire deaths related to this equipment. Properly constructed chimneys and proper maintenance are essential. So is proper mounting of the equipment. The clearances from it must be maintained, fuel must be kept at a reasonable level, and combustible materials must be kept from the vicinity of stoves.

As I listened to the earlier speakers one at a time covering virtually every point that I have made, I realized several things. First, I would like to emphasize that building codes are the most important communicating link between the thinkers and researchers and the ultimate user of the product, the building. Second, codes are reactive. They do not lead technology and they address real, not theoretical, problems. In that regard, given what I have heard at this conference about current technology and problems, codes are remarkably up-to-date. Third, missing from this conference is the energy-conservation spokesman, the individual who is not at all concerned with building safety and who is pushing energy conservation wholeheartedly.

I will conclude by inviting every one of you to attend and to become active in building code hearings to learn, if you do not already know, the language of building codes and then to submit your ideas in the form of changes to these codes. I often hear codes criticized for failing to address a particular problem. This criticism frequently is not justified, but if it is, keep in mind that codes are written by you and those who are sitting around you. If you know about an unaddressed problem to which you can contribute any part of the solution, you are the one who is negligent if you do not do so.

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PRESENTATION

Theodore Mariani, AIA
President
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Before beginning, I would like to point out that I am here representing the American Institute for Architects (AIA), where I serve on the Board and as the commissioner for the AIA's energy activities. I will try to convey a general and broad perspective of the problem without getting too deeply involved in some of the details.

Our earth is known as the water planet. Interestingly enough, however, we also are a product of the sun because all of our energy, both our direct energy on a daily basis as well as our fossil fuel energy, has come from the sun.

The sun also, of course, creates a great many of our problems. Because we have this energy, we have learned how to release it and that is what gives rise to our fire problems. Early man learned to use the regular cycle of the sun, both its diurnal and its seasonal cycle, and in his early designs he learned how to create an environment that would respond to the condition of natural sunlight as well as the environment that surrounded it. He also learned how to use fire at a very early stage and we have been using it ever since.

One of the finest examples of working with nature, of course, was provided by the Hopi Indians and the cave dwellers in the Southwest who took advantage of natural earth forms to shield their buildings from the north wind; to use the overhang to shield them from the hot, high south sun; and to take advantage of the low winter sun for heat. A later development in the Southwest was the adobe building, which also used the thermal mass process and small window openings and eliminated as much as possible the harsh breezes that, in a dry, hot climate, are not effective for cooling purposes.

Moving to the Northeast of the United States, we find another great adaptation of climate and architecture, the New England saltbox. The building faces north with a low, sloping roof that protects it from the gales from the north. Its large or open side, its glazed side, faces south to get maximum sunlight. It also has a fire pit in the center with a large masonry mass so that only one fire source is needed to

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heat the entire building in the most efficient way possible. Actually, it is a pretty good piece of architecture and people are still building New England saltboxes today.

Italy's famous hilltop towns also were designed to take advantage of natural climate by catching the breezes from the Mediterranean. Thomas Jefferson, one of America's great architects who also happened to be President at one time, did the same thing at Monticello. He put his house on a hilltop, captured the breezes that were available in the rather damp, warm Virginia summers, and created, once again, a great piece of architecture in tune with nature.

As we moved into a more confined city environment and began to feel the economic pinch because of the value of city land, we began to cram our buildings together. This cramming together created certain energy problems, but, more important, it created fire problems. We are all aware of what happened in some of the earlier cities where we had the great fires. Chicago, of course, comes to mind as does the great fire of London, which destroyed essentially all of that great city.

Now to consider the ultimate folly, New York City, where we have jammed together more people than one can imagine on less real estate than one wants to think about. This is probably the end point of centrifugal development focused into the high-density core.

A lot of technology went into the construction of city buildings, but I think we forgot some very simple things, simple things that we should have learned from our predecessors. We have compounded the energy problem as well as the fire problem.

The great cities that we live in are energy hogs. They also have other problems--for example, water problems. In some situations there is not even enough water to allow a city to operate.

The typical building of the 1960s and 1970s has its own problems. Instead of using the wind as an advantage, as did the Italian hilltop towns, the typical building now fights the wind. Probably 50 percent of the structure is intended to support it against wind loads as opposed to supporting it against gravity. The typical building is all glass and has all the problems of energy consumption that we spoke about. It also obviously has fire problems that can sometimes be dramatic since it is tall and encourages this type of phenomenon. This does not happen very often in this country, but when it does, it is very dramatic and it gets the nation's attention.

Thus far I have talked about architectural failures. What do we do when we have an architectural failure? We call in the engineers and we try to figure out some way to solve the problem; therefore, we have to have high-pressure fire pumps, automatic sprinkler systems, and a manual backup system.

When the home remedy does not work, we call the professional. Sometimes the professional, who is usually prompt, arrives on the scene, and if he is early enough, he ends up being a hero. Unfortunately, if he is too late, he may end up being the victim.

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The AIA has recognized that we have both an energy problem and a fire problem. Addressing the energy problem back in the early 1970s, the AIA began to look at what we should be doing about it.

We were one of the earliest groups to propose a national program for energy conservation. It took us a while to get the rest of the country to catch up with us, but that has now happened. The energy conservation program is being driven by economics as much as anything else. When I talk to my clients, their greatest concern is not that we are dependent on Arab oil but that oil costs $1.32 a gallon and their utility bills have tripled in the past five years or so.

Thus, the economic engine now is driving energy conservation, but we unfortunately do not have the same kind of drive behind firesafety. We have to look at that from a different point of view. In 1977 the AIA published a paper called "Fire and Life Safety, Educating the Architect." We are about to move forward with the program proposed in that paper even though it does not have the same kind of public support that energy conservation does. We recently have had a sporadic outburst of concern about firesafety because of certain major building fires, but it seems to die out after a while. I think the AIA is going to take the lead on this, however, and begin to push more forcefully because we do see an area where we can integrate in our energy activities a more sophisticated approach to firesafety design.

Let us look at what the architect does when he begins to design a building. He is the true synthesizer of the building process. All the technology that is developed, both by manufacturers and research laboratories, really cannot be brought to bear until the architect brings it together into the building form itself.

He wants to design a new building, a fascinating building, and he has a lot of things to consider. First, he has to look at the building's function, its economics, its aesthetics, its marketability, and its maintenance over the long term. He also has to consider security problems, zoning, and historic preservation. Environmental impact also is a big issue as is social impact, and access for the handicapped is now becoming more important. Finally, he must consider the codes, firesafety, life safety, and energy conservation.

Putting all these things together in this mix we call design, we sometimes come up with some exciting buildings, and the results of this process are sometimes quite unique. We have buildings, for example, that have the mechanical systems on the outside of the building exposed rather than on the inside of the building. We have a building that has a unique structural system, namely, water-filled columns for firesafety purposes. However, sometimes we are not quite as forward-thinking as you might imagine because we can still have in a very "high technology" building a pretty ancient system for controlling a fire.

Getting back to the design process, the architect first must try to diagram the problem he is trying to solve, and he has to take one step at a time. Since he is synthesizing the whole building process,

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he begins to look at options, trade-offs if you will. This results in some buildings that are obvious trade-offs. We talked earlier about the underground house or the earth-sheltered design, and there are some trade-offs involved. I do not know that I would be happy about living underground, but some people seem to think that is the way to go. It does have the problems of access to fighting the fire inside, egress for the occupants, and the possibility of roof collapse with a heavy surcharge on the roof.

A totally different approach involves looking at the sun as a source of light and energy and determining how to control that. In some cases, the sun control system, the balconies and the overhangs, is not antithetical to firesafety and life safety; those balconies might come in very handy in case of a fire.

Other techniques involve the use of daylighting and solar heating and also create certain problems. Internal atrium spaces in a building can create areas that make smoke evacuation difficult, and roofs essentially made entirely of glass present a problem in terms of collapse in a fire situation. However, sometimes we go back a little bit and realize there is nothing wrong with being able to open the window from time to time.

One goal in designing a building is to let light in because we have found in our energy analyses that one constant from season to season is the need to light space for people who use it. In office buildings, the energy load for lighting is probably the greatest contributor to the total energy package. If we can eliminate artificial light and substitute daylight, we can save a considerable amount of energy and, obviously, a considerable amount on the utility bill.

The trick is to let the light in where we can use it. Sometimes, however, we want to keep the sun out because of vertical surfaces with high energy absorption. A sun screen probably will work very well to keep the sun out, but, should a fire occur, it also will work very well to keep the people in and to keep the firefighters' water out of the building.

One of the most disastrous fires in Washington occurred in the Kann's Building on Pennsylvania Avenue. I am familiar with that building because we surveyed it as a historic preservation project for the Pennsylvania Avenua Development Committee and then a few months later it burned down. What had happened was that over a period of time the owners of the building had covered old Victorian masonry with an aluminum screen that stood about 3 feet out from the face of the building. When the building was abandoned and a vagrant, I think, set fire to the building internally, there was no way to get water into the building. The fire hoses could not get the water up high enough to the roof; they could not get through the glass because there was this marvelous aluminum screen protecting the glass; and the fire was racing up inside this marvelous flue on the outside. The building burned uncontrolled for about 16 hours. Washington had every piece of fire equipment on hand to try to work against it and it was all to no avail.

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We are using a lot of technology today. We are using active solar panels and active solar panels together with passive systems of roof overhangs and balconies. We even have gone so far as to have totally integrated systems that combine both active and passive solar, daylighting, and earth shelter.

There are buildings that have many features that are tremendously effective for energy conservation and I am sure that they probably have some life safety problems inherent as well. These are problems that must be resolved by the architect as he produces his design.

Another thing we are doing today is joining buildings. We have found that by joining two buildings together we can reduce energy consumption. The use of a galleria space is a classic example of how we do it. The Henapin County building in Minneapolis is a great example of this; two high-rise buildings of about 25 stories each, originally designed as two separate structures, were brought together on a site and joined by virtue of a large galleria space 25 stories high. The result was great energy efficiency and great efficiency for people who work in the two separate buildings, but some fire egress problems were created.

Another typical example of what we are doing today in modern buildings is the atrium. Atrium buildings were very popular in this country before 1900, but they went out of vogue when we developed mechanical air-conditioning systems. Now we have found that the atrium is very efficient as an energy-saving device. One atrium building in California is quite unique in that it uses the daylight cycle of warm days and cold evenings to create drafts that ventilate it. It uses a heavy concrete frame as a thermal mass to absorb heat in the daytime and give it back at night. It utilizes daylight to the greatest extent possible. It also has, as does any atrium building, certain fire and smoke problems.

A northern climate poses a different type of problem from California. In one Minnesota building a south-facing overhang is used that allows the sun to come in at low angles in the winter but that keeps the hot sun out in the summer. The north side is fully sheltered so we do not have to worry about wind blast from the north. A thermal pool in the front of the building is used both for heating and cooling via a heat pump. It is very interesting that this type of modern building is similar to the early cave dwellings of the Hopi Indians in almost every respect.

Every improvement for energy is not antithetical to life safety design. The Minnesota building, for example, does not have any serious life safety design problems built into it. The important lesson I think we can all learn from this is that architects have had to respond, from the earliest times, to natural events--to the rise and fall of the sun, to the local climate, and to new technology. For example, when we got better glass, we got larger windows, When someone discovered steam, we got central heat. Steel and elevators brought us

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the skyscraper, and air conditioning brought us large sealed buildings. All of these changes have created new issues and new problems to be solved.

Today we are not in a design revolution. Rather we are part of a long, continuing evolutionary process of design. I think today is really a great period for architects because we are going back not to reinvent the wheel, but to rediscover and understand what our predecessors did when they designed buildings years ago.

We are seeking what we call regional architecture, buildings that respond to their particular climate. I think a great error was made when we began to take a slick, all-glass building that won a design award in New York City and put it in every village and hamlet in the United States and every foreign country overseas. As a matter of fact, a building that won a recent design award has every facade exactly alike. Buildings should not be alike north, south, east, and west because the climatic conditions are different on each of the four sides of a building.

One of the earlier speakers mentioned another phenomenon, rights to the sun. This is probably the next frontier. Will we be able to define a way that people can have solar rights? In a very interesting study, by Ralph Knowles on the West Coast investigated establishing solar envelopes that would indicate that if you have a piece of property in an urban setting, you can only build a certain size and shape building so that you do not shield your neighbor from his right to the sun. That is a very interesting analogy he has worked out.

As we look at what an architect should be doing, it is pretty clear that the energy engine is driving us now. We are also, however, always facing problems of firesafety and life safety and we would like to be able to respond to those as intelligently as we can.

