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WITH 1-INCH CONCRETE TOPPING

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This report describes a fire test on a joist-supported steel roof system with 1-in. concrete topping, protected by a suspended ceiling membrane of mineral board in an inverted "T" suspension system.

ANALYZED

In Canadian building construction it has become common design practice to use relatively light-gauge steel roof deck to span 6 ft (1.83 m) or more. Although this practice is theoretically sound in areas of low snow load, several in-service difficulties have been noticed. The most serious of these are susceptibility to damage by unexpected impacts and membrane damage caused by deflection from temporary concentrated loads. In addition, it has been found in fire tests that light-gauge steel decks (0.030 in., 0.76 mm) spanning more than about 5 ft (1.52 m) tend to early load failure, with large deflections.

It is proposed that a roof system with a small amount of concrete topping would provide the stiffness and heat sink properties desired. A 1-in. (25.4 mm) topping thickness was chosen because it is the minimum that can be used without encountering serious cracking problems. As well, this thickness provides a significant heat sink effect, as shown in Figure 1 (1). The Canadian Steel Industries Construction Council has built and tested a prototype system and found that it has the required stiffness and resistance to cracking.

The fire test to be described was conducted to demonstrate the superior fire endurance properties of this roof system. A conventional roof-ceiling assembly of similar construction, but without concrete topping, would achieve a fire endurance time of at most 1 h.

DESCRIPTION OF SPECIMEN

Specification

Details of the test specimen are shown in Figures 2 and 3; the item numbers below correspond to the part numbers in Figure 2.

1. Open-web steel joist (OWSJ), 14 in. deep (356 mm) by 15 ft 10 in. long

(4.83 m), with an effective span of 15 ft 6 in. (4.72 m), moment of inertia 38.38 in.^{4} (15.97 x 10^6mm^4) fabricated of CSA 640 20-44W steel.

2. Steel roof deck unit, fluted 8 in. (203 mm) O.C. 00.030 in. (0.76 mm) wiped zinc-coated steel, 1½ in. (38 mm) deep by 30 in. (762 mm) wide. Deck units attached to the joists with ½-in. (13 mm) arc spot welds (puddle welds) through welding washers 16 in. (406 mm) O.C. Interlocking flanges of adjacent units were crimped together on 24-in. (610 mm) centres.

3. Concrete topping, 1 in. (25.4 mm) deep over top of steel deck. Density 149 lb/ft^3 (2388 kg/m^3), 3,300 psi (22.8 MPa) average compressive strength, placed at 3 in. slump.

4. Vapour barrier.

5. Mineral board insulation, 1½ in. (38 mm) in two 3/4-in. (19 mm) layers, total thermal resistance 4.4 ft^2 h °F/Btu (0.77 m^2 K/W).

6. Roof covering, 3-ply felt membrane with asphalt interlayers.

7. Steel duct, ends closed, manufactured from 0.024-in. (0.6 mm) galvanized steel 12 in. (305 mm) by 24 in. (610 mm) cross-section, by 12 ft (3.66 m) long, provided with two headers 18 in.^{2} (456 mm^2).

8. Diffuser grille, 24 in.^{2} (610 mm^2), lay-in type (compatible with suspension system) constituting an opening area of 640 in.^{2} /100 ft^2 (4.44%) of ceiling area.

9. Recessed-type lighting fixture, nominally 2 ft (610 mm) by 4 ft (1.22 m), manufactured from 0.024-in. (0.6 mm) steel, complete with ballast and lampholders. Four fixtures were used constituting an area of 18 per cent of the ceiling area.

10. Main tee*, manufactured from 0.020-in. (0.5 mm) wiped zinc-coated steel, 12 ft (3.66 m) long, 1½ in. (38 mm) deep with a 1-in. (25 mm) flange capped with a white pre-painted steel 0.010 in. (0.25 mm) thick. Each length of member incorporates one expansion point.

11. Cross tee*, same section as main tee, equipped with interlocking ends, supplied in 4 ft (1.22 m) and 2 ft (610 mm) lengths.

12. Mineral fibre board acoustical ceiling panel*, nominally 24 in. (610 mm) by 48 in. (1220 m) by 5/8 in. (16 mm) thick.

13. Perimeter moulding angles (not shown), 12-ft (3.66 m) long 3/4-in. (19 mm) by 3/4-in. (19 mm) angle section manufactured from 0.021-in. (0.5 mm) wiped zinc-coated steel.

