fire protection planning report

BUILDING CONSTRUCTION INFORMATION FROM THE CONCRETE AND MASONRY INDUSTRIES

NO. 7 OF A SERIES

Effects of Thermal Insulation on Fire-Resistive Assemblies

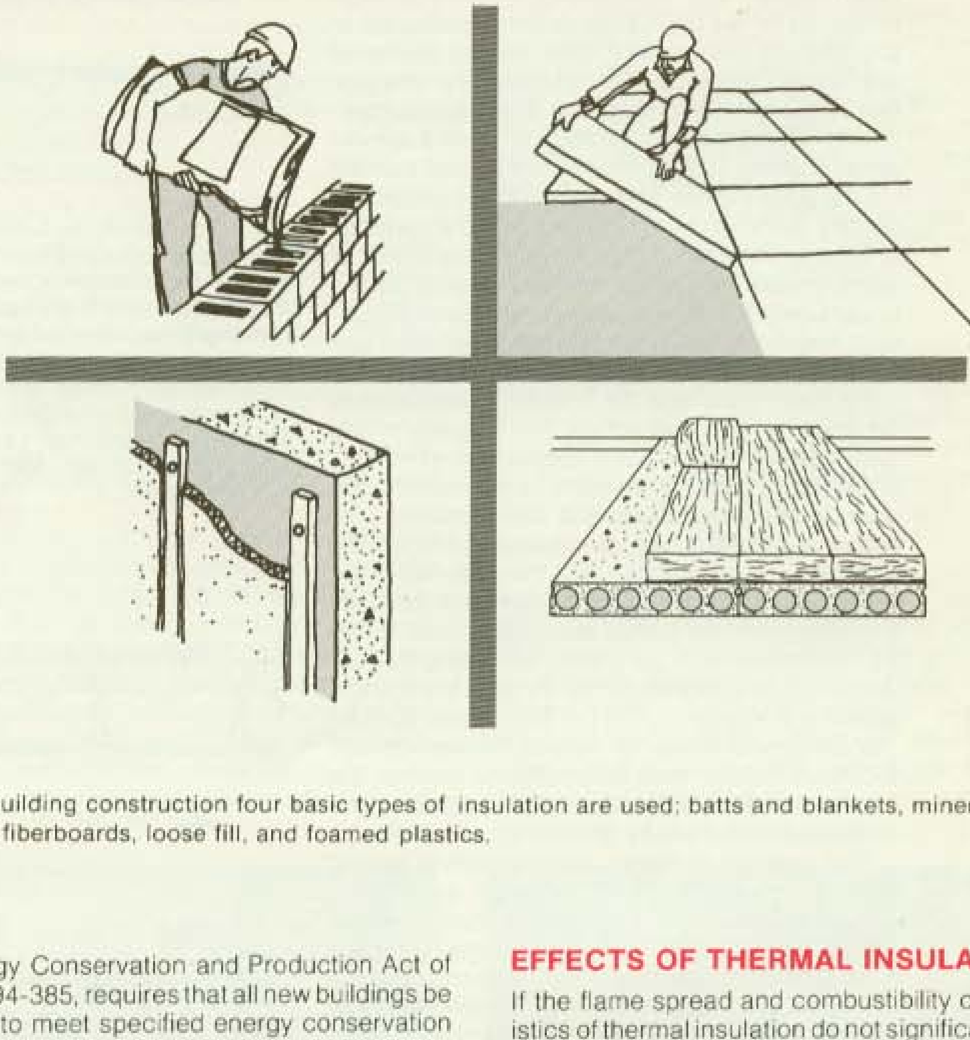

Fig. 1. In building construction four basic types of insulation are used: batts and blankets, mineral board and fiberboards, loose fill, and foamed plastics.

The Energy Conservation and Production Act of 1976, PL 94-385, requires that all new buildings be designed to meet specified energy conservation guidelines. These conservation efforts have raised questions as to how the fire protection provided by building assemblies is being affected.

Architects, designers, and building code officials are being required to select or approve thermal insulation for roof-ceiling assemblies and exterior wall elements without knowing the impact that insulation has on hourly fire ratings. For example, it has been found that increased levels of insulation restrict the heat dissipation capabilities of some fire-resistive assemblies, thereby causing greater heat buildup in them and a possible reduction in the fire resistance.