I know the AIA is committed to doing something about it. We have spent, during this current year, almost a million dollars on research and education in energy-conscious design. We are taking a modest step this year to start something on firesafety and life safety and, hopefully, it will gain that kind of momentum downstream.

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PRESENTATION

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What has been said at this conference thus far has laid some groundwork for a focus on the relationship between firesafety and energy conservation. To explore the relationship, we must widen the focus to include the concept of integration--the integration of building systems and functions.

A good starting point is to ask what we mean by energy conservation. It is fascinating to listen to the various approaches and to understand the different orientations that affect our ideas about the subject. In one sense, you can reduce energy consumption by simply eliminating or degrading a function. If you eliminate or do not create air conditioning, you eliminate the problem (i.e., there is no need to consider the energy implications of the function).

From the standpoint of design, however, the fundamental issue is energy efficiency, using energy to achieve maximum productivity in providing needed functions. That is a central concern in the design of our buildings today--and in the design of their energy-using subsystems. What, then, are the elements of energy efficiency and how do they relate to the different subsystems and to firesafety? How can we focus in a rational way on the variables and how they interact? A key question is whether there is a design methodology that enables us to interrelate the diverse elements of a building--architectural features, mechanical and electrical systems, firesafety, etc.--to achieve a truly energy-efficient structure relative to current technology.

To explore these questions concretely, it will be worthwhile at this point to turn to specifics and to look at some of the variables, the order of magnitude of those variables, and how they interact. Figure 1 identifies the various components that go into establishing how large a building's air-conditioning system must be. For example, if the facade of the building envelope is 25 percent glass, approximately 35 percent of the so-called heat gain is due to solar input, 32 percent is due to the internal heat gain from lights, 15 percent is due to the ventilation requirement (bringing in outdoor air and cooling and dehumidifying that air), 4 percent is due to the opaque walls, and 14 percent is due to the

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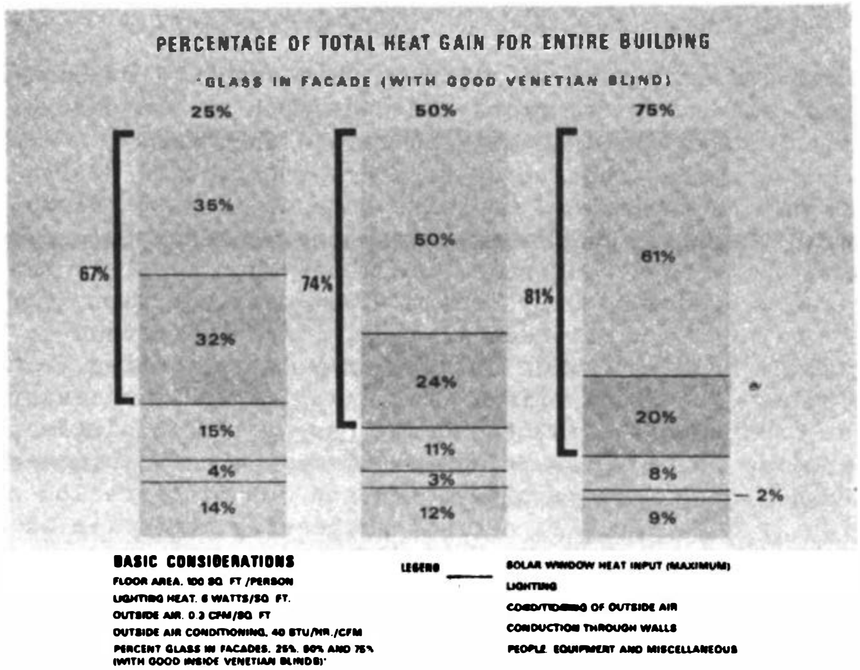

FIGURE 1 General characteristics of the heat gain profile.

heat given off by people. There are techniques for modifying these elements and numbers, but Figure 1 illustrates the general characteristics of the heat gain profile.

As we look at this profile, we can begin to appreciate some interesting and highly relevant facts. The air-conditioning system is actually a major heat sink. Its purpose is to keep people comfortable within the environment; its principal method is removing heat generated by various other components. In a sense, it is a large refrigeration system, refrigerating the skin of a building to handle the solar heat gain and the interior to absorb heat from the lighting. The amount of energy associated with removing heat generated by people is small compared to these other elements.

To get a sense of how much of this is unavoidable, let us look for a moment at what people need to be comfortable. For people's comfort, we must do two things simultaneously--remove heat and dehumidify the space--to maintain conditions of about 75 to 78°F and about 50 percent relative humidity. The humidity requirement--the need to bring in dry air--establishes that conditioned air entering the space must be at about 55°F. The real variables here are how much conditioned air must be brought in and the quantity of refrigeration required to cool that air. These quantities depend on the amount of heat that is in the space as a result of the heat-generating factors presented in Figure 1.

This points to a central question related to energy efficiency: Can we design to gain the benefits of such features as glass and lights without all this heat gain in the space? Do we really need to commit

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the machinery and energy to refrigerate this quantity of heat in a "brute force" attack on the problem as was done in the past or can we use our wits instead of our energy to remove the heat?

There are examples that point to a new approach to design and show how systems can be integrated to solve some of these problems. The key is looking at the total building system from an energy-conscious perspective and thinking at the same time about what people's real needs are. How can we reduce energy consumption--refrigeration, for example--while providing the environmental conditions people need to be comfortable and productive? When our thinking is reoriented in this way, all kinds of new questions arise. For example, is it necessary to remove heat and humidity simultaneously, as part of a single process, as has been done in the past or can we find ways to remove heat before it becomes a load on the refrigeration and dehumidification system? This particular question will attract increasing attention as designers focus on saving energy; therefore, it is important to understand the concept and how it relates to fire protection systems.

We got into this area of design some years ago in exploring how to minimize the amount of refrigeration associated with air conditioning the space. Which components of heat and how much of the heat could be removed at higher temperatures without requiring refrigeration? Put another way, how could we limit the refrigeration to the amount required by people, excluding as much as possible heat from other sources such as lighting? It became obvious that the fundamental principles of thermodynamics had not been applied effectively to the design of air-conditioning systems for buildings. This area is just now being reexamined in light of the concern about energy efficiency. Design of environmental systems will increasingly take account of the fact that it is more efficient to remove heat at the highest temperature possible while still meeting environmental needs; conversely, it is more efficient in energy terms to add heat at the lowest possible temperature.

Appreciation of these facts leads to design techniques that allow us to examine energy sources and flows and to discriminate among the different components of the heat load. With these techniques we have a rational basis for refining our design and treating different heat components differently based on their relation to each other and to the desired performance results. These techniques show us how to interrelate a building's systems and subsystems to minimize energy use. They will be an increasingly prominent part of building design.

In a practical sense then, what we are talking about is integrating systems and hardware--looking at the elements that go into heating, cooling, lighting, firesafety, etc., and then designing or arranging the components and systems in a more effective, energy-efficient way. Figure 2 helps us focus on how to design for energy-utilization efficiency. All the elements are here: internal heat gain components such as people, lights, and equipment; external components defined by the architectural design (e.g., window area, building orientation); and all the requirements defined by user needs, standards, and other

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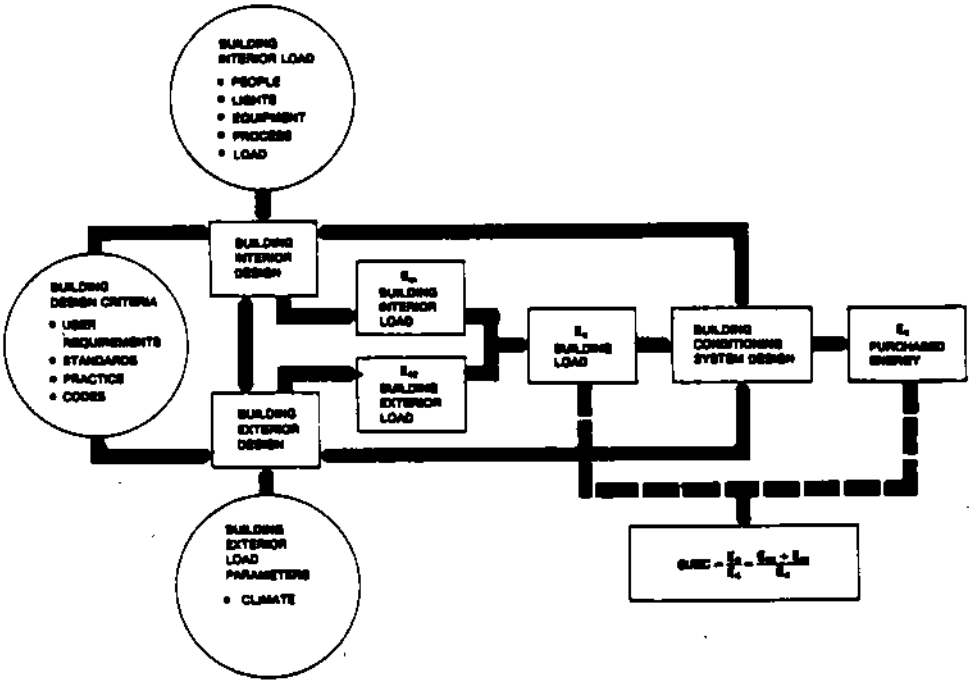

FIGURE 2 Interrelationship of various elements of energy-utilization efficiency coefficient.

constraints. When we break out the elements in this way and think in terms of thermodynamic efficiency, we have a rational basis for manipulating these components to minimize energy consumption. The key question to ask--the "bottom-line" of energy efficiency--is this: What is the actual amount of purchased energy that has to be put into that system to maintain that building load?

An important point to appreciate is that the quantity of purchased energy a building requires is a function of the kind of air-conditioning system it has as well as of the architecture or the load in the space. You can reduce the amount of glass area, for example, and you can improve insulation, but you will still have energy waste if the HVAC system is not properly designed. This system's design must take account of its interactions with the architectural elements, lighting, and other building systems. The energy flow diagram in Figure 3 is a useful tool for conceptualizing these energy interactions and thinking of the building as one energy system with components that can be manipulated to achieve energy efficiency. The diagram is an abstraction in that it is about energy flows that we cannot see but must evaluate rather than about mechanical equipment and pipes and ductwork. It can help us understand energy efficiency from yet another angle, that of the so-called coefficient of performance (COP). Then we will be ready to look at the design of some actual buildings where the HVAC, lighting, and fire protection systems were integrated to save energy.

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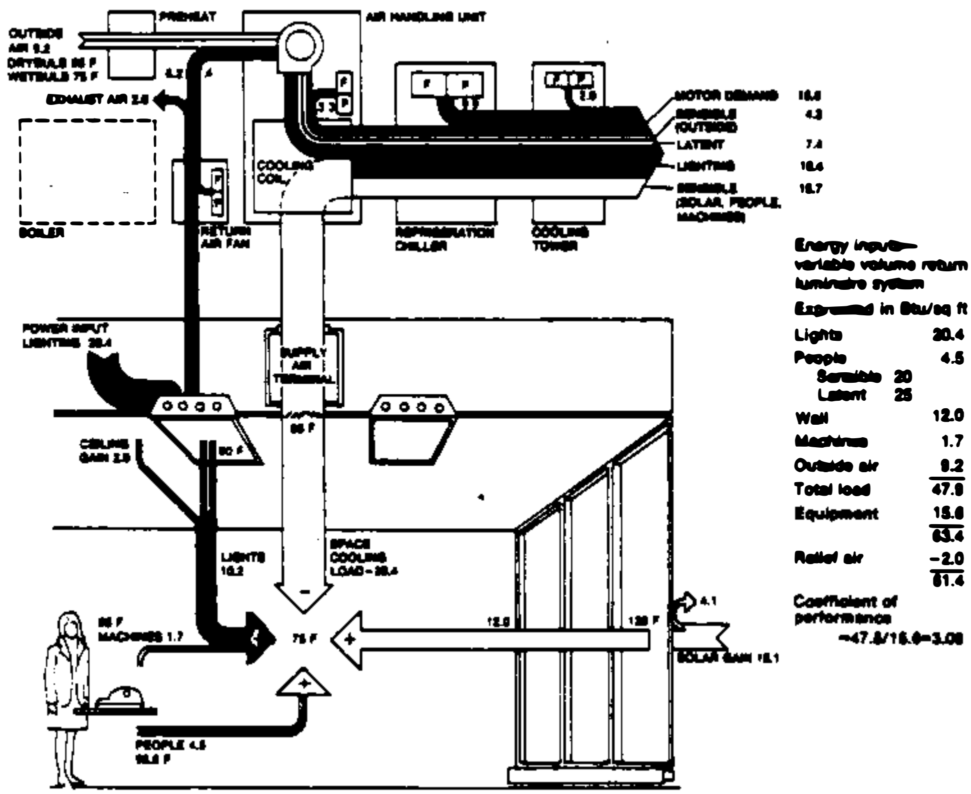

FIGURE 3 Energy flow diagram of a conventional system.

