FIRE PERFORMANCE OF REPLACED AND RECOVERED ROOF ASSEMBLIES

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Model building codes and insurance rules contain three major requirements that concern the fire performance of roofing materials and roofing systems that apply to new construction as well as to roofs being repaired or renovated.

The first requirement is that the roof must resist an exterior fire and prevent the flames from spreading to the interior of the building, to other parts of the roof, and/or to adjacent roofs. The second requirement is based on the intent that the roofing material not add fuel and cause the spread of an interior fire. The third requirement addresses containment of the fire to the room of origin so that it will not spread to adjoining rooms or buildings. Roofs are involved with this requirement when the roof is immediately above the ceiling in the room of the fire's origin.

Building codes and insurance rules specify nationally recognized test standards designed to measure the fire performance of roofs and to establish compatibility with these general requirements. The fire test standards are "Tests For Fire Resistance of Roof Covering Materials," UL 790 (ASTM E108, NFPA 256) "Fire Test of Roof Deck Constructions" ANSI/UL 1256 and "Fire Test of Building Construction And Materials" UL 263 (ANSI A2.1, ASTM E119, NFPA 251). This paper discusses: 1) the response of common roofing materials to these fire tests, and 2) the effects of composition and the location of the materials relative to each other on performance in fire situations. Discussion will focus on the possible changes in fire performance caused by replacement or recovering of roof assemblies.

"Replacement," as used in this text, means the practice of removing an existing roof system from the deck up and replacing it with a new roofing system. "Recovering" means the practice of covering an existing roof system with a new roofing system. The manner in which individual materials respond to a fire indicates how the fire performance of a roof may be affected by replacement and recovering operations.

EXTERIOR FIRE EXPOSURE

A standard test procedure entitled: "Tests For Fire Resistance Of Roof Covering Materials," UL 790 (ASTM E108, NFPA 256) is used to rate roof systems for resistance to an exterior fire exposure. For these tests, a representative roofing system is applied to a wood deck. After a curing period, the deck is mounted on a sloping rack in an air stream and exposed to one of three sizes of burning brands and gas flames.

Ratings of Class A, B, or C are assigned to the system based on three levels of fire test severity, wherein Class A is considered the most flame resistant, Class B is of intermediate resistance and Class C has the least fire resistance.

Essentially, three characteristics of a roof system are measured in the fire tests:

1) The resistance of a system to prevent burn-through and ignition of the combustible deck below. (If the brands or gas flame causes decomposition of the system and ignition of the deck, the system fails that class of fire severity.)
2) The potential for burning pieces of a system to be picked up in the air stream and carried away as potential ignition sources, and
3) The propensity of a roof system to spread flame over its surface from the point of ignition to other areas of the roof or to adjoining roofs.

Discussion and influence of replacement or recovering

Fig. 1 shows a representative roof that consists of insulation on a wood deck covered with multiple plies of felt and bitumen built-up roofing (BUR) and a gravel surfacing. Under fire conditions, the gravel surfacing absorbs a large amount of heat that would otherwise be available to melt and decompose the BUR or insulation and to eventually ignite the deck. Gravel surfacing also tends to hold melted bitumen in place on sloping roofs so that it can continue to protect the combustible substrate from direct fire attack from the outside. To illustrate its importance, gravel surfacing is required on felt and asphalt BUR systems with Class A and B ratings, while Class C ratings require a clay emulsion coating, which absorbs a lesser amount of heat energy.

Some single-ply membranes require the application of stone ballast above the membrane. This ballast also absorbs a large quantity of heat during an exterior fire attack, thus providing protection to the membrane, to the insulation and to the deck below. Roofing systems consisting of a single-ply membrane without stone ballast usually have greater limitations on 1) the type of deck, 2) the type and thickness of insulation and 3) the roof slope as compared to similar ballasted single-ply systems having similar fire performance.

When roofs are exposed to fire from the outside of structures, insulation also provides protection by limiting the flow of heat to the deck providing the insulation is not easily ignited or decomposes upon exposure to fire. Conversely, insulations that are not heat sinks tend to prevent the escape of heat from the roof coverings causing the covering to burn more rapidly.