EFFECTS OF THERMAL INSULATION

If the flame spread and combustibility characteristics of thermal insulation do not significantly contribute to the severity of the fire environment, adding insulation to an assembly will generally reduce the overall heat transmission through the assembly under fire-exposure conditions. This results in lower unexposed surface temperatures. (See Fire Protection Planning Report No. 3 for explanation of standard fire-test end-point criteria.) However, this reduction in heat transmission can cause other regions within certain assemblies to develop higher temperatures in comparison with similar assemblies without the added insulation. This may lead to premature structural failure of the assemblies and a subsequent reduction in fire resistance.

The magnitude of the temperature increase of components within an assembly and the overall effect on the fire-resistance rating of an assembly incorporating additional insulation depends on several factors, including

(1) Basic construction and structural characteristics of the assembly
(2) The composition and thickness of the insulating material
(3) The location of the insulating material within the assembly

FLOOR AND ROOF ASSEMBLIES

Floor-ceiling and roof-ceiling assemblies are classified for fire resistance as either protected or unprotected. Assemblies classified as protected are further categorized as to method of protection, that is, membrane protected or direct-applied protected. Membrane fire protection uses a fire-resistant ceiling to protect the floor or roof framing from a potential fire. Direct-applied fire protection usually comes in direct contact with the surfaces of structural members. A blanket of mineral fiber or cementitious mixture is sprayed directly to the underside of the decking and to the exposed structural members. Examples of these assemblies and location of protection are shown in Fig. 2.

To understand how the addition of insulation to an assembly can affect its fire resistance, the heat-transfer mechanisms associated with different kinds of assemblies must be considered. For unprotected assemblies and direct-applied protected assemblies, heat is transferred through the assembly by conduction and then carried to the ambient atmosphere by convection and radiation. For membrane-protected assemblies, heat is first transferred through the protective ceiling by conduction. It is then transferred through the plenum space to the underside of the floor or roof deck by the combined action of natural convection and radiation. Finally, heat is transferred through the floor or roof deck by conduction and carried to the ambient atmosphere by convection and radiation.

The greatest problems associated with adding thermal insulation to fire-resistive assemblies occur with membrane-protected assemblies. If insulation is added to the top side of the protective membrane, the temperature of the membrane will increase. This can cause a premature failure of the membrane and ultimately lead to early failure of the assembly.

If insulation in a membrane-protected assembly is applied directly to the underside of the floor or roof deck or to the top of the roof deck, the ability of the assembly to dissipate heat to the ambient atmosphere is reduced. This causes a buildup of heat within the plenum and exposes the structural elements there to considerably higher temperatures. The results may be a premature structural failure and corresponding reduction in the fire resistance of the assembly.

Assemblies with direct-applied protection may also be affected by additional thermal insulation.

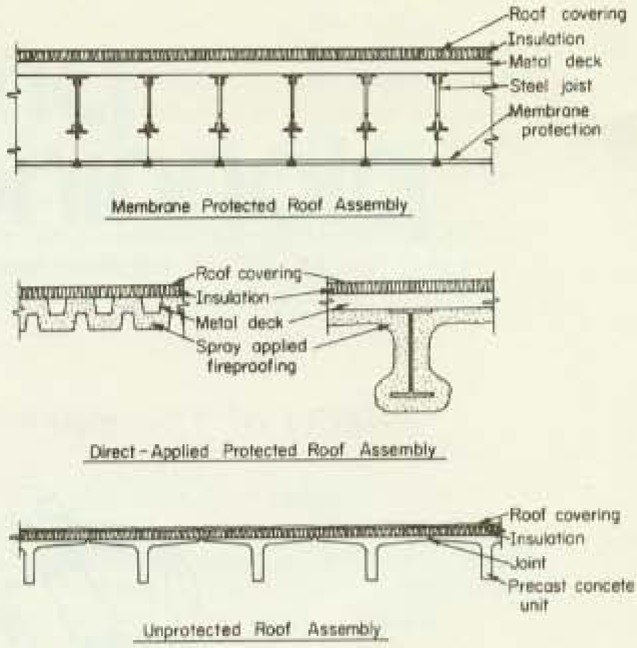

Fig. 2. There are three basic types of roof assemblies: Membrane-protected assemblies are protected by a noncombustible ceiling either suspended or attached directly to the underside of the floor or roof framing. Direct-applied protected assemblies utilize a sprayed-on application of mineral fiber or cementitious mixture to protect the structural members and the underside of the decking. Unprotected assemblies such as precast planks and tees and reinforced concrete decks have built-in fire protection.