The COP defines the ratio of the aggregate heat gain in a space to the amount of machinery used to offset that heat gain. It is one gauge of how efficiently machinery is being used. It is particularly helpful in comparing the efficiency of alternative designs. Figure 3 provides the numbers needed to compute the COP. It shows the heat given off by different components in terms of Btu per square foot: 20.3 Btu from lights, 4.5 Btu from people, 12 Btu from walls, and so on. The total load that must be offset by the air-conditioning system is 47.8 Btu of heat gain per square foot. Normally the system provides cold air equal to the amount of heat gain. This is done in a controlled way by the air-handling equipment, refrigeration equipment, and the equipment that rejects the heat to the outdoors. In our example it takes 15.6 Btu per square foot to run the machinery to cool this particular space. The COP, computed by dividing the heat load (47.8 Btu) by the energy used to remove it (15.6 Btu), is about 3. The less energy used to handle a given heat load, the higher the COP will be.

Thinking in terms of the COP is simply one technique for exploring the energy relationships between the heat-load elements and the systems and components that make up the hardware. What are the sources and quantitites of heat the system must handle? What is the relationship

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of the fan horsepower to people? What is the relationship of the fan horsepower and refrigeration to glass and light? What happens to the COP if we change components and techniques of air conditioning? The COP defines a key relationship; the higher the COP, the more energy efficient the total system is. Therefore, it provides a tool for evaluating and comparing various design options.

Another major consideration that must be tied into the evaluation process is cost. As we all know, every project, every design, has cost constraints. How we determine what the trade-offs will be is a critical factor. The technique of life-cycle costing--finding the minimum combination of initial capital cost and operating cost for a specified period--provides an extremely helpful and rational methodology for making the many trade-off decisions that go into a sophisticated design process. It can help us make decisions about all the building variables that must be evaluated simultaneously against specific criteria. Which architectural materials will we select? Which electrical and mechanical systems or combinations of systems will we include, and how do we determine at what point a particular technology becomes too expensive to justify the benefits? How do we select the energy type and source? Life-cycle costing permits us to evaluate and balance all these variables in a logical way. It justifies a higher capital cost for a system--an energy-saving system, for example--if the payback period is short enough so that the system actually saves money over the life of the building. This kind of evaluation process supports and encourages the use of advanced technology to achieve building performance goals with the least cost and energy. Specifically, it justifies and encourages the integration of building systems in new ways that minimize energy consumption.

Figure 4 shows a life-cycle cost analysis that was used for a particular General Services Administration (GSA) project a few years ago. The bidding and selection was based on a life-cycle cost procedure that took into account all the variables of design that we have been talking about, including, for the first time, the energy associated with the HVAC system. The design that resulted from this analysis and an energy flow analysis was a "systems" design that interrelated components (including the fire-protection system) to satisfy all building criteria in a cost-effective and energy-efficient way.

Systems building is what we are really talking about when we speak of integrating or interrelating functions in design to achieve the optimum balance of cost and energy use. I call it energy integrated design, and I call the new combinations of systems that result energy integrated systems. This is where the subjects of firesafety and energy intersect. There are many aspects of design that are not interrelated--that are strictly mechanical or architectural or electrical. But the cutting edge of energy-conscious design is in the overlay area where there is opportunity to conserve by integrating functions where system energies intersect.

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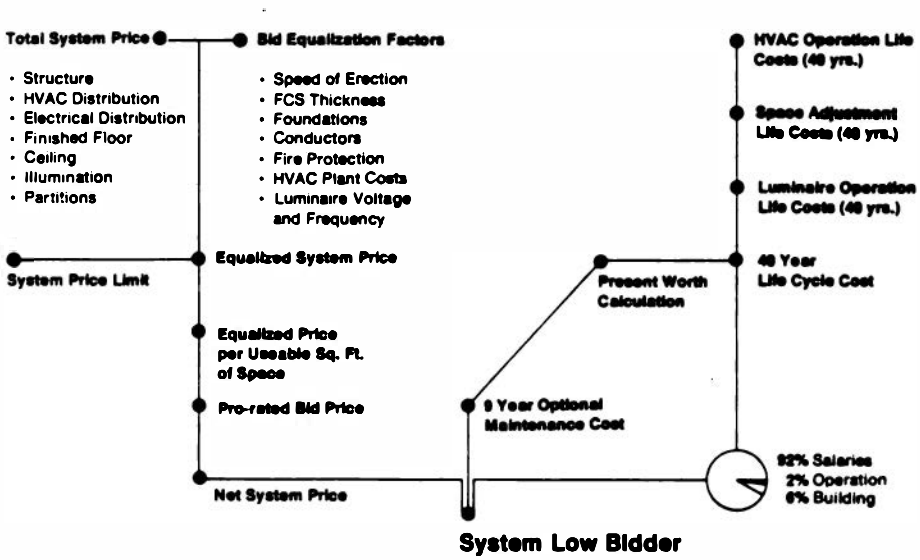

FIGURE 4 Illustration of the life-cycle bidding process.

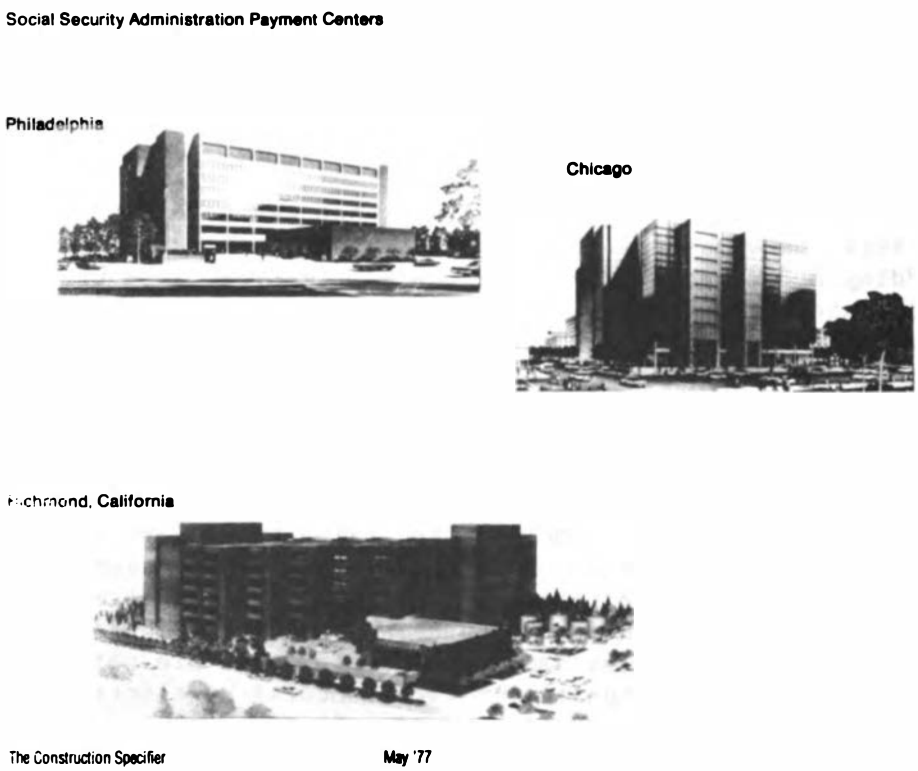

FIGURE 5 Social Security Administration payment centers.

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A specific example is the GSA systems project referred to above, which encompassed the three Social Security Administration (SSA) buildings shown in Figure 5. In these buildings the fire sprinkler systems and the lighting, heating, cooling, ventilating, air-conditioning, and structural systems were all interrelated for optimum performance and energy savings. As was mentioned earlier, these buildings were acquired by the SSA on the basis of life-cycle cost bidding. The design had to take into account the energy characteristics of all the components and systems. Lighting, for example, is primarily a heat source that also produces a little bit of light; 80 percent of the system's energy is given off as heat while only 20 percent goes into light. This heat is normally refrigerated. However, in the integrated system that was developed, which interrelates a mechanical and an electrical component, nonrefrigerated water circulating through the lighting fixtures absorbs and carries off to the cooling tower most of the heat without imposing that load on the refrigeration system. Not only is the amount of refrigeration associated with lighting significantly reduced, the cooler space around the fixtures increases the efficiency of the lighting so that more light is available from the same amount of energy. Figure 6 shows what the device looks like and how the energy flows: power in, heat out through the piping, and light into the space. This is a vivid example of the interaction of system energies that was mentioned earlier and of the energy savings that can result from integrating systems into a new kind of system. Seventy percent of the heat from the lights--a major portion of the usual heat load--is removed before it enters the occupied space. As a consequence, the amount of conditioned air that has to be circulated is significantly reduced and the size of air-handling equipment is minimized.

This particular integration story does not end there. The fire protection system also is related to the lighting and mechanical heat-removal system: in fact, the nonrefrigerated water loop is integrated

FIGURE 6 Lighting fixture incorporates nonrefrigerated water uniformly circulate to carry off heat.

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with and supplied from the sprinkler system. An extra safety feature of this system, in terms of fire protection, is that any interruption in the sprinkler system flow is rapidly detected due to the change in comfort conditions as heat from light enters the space. With this system, when heat is desired, the circulating water is throttled back and lighting heat is drawn through the plenum and into a ceiling induction box to be mixed with a minimized amount of conditioned air and then circulated uniformly through the space.

The system also is related to structure. The use of sprinklers eliminated the need to fireproof the cellular floor and, thus, significantly reduced cost. Economically we were able to trade-off fireproofing requirements for sprinklers; the use of sprinklers justified the heat-rejection system, and that system was traded-off against sheetmetal. This design clearly illustrates the concept of energy integrated design that involves many systems and stems from a complex pattern of trade-offs.

Figure 7 is a schematic diagram of the energy integrated lighting, air-conditioning, and fire sprinkler system. As a result of the successful use of this system in the GSA-SSA buildings, the NFPA code was changed, and the 1978 issue of NFPA 13 now permits such dual-purpose piping use. The code officially recognizes the feasibility of integrating the fire protection sprinkler system with the HVAC and lighting systems.

Another integrated system that is receiving a lot of consideration is water-cooled unitary heat pumps in a closed circuit of nonrefrigerated water that is also the sprinkler system. Several systems like

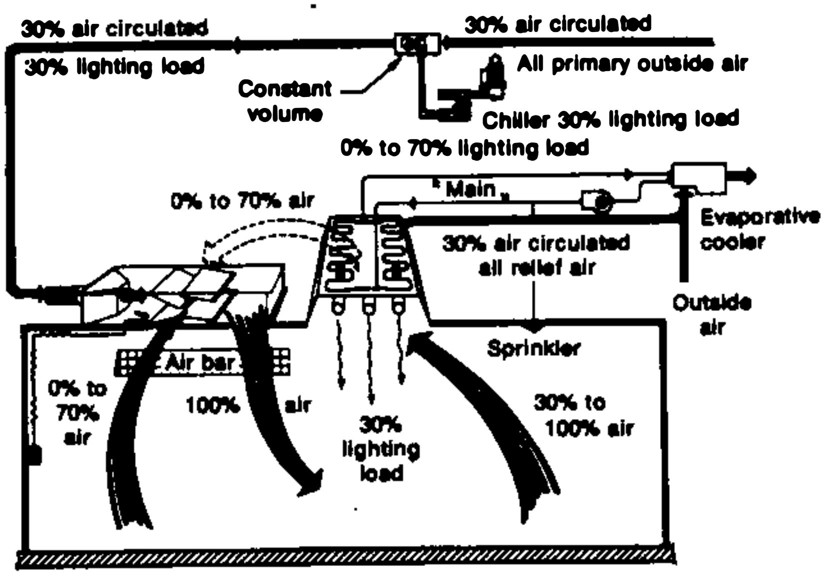

FIGURE 7 Schematic diagram of the energy integrated lighting, air-conditioning, and fire-sprinkler system.

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this, using a water-air unitary heat pump and sometimes incorporating water-cooled luminaries, now are being installed. Figure 8 illustrates such a system on one typical floor. From a central pump, the piping system distributes nonrefrigerated water to unitary heat pumps on each floor. In the normal (nonfire) mode, water flows through the heat pump and into the sprinkler loop on the floor and then out of the sprinkler loop and back to the central plant. In effect, the sprinkler standpipe and the horizontal sprinkler piping on the floor also are elements of the HVAC system.