Studies[1] have shown that aging can improve the fire performance of bituminous roofing systems. During aging, volatiles are liberated and the remainder of the bituminous covering becomes less combustible, which suggests that leaving the old covering in place wherever possible will enhance the resistance of new roofing to exterior fires.

Because of the large number of membranes and insulations and the interaction between the roofing covering and the substrate in a system, it is difficult to make accurate general statements or draw specific conclusions regarding the changes in resistance of the roofing system to attack from an exterior fire that may occur because of replacement or recovering. One fact, however, can be stated: gravel surfacing or stone ballast greatly improves resistance of the roofing system to burn-through, to the generation of flying brands, and to the spread of flame during attack from an exterior fire.

Roofing systems that have performed satisfactorily during the "Test for Fire Resistance of Roof Covering Materials" UL 790 (ASTM E108, NFPA 256) can be found in UL's Building Materials Directory.

INTERIOR FLAME SPREAD

In 1953, a disastrous fire occurred in Livonia, Mich. in which the one-story, 35-acre transmission plant of General Motors was completely destroyed.[2] It was widely studied and highly publicized at the time, not only because of the size of the fire, but also because of the wide use of what at the time was common roof construction. The flat roof assembly (Fig. 2) consisted of a No. 18-gauge steel deck topped with two-ply vapor retarder consisting of a 15-pound asphalt-saturated organic felts, hot-mopped in place with asphalt applied at a rate of 22 pounds per square. The vapor retarder was topped with asphalt also applied at a rate of 22 pounds per square into which was placed 3/4-inch-thick fiber glass insulation. The insulation was covered with a built-up roof covering consisting of three plies of 15-pound asphalt organic-felt adhered with 22 pounds per square of asphalt per ply and surfaced with gravel at 400 pounds per square and a flood coat of hot-mopping asphalt.

The fire originated inside the building. Heat from the fire collected at the steel roof deck and caused the unburned gases in the vapor retarder to be liberated. These gases were forced back into the burning building because of the roof covering above and thus the ignition of the unburned gases contributed to the continuation of the fire. As the fire progressed, melted bitumen flowed through the joints of the deck and the melted bitumen ignited and also assisted the spread of the fire.

Eyewitnesses reported that burning droplets from the ceiling ignited the wood block floor and contents of the building as much as 100 feet in front of the main fire. Collapse of the steel deck and structure added the BUR to the fire as it burned out of control.

The fire focused the attention of the fire insurance industry to the potential contribution the roof assembly may have to interior flame spread. This effort resulted in the development of the "White House" fire test method that attempted to reproduce the fire conditions experienced at the Livonia transmission plant.

The White House is a test building 20 feet wide and 100 feet long with two burners located inside one end of the building. Flames from the burners expose the underside of the first 20 feet of the roof deck being tested. It was believed by the developers of the test that the Livonia scenario had been duplicated when a fire severity was found that caused asphalt from the roof sample, simulating the roof construction at the Livonia plant, to drip and burn with flames spreading below the deck to the opposite end of the building. Experiments were then performed on other roof systems until a system was found where the fire spread was confined to the immediate exposed area.

This performance provided the benchmark by which other roof systems were to be judged. The initial acceptable system consisted of 1-inch fiberboard mechanically attached to the metal deck and covered with a four-ply BUR.

Because of the cost to conduct a White House test, UL developed a smaller, less expensive test method to measure the interior flame spread performance of roof-deck constructions. The test method is known as Standard Fire Test of Roof Deck Constructions, ANSI/UL 1256. The test method subjects 4.5 feet of a 25-foot-long sample to fire for 30 minutes. Acceptable performance was defined by UL based on comparative performance between assemblies tested using the White House method and the UL 1256 method. Spread of flame and damage to the roofing system during the UL 1256 test is required to be equal to or less than that found from tests of the acceptable deck in the White House test.

It becomes necessary today to conduct the White House test when there is limited or no experience with the roof system under evaluation. This occurs because scaled tests do not necessarily replicate all characteristics of full-scale test performance.

Roof systems performing satisfactorily in the White House test or the UL 1256 test are described in the UL Building Materials Directory under the category Roof Deck Constructions.