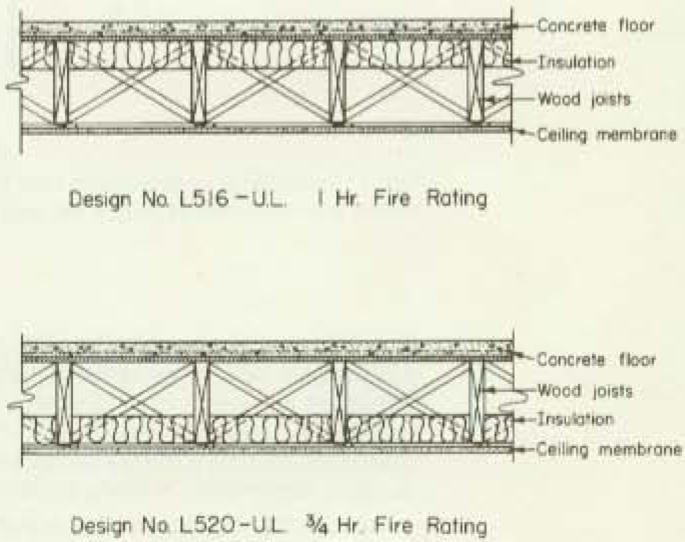

Fig. 3. Changing the location of the insulation within a given design can also change the hourly fire rating. Shown are two similar designs with different locations for the insulation. Design No. L516-U.L. with the insulation directly below the floor deck has a rating of 1 hour. However, when the insulation is placed directly on the ceiling membrane as in Design No. L520-U.L., the rating is reduced to ¾ hour.

Changing the composition of the insulation to a material with a greater *R* value (thermal resistance) or increasing the thickness of roof insulation above that specified in a rated roof-ceiling design can, according to Underwriters Laboratories Inc., "result in higher temperatures on the structural elements including the metal roof deck, leading to premature structural failure of the assembly."[1] The temperatures increase because of the decrease in heat dissipation.

For unprotected assemblies such as reinforced concrete decks and precast planks and tees, additional insulation has little effect on their fire resistance. That is because the fire endurance of most of these assemblies is determined by end-point criteria for temperature rise on the unexposed surface. In addition it has been observed that temperatures of the reinforcing steel in these assemblies is not significantly affected by additional thermal insulation.[2,3] When insulation is added to such an assembly, on either the bottom or the top, the heat transmission through the assembly is reduced, thus providing a lower unexposed surface temperature. In cases where the fire-resistance rating is governed by temperature-rise criteria on the unexposed surface, adding thermal insulation will increase the fire resistance of these unprotected assemblies.

BUILDING CODES

Model building codes do not specifically require retesting of fire-resistive assemblies when additional thermal insulation is added. Until recently, most building code officials had not questioned the effects of additional insulation on the performance of fire-rated assemblies. Yet, Underwriters Laboratories, a major testing agency of fire-resistive assemblies, clearly points out in their *Fire Resistance Directory*[4] that "roof insulation must be carefully controlled as to manufacturer, type, and thickness as specified. Less than the specified thickness could cause an early temperature end point on the top surface while a greater thickness could cause earlier structural failure."

According to the Basic Building Code,[5] thermal insulating materials "incorporated in construction elements shall be installed and used in a manner that will not increase the fire hazard characteristics of the building or any part thereof." One must question whether compliance with the code is maintained when insulation is added to a fire-resistive assembly, since the structural resistance of the assembly to fire may be severely diminished.

The Basic Building Code also requires that all building "plans or specifications shall include documentation or supporting data substantiating all required fire-resistance ratings." Similar provisions are found in the Uniform and Standard Building Codes. Building officials should therefore require reevaluation of fire-resistive assemblies that have been altered from their specified design by the addition of insulation to determine compliance with the intent of the code.