A unique feature of this system is that it can define where a fire is. When fire occurs, the direction of water flow is reversed, and the fire is identifed and located as follows: When the sprinkler head goes off there is a drop in pressure which activates a central fire pump. The fire pump pressurizes the piping system through the return side of the closed loop circuit, reversing the direction of water pressure. The consequent reverse flow of the fire water starts in pipes on the endangered floor where sprinkler release has lowered pressure. As water is forced out of the fire standpipe on this floor, one-way check valves direct the water through a water flow indicator that immediately annunciates the existence and location of fire at a central alarm supervisory panel. Only in the reverse-flow fire mode do the check valves admit water to the water flow indicator that signals fire, and the elapsed time from automatic sprinkler release to automatic central alarm is only about 1-1/4 minutes. Thus, the integration of the fire sprinkler and HVAC systems meets stringent firesafety standards, and it is this concept of directional check valves tripping a water flow indicator and pinpointing the threatened floor that makes the system both practical and safe.

An interesting and important aspect of these multipurpose integrated systems is that economically they permit us to bring sprinklers into buildings where they might not be justified with a standard HVAC design. Cost savings from the integrated system in effect pay for the sprinkler system that otherwise cannot be financed even with the insurance premium associated with sprinklers.

The principal points I have tried to communicate add up to this: Energy and cost pressures have created new problems that require new kinds of design solutions. The most efficient designs, in terms of both cost and energy, integrate different building systems that traditionally have been separate, including the fire protection system. Dual-purpose or multipurpose components--such as piping serving different functions--are the practical or hardware key to these integrated systems. The conceptual key is a total building perspective that analyzes energy flows and focuses on areas of functional interaction. The result is to streamline or rationalize our use of energy and system hardware; salvaged resources then can be applied to high-priority goals such as a safer environment. Energy integrated systems design will become, increasingly, a requirement in the design of successful buildings.

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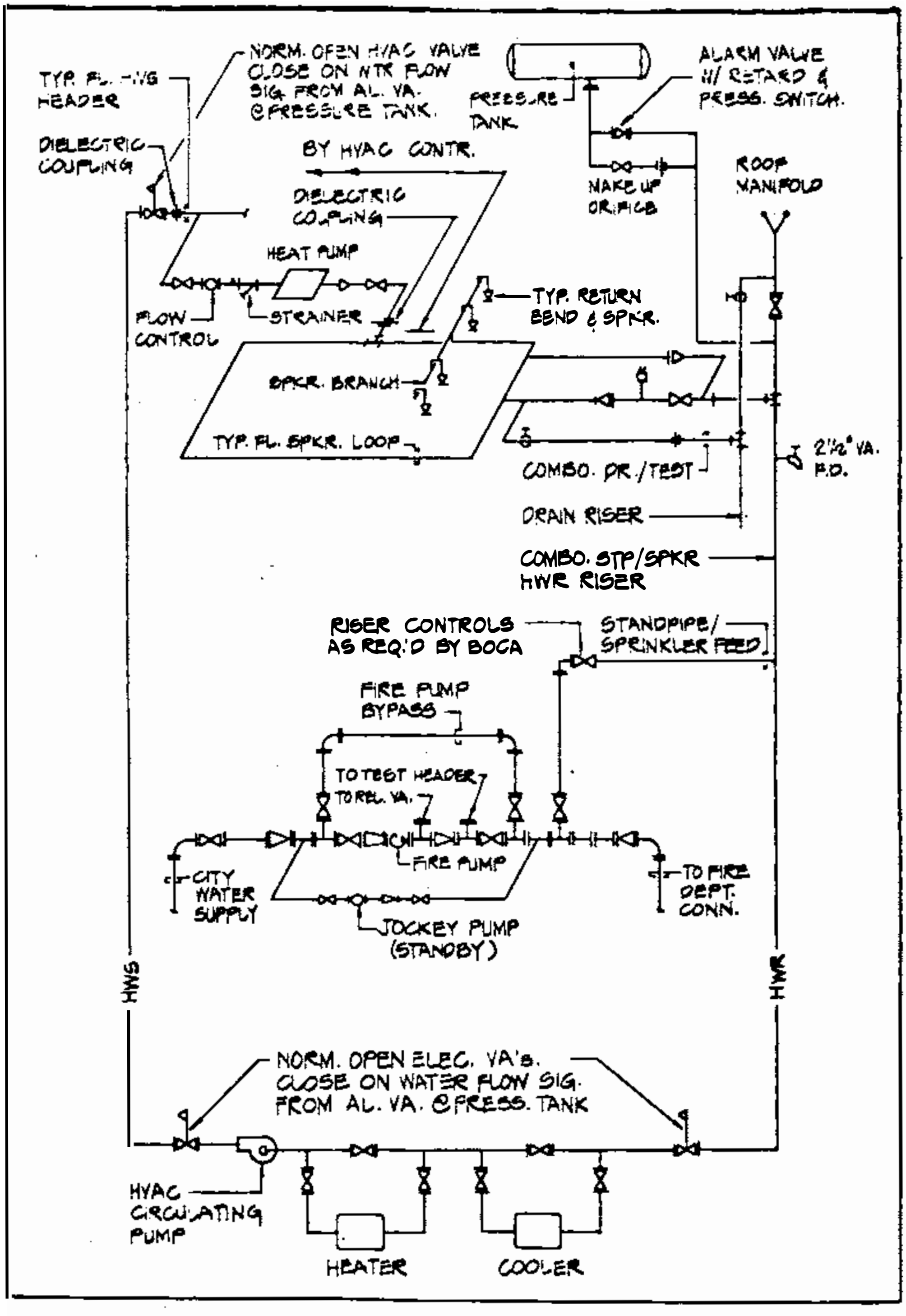

FIGURE 8 Combination HVAC and Fire Protection System.

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PRESENTATION

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I have been asked to talk about energy conservation and its effect on building firesafety from the practical viewpoint. How does a fire protection engineer working on new building designs and concepts integrate, in a practical way, the building fire protection program with building code compliance and energy-conservation requirements? While thinking about the subject in preparation for this program, it gradually became apparent to me that energy-conservation requirements systematically have affected the firesafety problem, particularly over the past 10 years, but that this had happened so gradually that the relationship was not recognized until now.

First I would like to identify the problem as I see it and then discuss the solutions to the individual parts of the problem from the viewpoint of a fire protection engineer working with building designers and building code consultants on a daily basis. Probably the most significant single factor has been the increased use of more effective insulating materials. This has affected the fire problem in at least two ways: (1) with insulation in the walls and ceiling of a room, less of a heat sink is provided, and (2) the possibility of flashover, should a fire occur, is enhanced.

I have participated in numerous fire tests as a former engineer at Underwriters Laboratories, and it was possible to see how the insulation affects flashover. A series of fire tests was conducted for the American Iron and Steel Institute approximately 15 years ago. Wood cribs were installed in a fire test room approximately 120 square feet in area with various window configurations. The fire test room was constructed with concrete walls and roof. In the first fire tests when there was much moisture in the concrete, flashover was much slower in comparison to later fire tests when the moisture had been driven out and the specific heat of the concrete had been reduced.

Likewise, I have investigated fires that occurred in mobile homes where the relatively small amount of mass in the exterior walls and the insulation within the walls tended to retain the heat generated by an incipient fire within the space and enhance flashover. This resulted

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in earlier flashover than in a comparable single-family residence with plaster or gypsum board partitions. Of course, the flame spread characteristics of the interior paneling and ceiling are an important factor.

Some of the more effective insulating materials used in building construction, particularly the foam plastics, have had a history of being highly combustible, the second way insulation has affected the problem. Although contributing to energy conservation, they have created a severe fire protection problem because they ignite easily, burn intensely, and spread fire rapidly. I believe foam plastics probably are the most serious part of the fire problem associated with energy conservation.

Although most people do not think of them as such, atriums in a building are a means of energy conservation. In effect, the atrium building has much less exterior wall area exposed to the elements since a substantial part of the exterior wall faces the atrium, which then is roofed over and protected from the elements. This serves to reduce the energy loss, but the roofed-over atrium tends to violate the building code requirements for fire-resistive construction to separate one floor from the next. When a fire occurs, the roof retains the heat and smoke in the building, increasing the hazard to the occupants. Atriums have been a part of the architectural bag of tricks for only a short time; however, fire protection engineers have learned to cope with the problem even though most building codes still do not officially recognize atriums.

Mechanical systems in many new buildings, and increasingly in existing buildings, have been designed to recirculate as much air as possible and thereby reduce the amount of fresh air introduced into the system. This is in contrast to the practice used not too long ago when many buildings were designed with the 100 percent fresh air concept (i.e., air went through once and was discharged to the exterior). In conjunction with this, toilet exhaust requirements are somewhat reduced from earlier years. The result is that the mechanical system may not be effective as a smoke control or smoke exhaust tool if a fire occurs. Rather than move the smoke out of the building, the system may recirculate the smoke and dangerous products of combustion throughout the building or, at best, allow them to remain in the fire area.

Along with mechanical system air recirculation, many new buildings have windows with fixed sash instead of operable windows. When a fire occurs, there is no practical way for building occupants or firefighters to open windows to ventilate the building and get fresh air in and smoke out. Breaking of windows endangers people on the ground.

In short, design efforts to minimize heat loss in cold weather and heat gain in warm weather serve to enhance early flashover of an incipient fire, cause the fire to spread rapidly after flashover occurs, and retain heat and smoke within the building. The question now is what can be done.

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Whatever measures the fire protection engineer takes must be consistent and in concert with the energy-conservation efforts incorporated into the building design and with the applicable building code. From a practical viewpoint, a number of things can be done that are in keeping with these goals.

Building specifications should require and construction should involve use of noncombustible building materials to the greatest extent possible. Acceptable building materials would include steel and concrete, gypsum wallboard, mineral wool insulation, and mineral fiber acoustical tile. If combustible materials (e.g., wood paneling) are needed, they should be of a flame-retardant-treated type. Thus, if a fire should occur, the building structure and its components will not of themselves contribute to the spread of the fire. Where building insulation is to be exposed, it is important that it be of a noncombustible type. There are many manufacturers throughout the United States producing noncombustible insulation, of a glass-fiber base or rock-wool base, that is acceptable under the various building codes. One must be careful to secure insulation with a noncombustible facing, such as aluminum foil, rather than with a paper facing, which could itself contribute to a fire.

The foregoing assumes an insulation that is exposed to the interior of the building. As noted earlier, foam plastics are a desirable building material since they are effective insulators. If used, such insulation should be covered with a flame barrier to protect it from direct exposure to a fire. An effective way to do this is to cover the insulation with 1/2-inch gypsum board mechanically secured to the insulation. The gypsum board, because of the water of hydration in the gypsum, will absorb large quantities of heat while calcining before the foam plactic substrate is sufficiently heated to contribute to a fire. The substrate can be kept at or below 200°F for 30 minutes or more depending on the severity of the exposing fire.

Because of their heat sink qualities, gypsum board partitions and ceilings will help absorb heat from an incipient fire, thus preventing flashover for a longer time than would be the case if thin high-flame-spread wood and cellulosic paneling had been used. This has been seen in a number of destructive fires in mobile homes that were built with such paneling. Thus, gypsum board and plaster partitions are preferred over light, thin paneling.

Although buildings are designed to be tight, building codes usually have required operable windows in certain occupancies such as hospitals and hotels. Today, recognizing the need for energy conservation, many codes have relaxed this requirement and instead require that the building mechanical systems provide a means to evacuate smoke. Under normal conditions, the system may recirculate all or most of the air, but in a fire emergency, the system in the fire area goes into an exhaust mode, air supply stops, all return air is exhausted to the outside, and adjacent mechanical systems go into a 100 percent fresh air supply mode. The purpose is to keep smoke away from other floors and to let

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the smoke out of the fire-affected floor. A number of variations are used, but the primary approach is to exhaust the fire area and pressurize adjacent areas. Likewise, some jurisdictions will recognize tempered plate glass windows in lieu of operable windows. Firefighters can break such glass without endangering people on the ground and ventilation of the fire floor is thus achieved.

As noted earlier, atriums have become an important factor in building design, and building codes have not directly recognized this. Fire protection engineers and building code officials, however, have recognized that they are an architectural design consideration which has arrived on the American construction scene and that they must be dealt with. The result has been that most atrium buildings have been designed with complete fire protection programs which deal directly with the problem of life safety. The programs generally have been based on complete sprinkler protection, a highly reliable water supply, smoke control consisting of exhaust at the atrium roof and make-up air at the base, and a reliable fire alarm system by which all of the other fire protection functions are controlled. In addition, many atrium buildings are high-rises, and dedicated elevators are provided to get firefighters to upper floors.