Discussion and influence of replacement or recovering

With respect to performance, it is apparent that heat from the fire must not penetrate to the combustible materials in the roof if acceptable fire involvement and fire spread are to be obtained. Isolation of the materials can be accomplished in several ways. It is important that materials between the steel roof deck and the insulation be of low combustibility. Metal fasteners or a reduction in the amount of combustible adhesive used to secure the insulation to the deck will generally improve the fire performance.

Several roofing systems that were recently investigated for internal fire spread resistance have included a layer of gypsum sheathing between the roof deck and the insulation. The addition of the gypsum sheathing resulted in a greater variety of insulations being acceptable in roof-deck constructions with acceptable internal fire-spread characteristics. Whenever replacing a system, the UL Building Materials Directory should be consulted for a description of acceptable roofing systems.

When recovering with a single-ply membrane in place of an existing BUR or with a new BUR added to the existing BUR covering, the interior flame spread is generally not affected, since the internal components of the acceptable roof system have not been disturbed.

INTERIOR FIRE RESISTANCE

Fire resistance of a roof structure is measured by the standard test entitled Fire Test Of Building Construction And Materials, UL 263 (ANSI A2.1, ASTM E119, NFPA 251). A sample for this test is 14 feet by 18 feet in size and contains all the elements of an actual roof structure. Prior to the start of the test, a load is placed on the roof to stress the structural elements to their design limits and temperature sensors are installed throughout. During the test, the ceiling side of the roof is exposed to the fire for the number of hours it continues to: 1) carry the load, 2) prevent combustibles on top from igniting and, 3) prevent flame from penetrating through the assembly. The fire resistance rating for the roof/ceiling assembly is expressed in time intervals such as 1/2 hour, 1 hour, 2 hours, 3 hours, etc.

Fig. 3 shows a commonly tested roof/ceiling assembly in which steel joists support a steel deck with insulation and a three ply BUR. A suspended ceiling or other protective material shields the structure from direct fire exposure from below.

For roof assemblies to withstand extended fire exposures, heat balance within the assembly must develop. Joists must not exceed temperatures of approximately 1000°F if collapse is to be prevented. Also, roof covering temperatures must not exceed 325°F (actual limit is 250°F plus ambient). At the same time, the roof insulation must allow some heat to escape without exceeding

325 °F topside limit. Reaching both temperature limits at the same time is the balance required for optimum fire performance.

Discussion and influence of replacement or recovering

Fire resistance ratings of roofs generally are determined by structural collapse before the top surface temperature limits are reached. High joist temperatures usually can be attributed to two causes: 1) either the ceiling allows excessive heat into the plenum or 2) the insulation above the deck prevents the escape of excessive heat.

It is apparent that adding insulation during replacement to improve energy efficiency will be detrimental to the rating of the roof unless there is compensation for the heat held in the plenum. Several recently test-roof assemblies have contained a layer of gypsum sheathing located on the deck and below the insulation. Since gypsum absorbs heat at elevated temperatures, steel joist and topside temperatures rise more slowly, compensating for the detrimental effect caused by the increased insulation. The use of gypsum sheathing above the structural supports and below the roof insulation should therefore be considered when replacement calls for an increase in insulation to the roof system and maintaining the interior fire resistance of the roof system is desirable.

Summarizing, it is a complex matter when it is necessary to maintain the interior fire resistance of a roof assembly during replacement or recovering. The complexity exists because: (1) there is an almost infinite combination of heat-shielding and insulating materials that can be used, (2) the materials perform interdependently, and (3) an appropriate combination of materials is required to achieve the balance necessary for optimum fire performance. Because of this complexity, it is recommended reference be made to publications such as UL's Fire Resistance Directory that describe the construction features and the hourly fire resistance ratings of roof assemblies.

Replacement or the addition of a new roof covering is not as complex as is total replacement when considering interior fire resistance of a roof assembly. A publication such as a UL's Fire Resistance Directory should be consulted before replacing existing coverings since the new covering may influence the heat flow balance. A single-ply roofing membrane with its lower mass (compared to a BUR) will allow the topside temperature to increase at a higher rate, and that could reduce the hourly fire resistance rating of the assembly. The addition of a BUR covering to an existing BUR covering will not reduce the hourly fire resistance rating of the roof assembly because of the addition of the new BUR will add to the heat-sink capacity of the assembly's covering.