Full-scale retesting of assemblies with additional insulation is not always necessary. Some research and tests have already been conducted that can be used to predict fire ratings for many assemblies incorporating added insulation.

RESEARCH

It has been observed during fire tests that additional roof insulation results in an increase in the temperature of the supporting members of steel roof construction.[1] The same is not true of the reinforcing steel in concrete roof construction.

Published test information[3] shows that strand temperatures in prestressed concrete double-tee beams are not significantly changed when insulation is added to the unexposed surface. This is because heat buildup in these members occurs near the unexposed surface away from the strand. Similar information is available for hollow-core roof units.[2] A comparison of fire tests of hollow-core specimens with and without roof insulation shows that the use of roof insulation does not result in higher strand temperatures. These test results also apply to the steel reinforcing used in cast-in-place concrete assemblies.

The tested fire endurance of concrete floors, roofs, and walls is usually governed by criteria for temperature rise of the unexposed surface rather than by structural considerations.[6] Fire tests of concrete slabs have shown that the temperature rise of the unexposed surface is a function of the slab thickness and type of aggregate used. Floor assemblies typically consist of concrete base slabs with overlays of concrete. Roof assemblies normally consist of built-up roofing with thermal insulation but may be undercoated with direct-applied fire protection. Fire tests of these multi-course assemblies have been conducted to determine heat transmission relationships.

The fire endurances of two-course roofs for two types of insulation[6] are shown in Fig. 4. It can be seen that fire endurance increases as thickness of insulation increases. This is because the decrease in heat transmission results in lower temperatures on the unexposed surface.

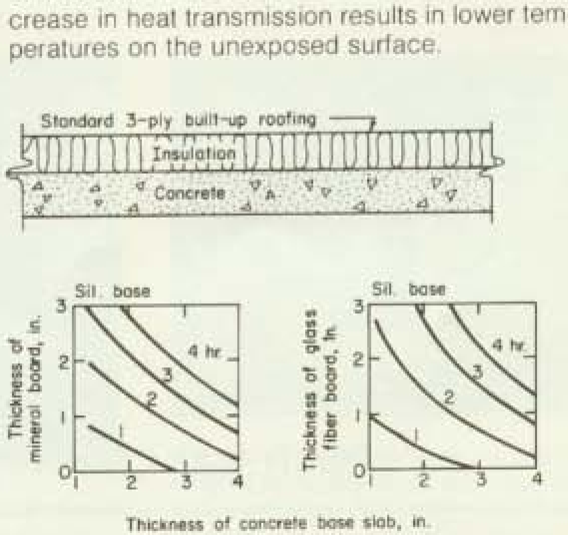

Fig. 4. Fire endurance of concrete roof slabs with rigid insulation—based on heat transmission.

WALL ASSEMBLIES

Similar to roofs, the fire hazard associated with adding combustible insulation to exterior masonry cavity walls is minimal since brick or block is unlikely to fail in a fire. Tests have shown that if the insulation completely fills the cavity, localized exposure of the insulation to fire will not result in rapid or extensive flame spread.[7] Where rigid insulation is used with an air space for insulating masonry cavity walls, the reduced ventilation plus the fire resistance of the masonry combine to restrict active flaming. When adequate perimeter cavity stops are provided, the danger of toxic gases diffusing into adjacent areas is practically eliminated.

Some precast wall panels are made by sandwiching an insulating material between two face slabs of concrete. Several building codes require that where noncombustible construction is specified, thermal insulation shall have a flame-spread rating of not more than 75 when sandwiched between two layers of noncombustible material without an intervening air space. Where the insulation is not installed in this manner, it is required to have a flame-spread rating of not more than 25.

The fire endurance of sandwich walls and cavity walls can be calculated from this equation:

$$R^{0.59} = R_1^{0.59} + R_2^{0.59} \quad + R_n^{0.59}$$

where R = fire endurance of the composite assembly in minutes and R_1, R_2, and R_n = the fire endurance of each of the individual courses in minutes.

Table 1 lists the fire endurance of several precast concrete sandwich walls and masonry cavity walls. Comparison is made between insulated and uninsulated walls. Adding insulation to these assemblies increases the fire resistance.