Over the years automatic sprinklers have been an important fire protection tool. The insurance industry long ago recognized their value by giving substantial premium reductions to buildings and contents protected by sprinklers. Now we fire protection engineers find that when sprinklers protect property, they will at the same time protect lives. When the sprinklers operate, they discharge water onto the fire and will extinguish it. At the same time they limit the smoke generated, making them a smoke control tool, and sound alarms, making them a fire alarm tool. In short, sprinklers are an effective means to help compensate for the incremental increase in the fire hazard caused by energy-conservation measures.

Current energy-conservation measures pose problems to the fire protection engineer in that buildings are designed to be better insulated and combustible insulations and paneling often are used, mechanical systems recirculate high percentages of air during extreme temperature conditions, and atriums have been designed into many buildings. Nevertheless, fire protection measures have been found and are available today to mitigate these hazards. They include use of noncombustible insulation, use of proper covering where combustible insulation is used, flame-retardant treatment of combustible finishes, smoke control using the mechanical system where operable or breakable windows cannot be used, and special fire protection programs keyed to automatic sprinkler protection for buildings with atriums. In short, I believe that fire protection engineers have met the problem of energy conservation in buildings and have provided reasonable solutions to the problem.

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PRESENTATION

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In my brief presentation I will discuss how we in the Bell System view firesafety and energy conservation. I will be focusing on potential problems and how we are dealing with them, including some of the positive aspects of combining firesafety and energy conservation. In order to give you a feel for the Bell System view of this issue, I will first present a framework from which we can operate.

I am in the real estate management organization at AT&T. We are a staff group for the real estate management organizations within the Bell operating telephone companies. Our mission is to provide the operating companies and long lines with advice and guidance, primarily through practices concerning the planning, design, construction, and operation of Bell System facilities. In this capacity, we work closely with Bell Laboratories and periodically with Western Electric. From the standpoint of numbers, we operate 29,000 buildings of all sizes. It is noteworthy that 20,000 of these buildings are facilities that house heat-producing telephone equipment.

In order to appreciate our perspective, it is useful to share with you how we view the building standards and codes process. We view this process as follows: Technology is the basis for consensus standards; the standards are referenced in the model codes; the model codes are adopted by state and/or city codes to become binding requirements; buildings are designed and constructed to local code requirements. Our group at AT&T fits into this process by attempting to stay abreast of building technology and to participate in the consensus standards and model code activities. Much of the knowledge gleaned from this interaction finds its way into our building engineering and building operations practices, termed Bell System Practices (BSPs). The BSPs are guidelines for planning, designing, constructing, and operating our facilities. In effect, the BSPs provide the necessary guidance to the operating companies in this area, unless local codes are more stringent.

As you might imagine, however, the BSPs do not address all building-related details. In fact, they primarily address unique considerations, special projects, and new programs, and we rely

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heavily on the model building codes and consensus standards for the majority of our requirements. With facilities as complex as telephone equipment buildings, there are many unique and special requirements. Two that are frequently of importance concern firesafety and energy conservation.

Three areas of special interest with respect to firesafety in telephone equipment buildings are detection and alarm, smoke control, and firestopping. In terms of energy conservation, our program is aimed at designing new building systems and fine-tuning existing building system to handle actual loads versus anticipated growth loads. Our concerns include excessive refrigeration capacity, excessive fan horsepower, excessive fresh air intake, humidity control, control systems designed for simultaneous heating and cooling, and insulating to an optimal U-value.

From our perspective, in implementing our firesafety and energy-conservation programs, there are two possible areas of conflict:

1. Smoke Control--Are we compromising our smoke-control program by reducing fan capacities and total fresh air intake to conserve energy?

2. Insulation--Does the use of combustible plastic foam insulation materials increase the fire hazard in our buildings? Let us deal with each of these issues separately.

After examining what is involved in the smoke control issue, we have found more pluses than minuses when combining smoke control and energy management:

1. We find that even reduced fan capacities are still high enough for an effective smoke control system (i.e., we can maintain sufficient positive pressure in the compartments adjacent to the compartment involved in the fire while exhausting the smoke and hot gases from the fire compartment).

2. Since an economizer cycle is used to cool heat-producing equipment with outside air when possible, the capability for 100 percent outside air is necessary. This 100 percent outside air capability also is needed for an effective smoke control system. The economizer cycle has been a standard recommendation for HVAC design in the Bell System since the early 1970s.

3. The biggest benefit we see involves the use of microprocessors in facilities management systems. We have found that by combining the controls for fire detection and alarm, security, energy management, and smoke control into a single system, the cost-effectiveness of both the energy management and smoke control programs is considerably improved. Thus, the bottom-line is positive when we bring smoke control and energy management together in an integrated approach.

As part of our energy-conservation program, the amount of building insulation is determined by designing to an optimal U-factor, conductance of heat, to minimize energy consumption. Because of the excessive heat generated by the newer electric switching systems and some

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older types of telephone equipment, this actually could result in a reduction of the amount of insulation required in some cases. Since we do not provide guidelines on types of insulation, plastic foam materials can be used; however, the use of exposed plastic foam insulation is precluded through an interior finishes and furnishings BSP that limits the flame spread and smoke contribution characteristics of these materials. In effect, what we are doing is relying on local codes in the area of insulation since it is not viewed as a situation unique to telephone facilities.

Before closing, I would like to add that, from our involvement and perspective in a real estate management organization, we do not see major conflicts between firesafety and energy conservation in telephone equipment buildings. We also believe that there are significant benefits to be achieved by combining energy management with smoke control, fire detection and alarm, and other features in a single facilities management system. Questions concerning proper testing procedures and evaluation of plastic foam insulation must be resolved, however, possibly by a new standard that would replace the present E84 test. We consider a good plastic insulation test standard that will ultimately impact on the use of plastic insulation and be referenced by the model codes and then adopted in local codes as a high-priority issue.

I want to emphasize that our views on this issue are weighted by the fact that we are an owner and operator of a large number of unique facilities (i.e., telephone equipment buildings). Our philosophy has been to develop our own programs when they are related to the uniqueness of the facilities since we would not expect them to be addressed adequately in the building standards and codes; our combined smoke control and energy management concept is an example. On the other hand, we have relied on the building standards and codes for those aspects of our facilities that are common to most building design and construction; the insulation issue falls into this category.

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PRESENTATION

Tom Berg, President
Ray Ellison Development, Inc., San Antonio, Texas

In the home-building business, firesafety is not the most pressing thing because the homeowner can figure out more ways to set his house on fire than a developer can. About three years ago a strange series of fires was taking place. The most telling one occurred when a family was having dinner and watching a television set on a bitter cold January night in south Texas where the winters normally are rather mild. The house was about three yeare old, but this was the first cold winter and the fireplace was lit for the first time. The phone rang and the neighbors called to ask these people whether they knew their house was on fire. You can imagine the sequence after that.

The problem occurred with about four other houses. What turned up during the investigation caused us to go through about 145 houses and to rebuild many of the walls. (In the case of the fires, we rebuilt the houses at no cost to the homeowners, less any insurance that would be recovered.)

What we found was that the installers of these fireplaces (primarily subcontractors) were rather sloppy in their work. Since you cannot find out what is going on in a fireplace or a chimney unless you take the side of the building off, we had to have crews take the sides of the fireplaces off to examine what was inside. We found that many had sections of the flue, as much as 12 and 18 inches, missing. In other cases, sections of the flue had slipped down and there was 3, 4, 5, or 6 inches of open space. We also found that the caps on top of the fireplaces, on top of the chimneys, were very faulty. Needless to say, it was a very disconcerting situation.

The strategy for rectifying the problem finally turned out to be the most simple one. One of our better managers toured the neighborhoods looking for these particular fireplaces. He explained the situation to the family, set up a repair time, and asked them not to use the fireplace until we fixed it.

The builders of those types of fireplace have since revised their entire field crews and construction and supervisory operations. It was a very disastrous situation and it appeared that these fireplace

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builders had this trouble all over the country but had been telling the homewoners that they did something wrong.

Now to move on to how we make a home energy efficient. In south Texas energy costs had been very, very low but skyrocketed within about two years to triple the cost. We took the initiative to find out how we could make a very energy-efficient house.

We had to make a tight house. The result of having made a tight house, I was told by one of our construction superintendents, was that the Veterans Administration (VA) inspectors said they thought our houses are getting too tight because there did not seem to be enough air coming in.

We also use a caulking system, and everything is caulked to the slab. We use tar paper sealing around windows and weatherstripping and storm windows are standard. We site the house for a solid wall, wherever possible, on the west side (our sun is more intense on the west than on the south) and every house has overhanging eaves. We also try to place the house carefully with regard to the trees that will be put on the lawns. The upshot is that the homeowners report to us about a 30 percent saving in their utility bills.

Before closing, I also should note that we use attic fans but are phasing them out. Although they move an enormous amount of air, they do not appear to be a very efficient way of removing heat.

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Session IV
ENERGY CONSERVATION AND FIRESAFETY IN BUILDINGS

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INTRODUCTION

Charles E. Schaffner
Executive Vice President and Director
Syska and Hennessy, Inc., New York, New York

This conference is a typical example of the good news-bad news syndrome. The good news is that we are drawing national attention to the secondary problems created by single-minded concentration on a national objective. People talk today about the systems approach, but when we get involved in something like the energy problem, we forget all about systems. The bad news is that this concentration illustrated our failure in American life to concentrate on the system rather than on the parts of the system.

We tend to forget that we have gone through hundreds of years of history in this country without ever having energy conservation in a building code, and I do not think that there are many building code people in the country who are really convinced yet that energy conservation belongs there. At any rate, we have put it there. Mr. Everly pointed out earlier that the three important aspects of building codes are health, structural safety, and firesafety. I think that when we, in our single-minded devotion to solving the problems of energy consumption, went pell-mell putting it into building codes, we lost sight of those three basic reasons for the building code.

This conference certainly is helpful in pointing out the problems and some of the successes of integrating energy conservation with fire protection, but we also should be taking a look at the impact of energy conservation on structures and, more important, on health. We have given very little attention to the effect of energy-conservation measures on the health of the occupants of all kinds of buildings, and I think it is long overdue. I know some research is under way, but I believe we also have to be talking about it very loudly in public so that we do not lose sight of the fact that the single most important aspect of the utilization of a building is the people's comfort and the creation of conditions under which they can function most productively.

This conference session really is intended to tie together brief summaries of the first three sessions by the leaders of those sessions and critiques by four panelists who represent academia, architecture, engineering, and fire practice. The remainder of our time is reserved for discussion and questions by the audience.

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SESSION I SUMMARY

Harold E. Nelson

I speak now neither as a representive of the National Bureau of Standards nor as an officer of the Society of Fire Protection Engineers. Instead, I will present my personal opinion of the first conference session.

I come away from this conference with one question. Is there a problem or is there not a problem? In general I believe that for every fire problem, real or not, there is a clear and simple but often extremely expensive answer. Often we find these answers very readily and we institutionalize them. The effectiveness or worth of the solution is often a random variable to be worried about later. We seem to be more concerned about the process of institutionalizing the approach than about the effectiveness of the approach.

With respect to whether there is a problem, my personal opinion is that there truly are some real fire risk problems arising from energy conservation. Sometimes these risks are minor and sometimes they are major. What do I mean by major? Sometimes there is a major fire problem and sometimes there is a major design problem. The degree to which it is one or the other is an open question.

Loss data are historic data. They are good for yesterday's design but are not really good for tomorrow's design unless it is like yesterday's design. If we are going to talk about innovation, loss data are unreliable predictors. Part of the difficulty arises in my own profession and involves the inability of traditional fire protection technology to handle a new problem, one that requires new applications of technology and is not supported with feedback fire data. We seem to be totally incapable of handling a problem if we do not have a body count to consider.

There is certainly a real problem created by our belief that there is a problem. Just the statement that there is an energy-fire problem is part of the energy-fire problem. We encounter voids or conflicts in our codes, regulations, and insurance impacts, and we then try to fill them with a new code, a new regulation, or a new insurance rating requirement.

The true cause of fire and fire products in a building is really a complex, nonlinear, state transition type of situation and one of our problems is the desire to keep things so simple that, as was stated this morning, the man with the hammer can handle it. Yes, he can

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handle it but only if you put enough money behind that hammer. If you want efficiency and cost-effectiveness, it is not going to be an easy problem to solve.

Our current criteria generally are on a component performance basis. Component performance works well for standardized tests but not for total systems or engineered solutions. Our current problem really is a golden opportunity to move the technology forward. Mr. McCollom emphasized it in his proposal for a systems approach. I like to think of it more as an engineered approach. A tractable system is within view--a sound and, I think, rationally conservative system of engineering analysis using the best mix of specific analysis from fire modeling and other developments, empirical data, and conservative engineering assumptions. A good deal, but by no means all, of the engineering models, data, and test results needed are available now.