SUMMARY

Model building code and insurance requirements specify the fire performance requirements of all roof assemblies including roofs being repaired or reconstructed. Fire performance requirements include: 1) external fire resistance, 2) internal fire spread and 3) internal fire resistance.

When replacing and/or recovering a roof assembly, consideration must be given to possible changes in the fire performance. If external fire resistance is to be maintained, the previous BUR covering should be retained when possible. The quantity of gravel surfacing or stone ballast placed on a new covering should at least equal the previous gravel surfacing or ballast. If internal fire spread is to be controlled, the combustible level between the steel deck and the insulation must not be increased. If internal fire resistance is to be maintained, the heat flow balance between the protective materials and the roof covering should remain unchanged.

Because of the many materials and roofing systems available, publications such as UL's "Building Materials Directory" and "Fire Resistance Directory" should be consulted before alterations are made in fire-rated roof assemblies.

REFERENCES

[1] Donahue, R. L. and Castino, G. T., "Fire Performance of New Roof Covering Materials and Systems and Weathered Asphalt Shingles," Roofing Systems, ASTM STP 603. American Society for Testing and Materials, 1976, 51-56.

[2] Harris, William B., "The Great Livonia Fire," *Fortune*, Nov. 1953, pp. 32-35, 171-176.

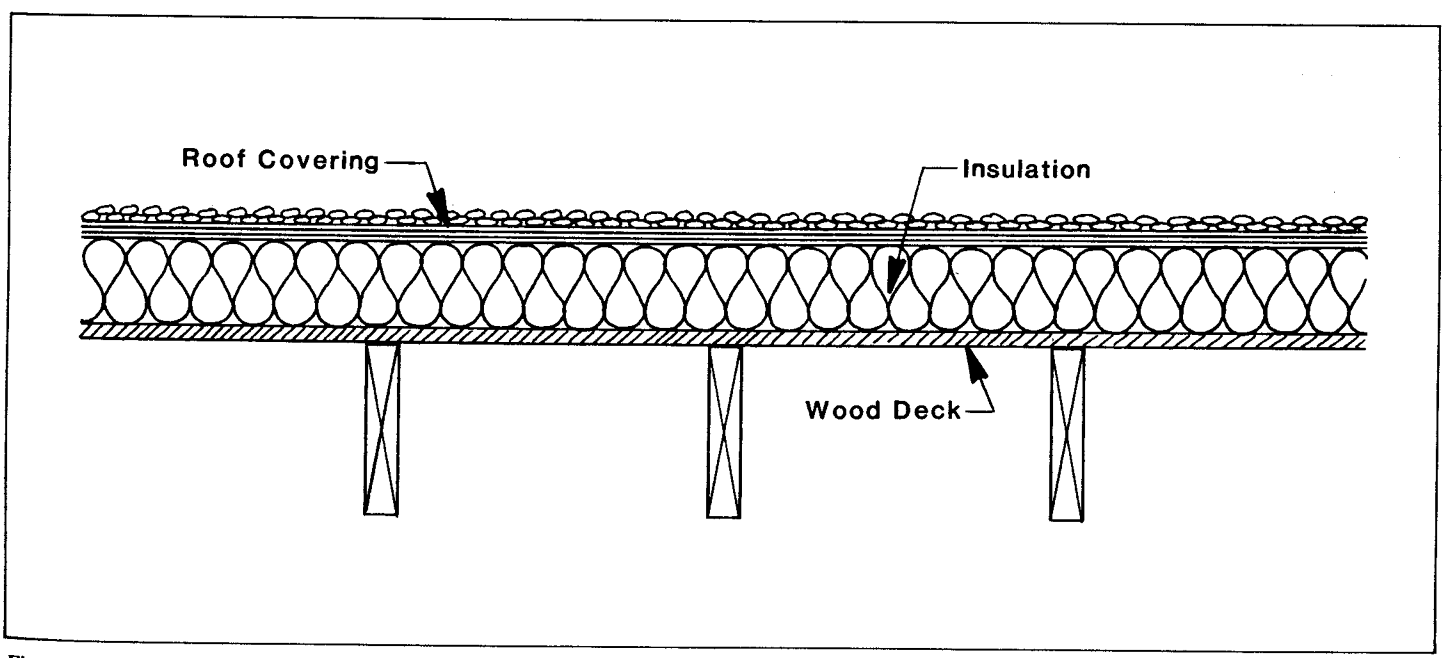

Figure 1 *Combustible roof and exterior fire exposure*

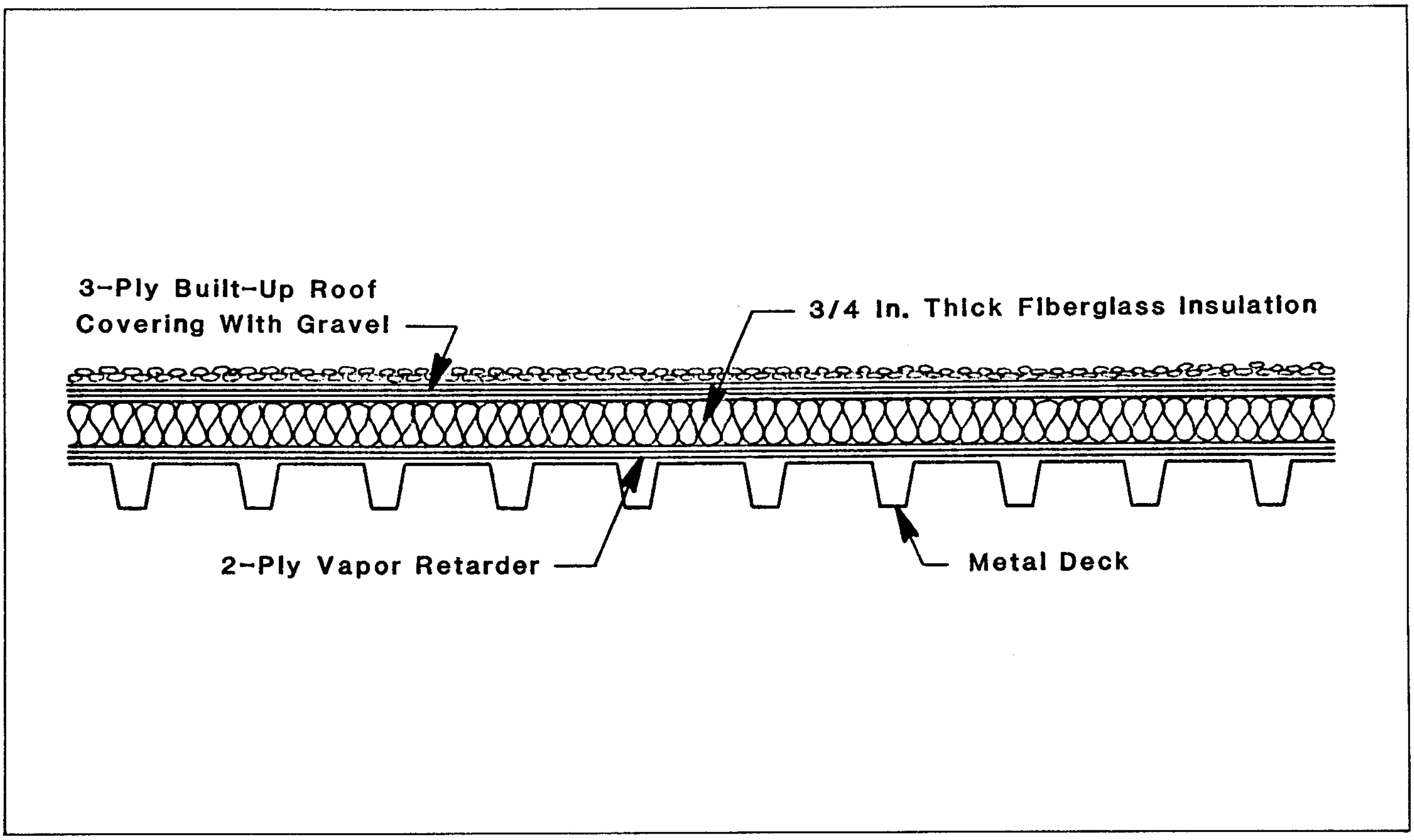

Figure 2 Metal deck roof and interior flame spread

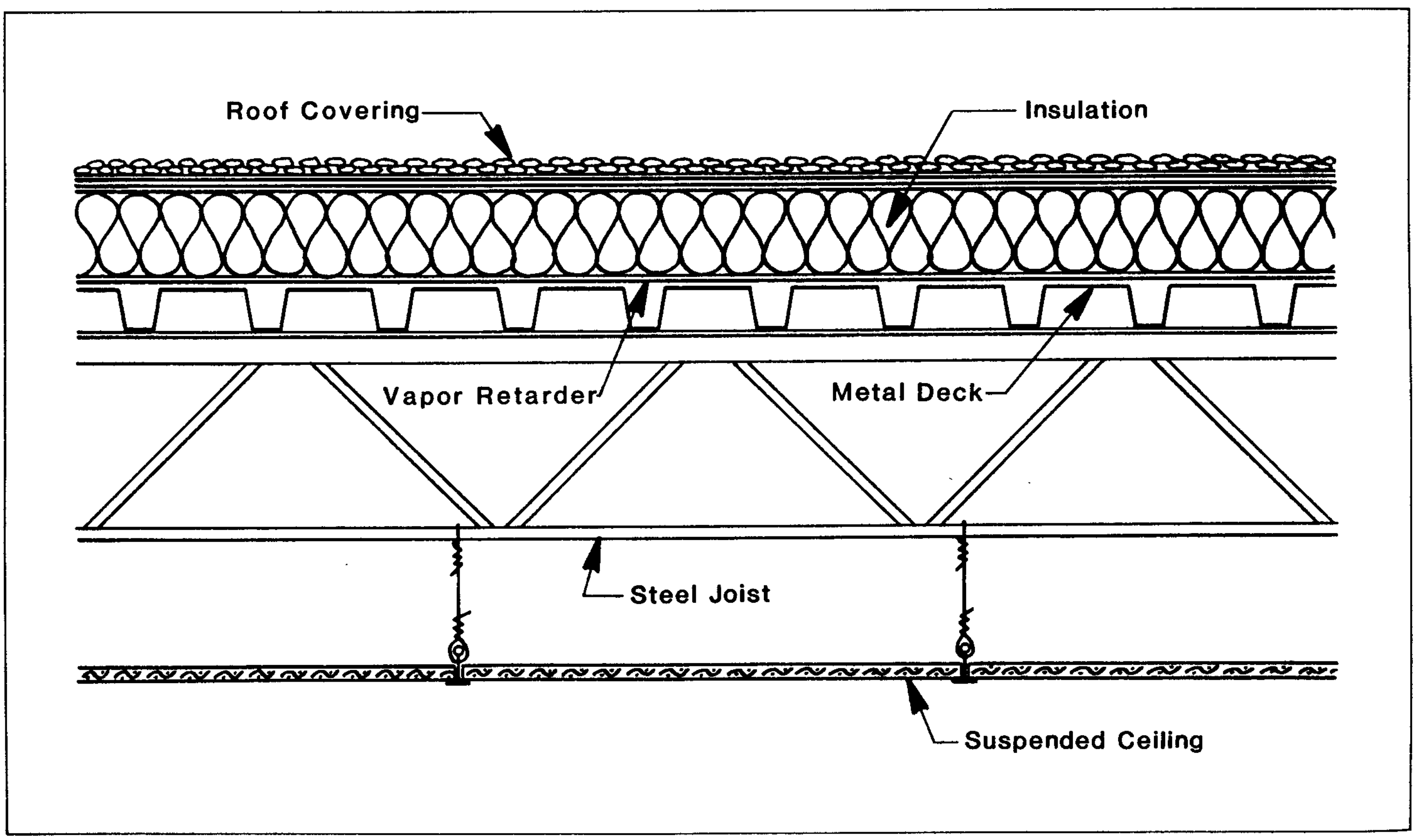

Figure 3 Protected metal deck roof and interior fire exposure