EVALUATING PREVIOUSLY RATED ASSEMBLIES

There is a need for evaluating the effects of adding insulation in fire-rated assemblies. Since the cost of full-scale tests tends to prohibit the mandatory retesting of all assemblies incorporating added insulation, other forms of evaluation are needed.

Factors necessary for such an evaluation are (1) the fuel contribution characteristic of the insulating material, and (2) the magnitude of temperature increases within the assembly and the resulting effect on structural performance.

The characteristics of an insulating material that must be considered include combustibility, flame spread, and smoke developed. In most cases these have been evaluated in other full-scale fire tests.[1] For new types of insulation, small-scale fire testing of model constructions can be used to evaluate the fuel contribution characteristics. Tests for flame spread and combustibility can be used as supplementary information.

Building codes and other regulations usually include provisions limiting the use of combustible materials in certain types of construction and provide material-flame-spread requirements based

Table 1. Fire Endurance of Masonry Cavity Walls and Precast Concrete Sandwich Walls (calculated)

Insulated wall						
Inside wythe	Insulation	Outside wythe	Fire endurance	Uninsulated wall	Fire endurance	Insulated contribution
Concrete, inches	Inches	Concrete, inches	(hr:min)	Concrete, inches	(hr:min)	(min)
2	1-CP	2	1:50	4	1:18	32
3	1-CP	2	2:25	5	2:00	25
4	1-CP	2	3:15	6	2:50	25
5	1-CP	2	4:14	7	3:53	21
6	1-CP	2	5:20	8	5:00	20
2	¾-GFB	2	2:07	4	1:18	49
2	1½-GFB	2	3:08	4	1:18	110
Concrete masonry, inches	Inches	Brick, inches	(hr:min)	Inches	(hr:min)	(min)
4-NWCM	1-CP+1-Air	4	5:05	4,2-Air,4	4:20	45
6-NWCM	1-CP+1-Air	4	6:08	6,2-Air,4	5:19	49
8-NWCM	1-CP+1-Air	4	7:27	8,2-Air,4	6:35	52
4-LWCM	1-CP+1-Air	4	5:35	4,2-Air,4	4:49	46
6-LWCM	1-CP+1-Air	4	6:51	6,2-Air,4	6:01	50
8-LWCM	1-CP+1-Air	4	8:28	8,2-Air,4	7:33	55

Notes: Concrete information shown is for siliceous aggregate concrete.
CP = Cellular plastic (polystyrene or polyurethane)
GFB = Glass fiberboard
NWCM = Normal-weight concrete masonry
LWCM = Lightweight concrete masonry

on type of occupancy. Therefore, in specifying thermal insulation for a given location, flame spread and combustibility should be determined to ensure they meet the requirements of the applicable code.

Three methods by which the effects of higher temperatures on assembly components can be evaluated have been suggested by Underwriters Laboratories Inc.[1] These are (1) engineering studies, (2) small-scale fire tests, and (3) full-scale fire tests. The particular method used depends primarily on the type of assembly.

ENGINEERING STUDIES

Engineering studies can be used as one method of evaluation where full-scale fire test data has been developed for a particular type or group of designs with and without insulation, and information is therefore already available on the effects of adding insulation. Such is the case for many concrete floor and roof assemblies and metal-faced exterior wall assemblies.

SMALL-SCALE FIRE TESTS

Another method of evaluation involves small-scale tests where temperature rise of the unexposed surface is the limiting factor. A fire test is conducted on a representative segment of the assembly to determine temperature rise within the assembly and on the unexposed surface. This method of testing is only appropriate when it is certain that the addition of insulation will not cause the structural resistance of the assembly to control the fire rating.

Small-scale fire tests are useful in providing data on the maximum temperatures of components and the critical thickness of insulating materials. Quite often full-scale fire tests are continued beyond the hourly rating period for which an assembly is being tested. When this is the case, the data can be utilized to evaluate the structural performance of an assembly at the elevated temperatures associated with the critical thickness of insulation as determined by the small-scale fire tests. However, if the temperature rise is considered significant and structural performance has not been evaluated at the increased temperature, it may then be necessary to evaluate the performance of the assembly with a critical thickness of insulation by a full-scale fire test.