SESSION II SUMMARY

William E. Fitch

What we heard during the second conference session, as Mr. Nelson pointed out, were examples of some of the work that is being done in evaluating applications of material. We heard presentations on the energy loss-gain control part of energy subsystems and we learned that work is being done on confining the fire (i.e., on controlling flame spread, rate of heat release, and total energy), on controlling ignition, on preventing ignition, on controlling the fuel, and on shielding the fuel from ignition sources.

We learned that the problem is not being ignored. But I believe Mr. Nelson is correct in saying that the problem is being attacked in a disjointed manner. We are gathering bits of information, but nobody has put it all together. I must say, however, that Dr. Harmathy's presentation was a fantastic attempt to do just that and I look forward to reading his paper in the proceedings of this conference because I think that with it we can begin to pull our disjointed information together.

What do we do with the information? As Mr. Everly said, we need to get it into the hands of the people who can use it, both the designers and the enforcers, and to have it in terms that they can use. Fortunately, much is being done in this area.

A number of the research programs described during this conference already have provided the bases for revisions to the building codes. In fact, when the Building Officials and Code Administrators meets, specific code changes concerning the combustiblity hazards of insulation materials will be discussed.

What we need to look at is education and the cost of technology. It is not enough to write a new law. We must understand what we are going to gain from that, what other paths there are to take, how we can educate the public, and how we can educate the contractors and designers. We must determine where is the best point to attack and whether we should attack all of it.

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We attempted to present in the second session and throughout this conference information on the issues and how they are being attacked. Now we need to provide that missing link that will tie it all together. Hopefully, we can do that during this discussion.

SESSION III SUMMARY
H. J. Roux

I will summarize the presentations made during the third conference session and at least convey what I thought to be the highlights of those presentations. I also will draw some conclusions that might prompt discussion.

Mr. Freeman, in his discussion of the fire properties of insulation materials, made two key points. The first was that we are in a "transition from an oil-dependent economy to an energy-diversified economy." To me this means that new types of energy sources will be used and that we must determine whether these new sources, used for home heating and cooling, create some unidentified problems in the form of new ignition sources. One example of this might be solar heating panels, something that most of us are not too familiar with but something that can create fire problems. Mr. Freeman's second major point was that "energy efficiency is productivity." We must consider the changes being made to eliminate inefficient home construction and inefficient heating and cooling equipment in homes and determine how these changes might in themselves affect the fire problem.

Mr. McCollom spoke about the systems approach, the only real way to achieve energy-efficient and firesafe buildings. He effectively conveyed, citing the various projects that the U.S. Department of Housing and Urban Development has been involved in, the need to look at the overall picture rather than at the individual parts and to seek, in combining those parts in a systems approach, a far better solution.

Mr. Everly spoke about energy conservation and firesafety in building codes. One point he made was that energy efficiency is now part of a building code and that in the past firesafety has been a large part of the building code. Thus, I concluded that the building code is essentially a kind of playing field, a ground of combat if you will, where the two interests of energy conservation and firesafety are coming together and that there is a need for a balance between the two interests.

Mr. Everly made two other interesting points relative to the building code: (1) that it is a communications link and one therefore might look at that very purpose as a way of addressing this conflict between energy conservation and firesafety, and (2) that it is reactive, which is probably most appropriate.

Mr. Mariani spoke about architecture as a challenge for the 1980s. He related the history of buildings from when they were tuned to nature

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to their concentration in the cities and the fire problems that created. He noted that cities are energy hogs and made the very telling point, at least in my mind, that the energy program is being driven by economics whereas the firesafety program is not. The fact that these two programs are driven by different forces may, in a sense, create some of the problem. If we could find some common force that was the driver for both of these programs, maybe we could obtain a better resolution of the conflict in a quicker way.

Mr. Meckler spoke about how to provide energy-efficient and firesafe buildings. Specifically, he talked about the integration of building systems (lighting, heating, cooling). He emphasized life-cycle costing (and economics certainly has been a consideration all through this discussion) and showed us two excellent examples of integrated systems (i.e., of a sprinkler system integrated with a water-cooled recessed fixture or as part of the loop of a heating pump system).

Mr. Bellman talked about energy conservation vis-a-vis fire protection from a practical viewpoint. He specifically addressed some very real and immediate problems: the increased use of insulation materials and atriums and the recirculation of smoke by mechanical systems. He emphasized that systems need to work in concert.

Mr. DeCapua spoke about firesafety and energy conservation in Bell System buildings and he referred to the problems involved in both designing new building systems and fine-tuning existing buildings. He specifically addressed two areas of conflict--smoke control and the use of increased insulation.

Mr. Berg spoke about energy conservation and firesafety in homes. He exemplified what I would characterize as a very responsible builder by reporting on a particular fire problem created by the quality of installation of fireplaces.

In reviewing these presentations, three thoughts came to my mind: Is there a problem? If there is, may it not be better treated as an opportunity since the goals of both energy conservation and firesafety are acceptable ones? Is there in all of this the need for both interests to meet on some common field of play, some common field of solution? We have a formal sort of playing field in the building code where there are requirements for both energy conservation and firesafety, but the practicing engineer, the mechanical engineer, the fire protection engineer, and the architect or building owner also represent playing fields where both these interests can come together in a more informal manner.

Maybe our overall goal, if we look at it as an opportunity and can find some common playing field for both interests, is to seek a balance between the two goals. Interestingly that may require redefinition of the goals themselves. Maybe we should not seek optimum energy conservation or optimum firesafety but rather some optimum between the two.

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PRESENTATION

Richard E. Bland
Associate Professor of Engineering Research
The Pennsylvania State University, University Park

I was invited to this conference session as an academic, but I will approach the subject from my position with the National Commission on Fire Prevention and Control. The Commission was composed of a dedicated group of people representing a wide spectrum of interests and views. Its stated goal was to reduce significantly U.S. life and property losses from destructive fire. It then defined "significant" to be a reduction by half in a generation. On that basis, the priorities were established as prevention, detection, and suppression, in that order. The Commission worked for a very intense two years--so intense, in fact, that I crawled back into a hole as soon as the two years were over and have only ventured forth now to give my personal views on what is going on in the fire world.

I observe a continuing scarcity of programmatic innovation to serve the needs of the general public, the people impacted by fire. Those of you who might like to explore some of the political reasons for this should read the report of the Advisory Commission on Intergovernmental Relations (ACIR), Fire Prevention and Control: Two Case Studies in Pragmatic Federalism. The report analyzes how the federal government became involved in the matter of fire and outlines a prognosis. It isolates three streams of influence that converged in the Fire Prevention and Control Act of 1974. The streams were the engineering community, the forest protection group, and the fire suppression forces.

The engineering community was composed of the U.S. Bureau of Standards, the National Fire Protection Association, the insurance industry, and a variety of commercial and industrial groups. In retrospect, it is not quite clear what they wanted. Those in the second group were concerned about forest fire prevention and control. They had a unique position since they had an established link with federal, state, and local governments that had matured since the late 1920s. They were well-informed and experienced but cautious participants. The fire suppression group was composed primarily of members of the International Association of Fire Chiefs and the International Association of Fire Fighters. Their motivation was primarily one of establishing their identity and gaining influence.

What I thought I saw, at the time, was a constituency that could put the federal government in a proper functional position and that could lead a carefully considered prevention program against fire loss. Since all levels of government are involved in fire as stewards of the public trust (welfare, health, and happiness), the federal role should be one

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of contribution based on a unique capacity or capability. For instance, the federal government has restricted policing powers under the Constitution; the states have the clearly vested power to enact and enforce firesafety codes. Earlier someone mentioned the European fire experience and that it appears to be better. In this regard one must remember that few European governments are the same as ours with respect to policing powers or safety services. Foreign fire departments are primarily military units; they are a function of the national government and regulation generally is a responsibility of the central government. In the United States, we do not encourage regulation at the federal level.

Now I will discuss what I think has happened during the 10 years since the Commission disbanded. First, the constitutency, the coalition that supported a federal role, has evaporated. To put it bluntly, everyone came into the program to get his two bits, and when big funding did not emerge, each pulled away toward his traditional position. Splinter groups emerged to establish influence and the fragile structure collapsed. In effect, we "threw the baby out with the bath water."

The basic problems now concerning destructive fire control are that: (1) the public is not really excited about fire losses, and (2) their elected representatives are not excited about fire as a social problem. The federal effort concerning fire is going to disappear. It already lost its identity when it was submerged into the Federal Emergency Management Agency. Administratively, it fits well with dam safety, flood insurance, and national defense. However, the probability that a dam will break today or that a disastrous flood will result from a 100-year statistical rainfall is remote whereas the death of 40 or more people from destructive fire during the two days of this conference is highly probable.

As architects, architectural engineers, and professionals in the provision of the built environment, you are going to need to understand more about the phenomenon of fire if you are to fulfill your obligations. You talk about pragmatism in relation to your client who pays for your expertise, but it is the public who really pays through insurance and loss of resources when a destructive fire occurs.

You will have to integrate life safety and loss management into your future design and material configurations on a systematic basis. There is not much Mr. O'Hagan and I as firefighters can do except attempt to control further loss once a fire is in progress. We can squirt thousands of gallons of water on fires but nature has a time-temperature relationship that dictates destruction. You can depend on us to inhibit the temperature rise, but ours is an after-the-fact operation that is neither very effective nor very efficient. For example, if you take all the fire houses in Pennsylvania and place them on a uniform grid, you will place two fire houses within 2-1/2 miles of any structure in the state. Despite that fact, the destruction of life and property continues to grow.

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At this conference you have discussed fire as both a social and a technical problem. It also is an economic problem and, as engineers, we must face that problem. I believe we have the maturity to accommodate that responsibility.

What are we going to do to bring the public along? We are going to have to learn to assess and express risk. A part of risk is statistical (you can number crunch to express probability). Another part of risk is social acceptance and, thus, a matter of social and economic values and judgments.

We are not going to design the perfect fire system since nature has the cards. However, we can design a dynamic and responsive system and the public will decide the risk it is willing to accept.

PRESENTATION

J. Armand Burgun
Chairman of the Board and President
Rogers, Butler, Burgun and Shahine, New York, New York

The conference sessions have led me to conclude that intelligent use of the natural environment, imaginative engineered design of mechanical and electrical systems, and knowledgeable use of materials can reduce cost, conserve energy, and enhance firesafety. As a corollary, if you use flammable insulation, if you overbulb fixtures, if you overload electrical circuits, if you do not clean your chimney, or if you have a windowless building with only one way out, you probably are going to have a fire and you surely are going to risk entrapment. I think this makes great and good sense.

The other thing that we have talked about is the matter of retrofit. We have already built by far the majority of the buildings that will be in existence in 2000, and that their retrofit has to be done intelligently and economically, or it will not be done at all, is obvious.

One other thing we talked about is the development of the Fire Safety Evaluation System, which is in the appendix of the 1981 Life Safety Code. Mr. Nelson was the leader of the delphi group at the National Bureau of Standards that developed a system to measure the degree of firesafety in an existing health care facility. He is now extending that system to include residential buildings and is doing a really magnificent job and I must give him credit for that.

We also have talked about the codes and how they should be responsive to new technology and should maintain credibility in the eyes of the public, the authorities having jurisdiction, and the design profession. Codes, standards, and regulations should be based on fact, where possible, and not opinion, and I agree completely with what Mr. Bland and Dr. Harmathy have said about their content.

One thing does concern me however. I believe that this study should be increased in scope to include health and other safety aspects as well

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as the problems of firesafety and energy conservation. The Department of Health and Human Services (HHS) currently is meeting to revise the federal regulations concerning the design of and equipment in hospitals. It is concerned with the impact of energy conservation on general health and safety (e.g., in terms of cross contamination and toxicity). I do not know whether or not you know what happens to that document, but it usually goes out to the states and the states automatically make it part of their licensure law. It also was used for Hill-Burton grants when such grants were given. The HHS is considering, for example, whether or not to use variable air volume in places such as operating rooms, intensive care units, and nurseries. The regulations currently call for 25 air changes of outside air, positive pressure, all air exhausted, etc. I think this study should take into consideration these items as well as firesafety and energy-conservation factors.

PRESENTATION

Thomas P. Goonan
Consultant
Schirmer Engineering Corporation, Springfield, Virginia

I think Professor Bland is much too modest about his accomplishment with the Fire Commission. The development and widespread use of smoke detectors in this country has its roots directly in the National Fire Commission, and I think it is starting to make a difference concerning our main problem, the dwelling fire.

There has been a little discussion during this conference of the difference between a perceived problem and a real problem. In fire protection engineering consulting, a perceived problem to a building official becomes a real problem to me. Therefore, just as soon as we assert that energy efficiency produces fire problems, I have a problem with building officials.

Getting back to the point Mr. Nelson made yesterday, we need rated roofs because the building code says that we need rated roofs. Now there is a problem with increasing the energy efficiency of a rated roof because we say there is a problem.

I recently had to recommend a very expensive fix on what I thought was a very good design for a rated roof that should not have been required to be rated at all. The need to improve the heat-loss characteristics of the roof made it necessary to forego an economical rated roof and switch to an expensive roof system.

There has been some discussion of the effect of minor deficiencies in rated fire assemblies. It is a tradition to reject an assembly that is lacking in any way. However, a growing number of building officials

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are receptive to engineering analyses of fire problems and, to the extent that we have these people, we are making considerable improvement. I routinely perform systematic analyses of building fire problems, and I often have found very receptive building officials and fire marshalls who are willing to consider a building as a unique entity and to conclude that some of the provisions of the building code do not necessarily apply to a particular building. To this extent, the acceptance of the systems approach is making progress.

I also believe, as Dr. Harmathy said, that technology cannot solve sociological problems. We heard a minor rebuttal from Mr. Schaenman, who said that sprinklers come pretty close to solving the problem, and I think that an analysis of a great many fire problems will produce a similar answer. Although sprinklers do not solve all of our problems, they certainly help us get pretty close to what an answer might be.

Our keynote speaker said that furniture and decorations create serious hazards. We all know that. There is very little control on furniture, either in the codes or in standards, and I think that this may be a textbook example of self-regulation by industry with very little interference by government. This seems to be the keynote of the Reagan Administration. Self-regulation by furniture manufacturers has produced increasing fire hazards. If we look at the problem of furniture fires, this may be a way of analyzing the response of unregulated private enterprise to a real national problem.

PRESENTATION

John T. O'Hagan
President, John T. O'Hagan and Associates
New York, New York

In my neighborhood I have two friends, Bill and Frank, and they are brothers. Bill is a doctor and Frank is an undertaker, and the joke in the neighborhood is that Frank went into business to take care of Bill's mistakes. In a sense, my career, at least in terms of extinguishing fires, has been one of dealing with the mistakes that have been made in building design and product development, and, as a matter of self-defense, I became involved with the 1968 New York building code.

To give you an indication of the extent of the Fire Department's involvement, we received the last draft of the code before it was to be published. The Building Department also was invited to write a critique. After three drafts we submitted a 75-page, item-by-item critique with case studies to back up our recommendations.

The Building Department Commissioner at the time submitted three cartons full of books. He said, "Those are the codes I would have to be familiar with if I were to critique this code. Let the code go in and we will amend it later on. The Fire Department could not afford that luxury.

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So I am very interested in codes. New York Local Law 5, which became the model for corrective high-rise legislation throughout the United States, has contributed to improved life safety. Mr. Schaffner and I played a major role in its development. The consulting firm in New York that probably gets the least work in designing Local Law 5 modifications is Mr. Schaffner's firm of Syska and Hennessy, and that is a reflection of the gratitude of the Real Estate Board.

I met a member of the Real Estate Board the other day and he said: "You know, every time we meet and we talk about Local Law 5, your name comes up. I wouldn't want to tell you what we say about you. I replied that it didn't matter because now I sleep better at night.

I think this is a very positive meeting. It is unique in that we are addressing a problem before it becomes a crisis. Perhaps, based on my experiences, I can identify some of the actions that we might take to make this meeting more effective.

One of the most encouraging things I heard were the remarks from Mr. Mariani, who is obviously a leader in the architectural community. I was very encouraged and I think all the people in the fire service would have been pleased with his positive attitude toward firesafety in buildings.

Most of the people in the fire community with whom I have worked over the past 15 years feel that the architectural community has an inadequate appreciation for design features--for their contribution to life safety and their ability to control a building on fire. Anything that corrects that impression on their part, I think, would be positive.

Mr. Mariani also mentioned the reintroduction of atriums as a popular design feature. I think the reason that type of design disappeared for a long time probably is related to two hotel fires (the LaSalle fire in Chicago, Illinois, and the Wanecoff fire in Atlanta, Georgia). The large losses of life were due to the distribution of smoke at the mid-levels of the hotels where a number of people were overcome by carbon monoxide. Following those fires, until the Hyatt Regency was designed and constructed in Atlanta, you would have had difficulty getting that type of design approved. Now several of those buildings have been constructed and three of them have had fires--the one in Atlanta, one at O'Hare Airport in Chicago, and one in San Francisco, California. Although no one was injured in any of those fires, the smoke control in all of them was unsatisfactory.

That brings me to my next point, the comments of Mr. Everly on codes. I have to take exception with Mr. Everly in the sense that he would lead us to believe that getting changes made in codes is a simple matter. The fire service community would disagree with that. Many code features are made as accommodations with reality or with economics. For example, the requirement for only six changes of air per hour to provide smoke control in a fire situation obviously is inadequate, but it happens to coincide conveniently with the maximum capacity of many HVAC systems.

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We also have had many experiences that we should be learning from in developing our codes, but we continue to disregard the lessons of the past. One of the issues that I would like to call to your attention is that involving the large unprotected open areas that are still allowed by our building codes but that are the base of many of our fire problems. About 5000 square feet has been recognized for a long time as the maximum area that can be controlled with manual firefighting. Above that, you are accepting, in my opinion, an unwarranted risk.

Another point I would like to make is that there is a lot of information to be gained from doing case studies of previous fires. Mr. Bland made a good point about that. Using case studies we can develop a sensitivity to hazardous conditions and develop an ability to do a risk analysis on the fire and recognize conditions that we may have missed initially. For example, no one that I know would have looked at the AT&T switching center on Second Avenue in New York and recognized it as a fire hazard, but we had the largest dollar loss of any fire in the history of the United States in that building. After the fact, we asked the AT&T people to calculate the fire loading in terms of insulation on those little skinny wires that were tracing through the whole building. It was measured at something in excess of 4 tons! Almost any fire can teach us lessons, and if we extended the same effort in investigation and analysis of fire as we do in testing, we probably would have a much better basis for our decisions. I am not against testing (in fact, I am all for it), but case studies provide another approach.

I also support the systems approach. In our consideration of the New York City building code and the changes related to high-rise buildings, we tried to use the systems approach. I would caution you, however, that there are some pitfalls. One is the application of a given tool to all situations whether or not it is applicable. Consider the matrix as an example. They attempted to use a matrix in New York to determine equivalencies to the requirements of the code. Using the matrix, you could select directional signs, interior wall finishes with a flame spread rating of 25 or less, and perhaps a manual alarm to get the equivalent of a sprinkler system. The basic problem or the core issue in high-rise building firesafety today is limiting the size of a fire. Compartmentation will limit it and a sprinkler system will limit it, but directional signs, wall finishings, and manual alarms will not. Any matrix that gives you that answer is obviously inapplicable.

We also have been talking about economics and it is obvious that economics are an important factor in achieving a higher level of firesafety. However, there are times when we can use economics as an ally. After the fires at the MGM Grand, the Hilton and Stouffers, corporate America became concerned about where it was putting its executives. Because of questioning by corporate America and the possibility of loss of business, hotels now are putting in more fire protection. We also had great difficulty getting building owners to retrofit their buildings with sprinkler systems to comply with Local Law 5, but a retrofitted office building in New York now brings a premium on the real estate

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market, and the investment, when the building is sold, will show as large an appreciation as the owner could have gotten in the financial market.

Let me close by saying that I share some of Mr. Bland's concern about the future of the federal effort in controlling fires. I think that some of us who were involved in the initiation of the effort to get federal support for the attack on the fire problem are rather disappointed that the goals we looked forward to in those days are not fully achieved. However, given the consequences of not doing anything, I do not think that we have any choice but to continue to fight, and I think this is a very good example of the type of conference and effort that shows promise for achieving some beneficial results in the future.

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Appendix A
LIST OF CONFERENCE PARTICIPANTS

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Appendix B
BIOGRAPHIES OF SPEAKERS

JESSE J. BEITEL, III, Manager, Fire Performance Evaluations and Fire Protection Systems, Department of Fire Technology, Division of Chemistry and Chemical Engineering, Southwest Research Institute (SWRI), San Antonio, Texas. Mr. Beitel joined SWRI in 1975 as a research scientist and assumed his present position in 1980. He has been involved in the development, design, and direction of numerous full-scale flammability evaluations; the design and operation of a multistory test facility to evaluate various construction materials; the operation of a large-scale burn room facility for measuring heat, smoke, combustion gases, and burning characteristics of various home furnishings; and the development of gas-sampling techniques and analytical methods for the analysis of combustion products in full-scale fire scenarios. Mr. Beitel is a member of the Combustion Institute, the American Society for Testing and Materials, the National Fire Protection Association, and the American Chemical Society. He holds a B.S. degree in chemistry from St. Mary's of Texas.

ROLAND F. BELLMAN, Senior Associate, Rolf Jensen and Associates, Inc., Deerfield, Illinois. Mr. Bellman has been affiliated with the Jensen firm since 1969 and previously worked with Gage-Babcock and Associates, Inc., the Illinois Institute of Technology, Underwriters Laboratories, Inc., and the Cook County (Illinois) Inspection Bureau. His project experience includes the development of fire protection master plans and firesafety programs for various facilities including hospitals, individual buildings, fire departments, and other entities; the analysis of building structural assemblies to estimate their fire resistance ratings; and the planning and conduct of tests of full-scale assemblies to determine their actual ratings. Mr. Bellman is a registered professional engineer and holds a B.S. degree in fire protection engineering from the Illinois Institute of Technology.

THOMAS BERG, President, Ray Ellison Development, Inc., and Vice President and Director, Ellison Industries, Inc., San Antonio, Texas. Mr. Berg began his business career with General Electric and subsequently owned and operated his own business, Arcway Equipment Company. He later served as chairman of the board of Friedrish Refrigerators, Inc.; vice president of Wylain, Inc.; vice president and director of Crutcher Resources Corporation; director of Universal Bindery, Inc.; and chairman of the board of Jim Berg Publications. He is vice chairman of the board of Southwest Research Institute and is a member of many technical societies and community organizations.

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JAMES R. BEYREIS, Managing Engineer, Fire Protection Department, Underwriters Laboratories Inc. (UL), Northbrook, Illinois. Mr. Beyreis has been associated with UL since 1966. He currently is responsible for the five-section Fire Protection Department that focuses on fire suppression, fire containment, fire growth control, solid fuel appliances, and industrialized housing. He is a member of the National Society of Professional Engineers, the National Fire Protection Association, the Society of Fire Protection Engineers, and the American Society for Testing and Materials. He is a registered professional engineer, holds a B.S.C.E. degree, and presently is completing work for an M.B.A.

RICHARD E. BLAND, Associate Professor of Engineering Research, The Pennsylvania State University, University Park. Mr. Bland has worked in underwater acoustics, noise and vibration control, and hydrodynamics, and he currently is the special assistant to the director of the Applied Research Laboratory, a part of the Intercollege Research Program and Facilities of The University of Pennsylvania. In 1971 he was appointed chairman of the National Commission on Fire Prevention and Control and was responsible for the functioning of the commission as well as the general management of the commission's permanent staff. He subsequently served as chairman of the NAS/NRC Evaluation Panel for the NBS Center for Fire Research. Mr. Bland is a registered professional engineer and holds a B.S. degree from Hiram College and M.S. degree from the University of Michigan.

J. ARMAND BURGUN, Chairman of the Board and President, Rogers, Butler, Burgun and Shahine (RBBS), New York, New York. As a principal with RBBS since 1963, Mr. Burgun has been responsible for many of its major projects, most recently as partner-in-charge of several hospital and medical center projects in the New York area. Before joining the firm, Mr. Burgun served as assistant director of the New York State Joint Hospital Survey and Planning Commission and as an architectural consultant to the Hospital Review and Planning Council of Southern New York. He is chairman of the National Fire Protection Association (NFPA) Life Safety Code Committee and past chairman of the NFPA Board. He is a registered architect; has written widely on design and technology for the professional, medical, and general press; is a member of many technical organizations; and has lectured at a variety of universities. He holds a Bachelor of Architecture degree from Columbia University.