Small-scale fire tests have been successfully used to evaluate the performance of different types and varying thicknesses of insulations in precast concrete roof units and also in direct-applied-protected and unprotected steel roof deck designs.

FULL-SCALE FIRE TESTS

Full-scale fire tests may be required for assemblies where increased temperatures on components may influence structural performance. This is often the case for assemblies with membrane ceiling protection. In these cases, it is necessary to conduct full-scale fire tests to determine if the increased temperature exposure of the structural elements adversely influences structural fire performance. An example would be the introduction of insulation on top of a steel deck or in the plenum of a roof-ceiling assembly incorporating bar joists protected with a suspended ceiling.

EVALUATION OF NEW DESIGNS

New assemblies should be tested to incorporate the maximum and minimum anticipated thickness of insulation in order that the rated assembly can be utilized with varying thicknesses of insulation.

RECOMMENDATIONS

Model building codes are beginning to recognize that the addition of thermal insulation in some fire-resistive assemblies can adversely affect their performance. Evaluation of assemblies with increased levels of thermal insulation should be required to substantiate new hourly fire ratings.

Fire-resistive assemblies provide the barriers essential for providing the time and protection

Fig. 5. Small-scale test furnace is used to determine temperature rise within an assembly and on the unexposed surface.

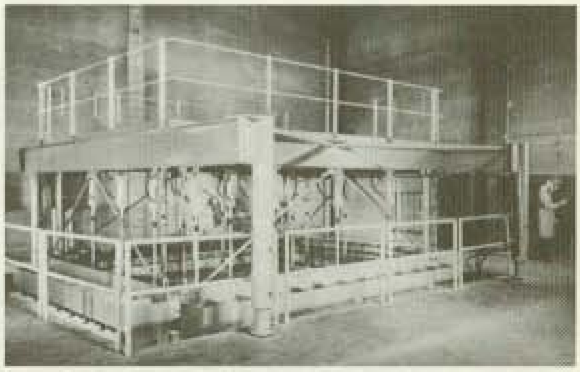

Fig. 6. Full-scale fire tests are used to evaluate the relative performance of construction assemblies under fire exposure conditions. Altering a tested assembly design by adding insulation can cause some assemblies to fail prematurely.

necessary to allow building occupants a safe means of egress, for providing the structural integrity necessary to permit firefighters to safely extinguish a fire, and for containing a fire and limiting its spread. Deterioration of the fire resistance of these assemblies can be caused by added thermal insulation. This should be recognized in the design of buildings for fire protection.

REFERENCES

1. Howell, K. W., *Informational Bulletin on the Effects of Adding Insulation in Fire Resistive (UL Standard 263) Assemblies to Comply with National, State, or Local Energy Conservation Requirements*, Underwriters Laboratories Inc.
2. Abrams, M. S., "Fire Tests of Hollow-Core Specimens With and Without Roof Insulation," *Journal of the Prestressed Concrete Institute*, Vol. 21, No. 1, January/February 1976, pages 40-49. Also Portland Cement Association publication RD044B.
3. "Report on Roof and Ceiling Construction Consisting of Prestressed, Pretensioned Concrete Double-Stemmed Units and Various Insulation Materials," U.L. File R4123-13, *Journal of the Prestressed Concrete Institute*, Vol. 11, No. 5, October 1966, pages 17-35.
4. *Fire Resistance Directory*, Underwriters Laboratories Inc., January 1975, January 1979.
5. Basic Building Code, 1978 Edition, Building Officials and Code Administrators International, Inc., Chicago, Illinois.
6. Abrams, M. S., and Gustaferro, A. H., *Fire Endurance of Two-Course Floors and Roofs*, Portland Cement Association publication RD048B, reprinted from *Journal of the American Concrete Institute*, Vol. 66, February 1969, pages 92-102.
7. Lie, T. T., *Contribution of Insulation in Cavity Walls to Propagation of Fire*, Fire Study No. 29, Division of Building Research, National Research Council of Canada.
8. *Fire-Resistance Classifications of Building Constructions*, Report BMS92, National Bureau of Standards, Washington, D.C., 1942, 70 pages.

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