NICHOLAS J. DeCAPUA, Assistant Engineering Manager, Standards and Codes, American Telephone and Telephone Company, Basking Ridge, New Jersey. Mr. DeCapua has been with AT&T since 1977 and currently holds primary responsibility for providing guidance to the Bell operating telephone companies concerning fire protection practices and for representing the Bell system on model building code and consensus standards groups. He formerly was a member of the technical staff of Bell Telephone Laboratories. Mr. DeCapua holds B.S. and M.S. degrees in mechanical engineering from New York University and a doctorate in engineering science from the New Jersey Institute of Technology.

CHARLES O. EVERLY, Director, Department of Building and Mechanical Inspections, City of Alexandria, Virginia. Mr. Everly's department has full responsibility for enforcing the basic building, plumbing, and mechanical codes of the Building Officials and Code Administrators International (BOCAI) and the National Electrical Code of the National Fire Protection Association in the City of

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Alexandria. He has served or currently serves on various BOCAI committees and as chairman of the NCS-BCS Building Technical Committee for a Model Document for Code Officials on Solar Energy. He also is the BOCAI representative to the National Research Council of CABO, the Model Code for Energy Conservaton, and the Board for Coordination of Model Codes. He is a graduate in architectural engineering from Virginia Polytechnic Institute and State University.

WILLIAM E. FITCH, Manager, Market Development, Owens-Corning Fiberglas Corporation, Toledo, Ohio. Mr. Fitch is responsible for developing and implementing new marketing programs and strategies in response to trends in building technology, life safety concerns, standards, and regulations and for managing fire research and testing programs for product liability and code compliance of products and applications. He is active on the fire standards and building construction committee of the American Society of Testing and Materials and is a member of the Southern Building Code Congress, the International Conference of Building Officials, the Building Officials and Code Administrators International, the American Society of Heating, Refrigeration and Air-Conditioning Engineers, the Society of Fire Protection Engineers, National Fire Protection Association, the Society of the Plastics Industry, and the Mineral Insulation Manufacturers Association. He holds a bachelor's degree in ceramic engineering from the University of Washington.

ERNEST C. FREEMAN, JR., Program Manager, Architectural and Engineering Systems Branch, Conservation and Renewable Energy, U.S. Department of Energy (DOE), Washington, D.C. Mr. Freeman joined DOE in 1978 and now is responsible for overall program management of the national program plan for thermal envelope systems and insulating materials. He formerly was manager of the Federal Supply Service Office of Standards and Quality Control Specifications and project engineer with Thomas P. Herkins, Inc., General Contractor/Builder. He is a member of the American Society for Testing and Materials, the American Society of Heating, Refrigerating and Air-Conditioning Engineers, the Fire Council of Underwriters Laboratories, Inc., and the Natonal Institute of Building Sciences.

RICHARD G. GEWAIN, Chief Fire Protection Engineer, American Iron and Steel Institute, Washington, D.C. Mr. Gewain's present duties include active participation on the Institute's Subcommittee on Fire Technology, which is responsible for all fire research involving fire protection of steel and all problems associated with the behavior of steel under fire exposure conditions. He is responsible for fire research presently being conducted at various colleges and universities and several nationally recognized testing laboratories. He represents the steel industry on the National Fire Protection Association (NFPA) Committees on Fire Tests and Air Conditioning and is a member of the building construction and rail transit systems committees of the NFPA. He also represents the steel industry on the American Society for Testing and Materials (ASTM) Committee on Fire Tests and serves on the ASTM Executive Subcommittee. Mr. Gewain holds a B.S. degree in civil engineering from New England College.

JOHN W. GILLESPIE, Specialist, Technical Sales Service, Conwed Corporation, St. Paul, Minnesota. Mr. Gillespie has worked with Conwed for 41 years and was

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involved in quality control, research and development, and sales before assuming his present position. He has worked closely with Underwriters Laboratories in the fire protection and fire hazard fields and is Conwed's representative on the American Society for Testing and Materials Committee on Fire Tests.

THOMAS P. GOONAN, Consultant, Schirmer Engineering Corporation, Springfield, Virginia. Prior to joining Schirmer as a marketing and fire protection engineering consultant in 1979, Mr. Goonan served as chief of the Engineering Development Branch of the General Services Administration, general engineer for the Veterans Administration, district fire protection engineer for the U.S. Navy, and engineer in charge of the Cincinnati District for the Factory Insurance Association. He is a member of the Society of Fire Protection Engineers, the Institute of Electrical and Electronic Engineers, and the National Fire Protection Association. He holds a B.S. degree in electrical engineering from Purdue University.

PAUL C. GREINER, Vice President, Customer Relations, Conservation and Energy Management, Edison Electric Institute, Washington, D.C. Mr. Greiner currently heads the EEI customer relations, conservation, and energy management division. Formerly he worked in engineering, marketing, and personnel for the Indiana and Michigan Electric Company of the American Electric Power System. He is a member of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), past chairman of the ASHRAE Public Affairs Committee, and chairman of the ASHRAE Task Group Subcommittee on Conservation--Legislation and Regulations.

JOSEPH R. HAGAN, Research Associate, Cellular Plastics Department, Jim Walter Research Corporation (JWRC), St. Petersburg, Florida. Mr. Hagan joined JWRC in 1970 and currently is involved in the development, production, and testing of cellular plastic products. He previously worked on the development of flexible polyurethane foam automotive seating for the Inland Manufacturing Division of General Motors. Mr. Hagan holds a B.S. degree in chemistry from the University of Dayton.

TIBOR Z. HARMATHY, Head, Fire Research Section, Division of Building Research, National Research Council (NRC) of Canada, Ottawa. Dr. Harmathy joined the NRC of Canada in 1958 and has been responsible for research concerning the properties of building materials at elevated temperatures, the fire resistance of building elements, and the mechanisms of burning of compartment fires. He is an active member of the American Society for Testing and Materials (ASTM) and currently is chairman of the ASTM Subcommittee on Research. He received a degree in mechanical engineering from Budapest University and holds a Doctor of Engineering degree from the Vienna University of Technology.

THEODORE FRANK MARIANI, President, Mariani and Associates, Washington, D.C. Mr. Mariani has been practicing architecture and engineering in the Washington area since 1957. His firm specializes in large-scale institutional work and its projects have included Georgetown University Medical Center, Washington Technical Institute, D.C. General Hospital, and the Northwest Airlines Terminal at Kennedy Airport. Mr. Mariani co-authored the Naval Hospital Design Manual and was an editorial panel member for the 1978 edition of the NFPA Fire Prevention Code. He is a registered architect, was named a fellow of the American

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Institute of Architects (AIA) in 1981, and currently serves on the AIA National Borad. Mr. Mariani received a B.S. degree in civil engineering from the Virginia Military Institute and a M.S. degree in architectural engineering from the Massachusetts Institute of Technology.

JAMES McCOLLOM, Director, Mobile Home Research, U.S. Department of Housing and Urban Development (HUD), Washington, D.C. Mr. McCollom's primary responsibility is to conceive, develop, and execute HUD's Manufactured Housing Research and Technology program. He also conducts most of HUD's firesafety research related to conventional buildings. Prior to joining HUD, Mr. McCollom was director of transportation and logistics for space and aeronautics programs at National Aeronautics and Space Administration Headquarters. He holds degrees from Georgetown University and the Massachusetts Maritime Academy.

GERSHON MECKLER, Partner and Director of Engineering Design, Haines, Lundberg, Waehler, New York, New York. Mr. Meckler's work has focused on energy integrated design and cost analysis and more than 30 patents related to building energy conservation and systems have been issued to him. He has served as a consulting engineer to the Owens-Corning Fiberglas/U.S. Steel Consortium for the General Services Administration's prototype building systems project and has been responsible for the design of the solar energy heating and cooling system for the U.S. National Fish Health Research Laboratory, the environmental system incorporating cogeneration for the Science Museum of Virginia, and the solar energy cooling and dehumidification system for the D.C. Veterans Hospital. He currently is chairman of the Energy Conservation Committee of the Council on Tall Buildings and Urban Habitat and the Solar Heating and Cooling Technical Committee of the International Solar Energy Society. He is a registered professional engineer and received a B.S. degree in engineering physics from The Pennsylvania State University.

HAROLD E. NELSON, Head, Design Concepts Research, Center for Fire Research, National Bureau of Standards (NBS), Washington, D.C. Mr. Nelson directs an interdisciplinary team of engineers, systems analysts, and psychologists that currently is concentrating on the development of sound engineering approaches to the evaluation of fire threat development and egress from buildings and of specific evaluation systems to measure risk. Before joining NBS, Mr. Nelson was director of the General Services Administration's Accident and Fire Prevention Division. He is national vice president and a fellow of the Society of Fire Protection Engineers and a member of various National Fire Protection Association, Underwriters Laboratories, and Federal Construction Council activities. Mr. Nelson is a registered professional engineer and received a B.S. degree in fire protection and safety engineering from the Illinois Institute of Technology.

JOHN T. O'HAGAN, President, John T. O'Hagan and Associates, New York, New York. Prior to organizing his firesafety consulting firm in 1978, Mr. O'Hagan devoted more than 30 years to the New York City Fire Department, serving as commissioner from 1973 to 1977 and as chief of the department from 1964 to 1973. He specializes in public fire administration; fire emergency planning, organization, and training; and fire risk evaluation. Mr. O'Hagan is a member of the National Fire Protection Association and the Advisory Committee to the National Fire College. He holds a B.A. degree from the City University of New York and a M.S. degree from the Columbia University Graduate School of Business.

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JOSEPH E. PRUSACZYK, Supervisor, Fire Research and Testing, Research and Development Division, Owens-Corning Fiberglas Corporation, Granville, Ohio. Mr. Prusaczyk directs a multidisciplinary staff of engineers, scientists, and health specialists conducting fire, smoke, and toxicity research. He is a member of the American Society for Testing and Materials and has published numerous fire research papers. He holds a B.S. degree in chemistry from the University of Dayton and a Ph.D. degree in physical chemistry from Case Western Reserve University.

JACK M. ROEHM, President, Jack M. Roehm and Associates, Virginia Beach, Virginia. Mr. Roehm's consulting engineering firm specializes in the design, development, specification, evaluation, testing, and marketing of building products, especially building envelope components and architectural metal parts. Mr. Roehm formerly was director of product and market development for the Architecture and Building Products Division of Reynolds Metal Company and vice president of the Research Division of Kawneer Company. He is a member of the National Society of Professional Engineers, American Society of Mechanical Engineers, and Institute of Electrical and Electronics Engineers. He also has served as a member of the Building Research Advisory Board and its Federal Construction Council and Building Futures Council and of the Consultative Council of the National Institute of Building Sciences. He is a registered professional engineer and received a B.S. degree in mechanical and electrical engineering from Tulane University and a M.S. degree from the California Institute of Technology.

H. J. ROUX, Coordinating Manager, Product Fire Performance, Armstrong World Industries, Inc., Lancaster, Pennsylvania. Mr. Roux joined Armstrong in 1950 and was named to his present position in 1972. He currently is a member of the Board of Directors of the National Fire Protection Association and chairman of its Committee on Systems Concepts for Fire Protection in Structures. He also is a member of the Society of Fire Protection Engineers Committee on Measurement of Fire Phenomena and the BRAB Building Futures Council Technical Criteria Resource Group. He is a registered professional engineer and received a B.Ch.E. degree from Rensselaer Polytechnic Institute.

PHILIP S. SCHAENMAN, Associate Administrator, National Fire Data Center, U.S. Fire Administration, Federal Emergency Management Agency, Washington, D.C. Mr. Schaenman is responsible for technology development and data collection, analysis, and dissemination. Prior to assuming this position in 1976, he served as director of the Data Center's Analysis and Evaluation Division. Before joining the Fire Administration he worked at the Urban Institute and Bellcom, Inc. Mr. Schaenman has a professional degree in electrical engineering from Columbia University, a M.S. degree in electrical engineering from Stanford University, and B.S. degree from the Columbia University School of Engineering and Queens College.

CHARLES E. SCHAFFNER, Executive Vice President and Director, Syska and Hennessy, Inc., New York, New York. Prior to joining Syska and Hennessy, Mr. Schaffner was professor of civil engineering and vice president for administration at the Polytechnic Institute of Brooklyn. As one of his principal achievements, he originated and led the effort that resulted in the writing of the new New York City Building Code. In addition to revolutionizing construction in the city, it eliminated overlapping jurisdictions and reduced costs

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substantially. He is a registered professional engineer; president of the New York Building Congress; a fellow of the American Society of Engineering Education, American Concrete Institute, and New York State Society of Professional Engineers; and past chairman of the Building Research Advisory Board. He received B.C.E. and C.E. degrees from Cooper Union, a M.C.E. from the Polytechnic Institute of Brooklyn, and a B.S.S.E. degree from the University of Illinois.

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