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*Listed and labelled by Underwriters' Laboratories of Canada; List of Equipment and Materials, Volume II, Building Construction, September 1978.

14. Hanger wire (not shown), 0.105-in. (2.7 mm) galvanized steel wire spaced 24 in. (610 mm) O.C. along main tees at the intersection of the cross-tees and at centre of cross-tees adjacent to lighting fixtures.

15. Hold-down clips (not shown), made from 0.015-in. (0.4 mm) spring steel, clamped over bulb of tee bars to prevent tiles from lifting.

16. Lighting fixture protection** (not shown), acoustical ceiling panel placed on top of lighting fixture leaving ends and sides open to provide ventilation for the fixture.

17. Duct protection** (not shown), one acoustical ceiling panel centred over each opening.

The assembly was designed to be simply supported in the refractory concrete frame of the floor furnace. Space was left round the perimeter to allow for thermal expansion; the construction is therefore classified as "unrestrained" according to the test standard ULC-S101 (3) (ASTM E119 (4)).

"Partial protection" was designed for the lighting fixtures and ductwork to reduce the cost of the fire resistive ceiling installation. In addition, the service life of a recessed lighting fixture increases considerably when the fixture is well ventilated.

Construction and Workmanship

All structural construction was carried out by members of the staff of the Division of Building Research. The roofing, ductwork and ceiling installation were done by workmen in the employ of local contractors.

The four OWSJ were placed on bearing plates in the loading frame and steel deck was arc spot welded to the top chords of the joists using ½-in. (13 mm) welding washers 16 in. (406 mm) O.C. Interlocking flanges of adjacent units were crimped together on 24-in. (610 mm) centres. A wooden form was constructed round the perimeter of the roof deck to provide the desired 1-in. (25 mm) concrete cover. One cubic yard (0.765 m^3) of ready-mix concrete from a local source was designed to yield a minimum compressive strength of 3000 psi (20.7 MPa); the mix comprised the following:

portland cement	420 # (191 kg)
pit sand	1400 # (636 kg)
gravel aggregate	1780 # (809 kg)
water	265 # (120 kg)

Figures 4 to 6 are photographs of the sample during the construction process. Slump of the concrete at time of placement averaged 3 in. (76 mm).

** This type of protection is known as "partial protection" (2) and is designed to minimize vertical radiation to the superstructure.

Two cylinders of concrete were taken for compressive tests.

The ductwork, ceiling and lighting fixtures were installed and located as shown in Figure 3. Both the tops of the headers to the duct and the tops of the lighting fixtures were protected by laying on a full-size ceiling panel to prevent radiative heat transfer. Workmanship on all parts of the specimen was judged to be good.

FIRE TEST

The specimen was subjected to fire test in accordance with the provisions of ULC S101-1975 (3) (ASTM E119-73 (4)). Average moisture content of the concrete topping was 2 per cent by weight at the time of the test.

Gas flow into the furnace was controlled automatically so as to follow closely the temperature-time curve prescribed by the standard. Furnace temperature was measured by nine symmetrically distributed thermocouples enclosed in 13/16-in. (20.6 mm) O.D. inconel tubes having a wall thickness of 0.035 in. (0.89 mm) and equipped with a carbon steel cap at the top. The hot junction of the thermocouples was placed 12 in. (305 mm) from the exposed face of the specimen. Both individual temperatures at the nine points and the average were recorded during the test.

Temperature on the unexposed surface was measured by nine thermocouples; five were located at the centre and quarter points of the assembly; four others were located adjacent to partially protected fixtures. All unexposed surface thermocouples were covered with standard asbestos pads 6 in. (152 mm) square and 0.4 in. (10 mm) thick.

Steel deck temperatures were measured at the centre of the assembly and at a point 40 in. (1016 mm) along the centreline of the assembly, as shown in Figure 7.

Joist temperatures were measured at 24 points at the centre and quarter spans. Location of the thermocouples on the cross-section is shown in Figures 8 and 9.

During the test a live load of 50 lb/ft^2 (2394 N/m^2) was applied to the roof assembly. Together with the estimated dead load (self-weight) of 22 lb/ft^2 (107 kg/m^2) the applied load was calculated to stress the steel joists and deck to the maximum allowable by CSA S16-1969 (5). The live load deflection of the assembly was 0.312 in. (7.9 mm) measured at the centre of each joist by an electrical device. At the start of the test the deflection was zeroed so that deflections due to the effects of fire on the assembly were recorded during the fire test.

Several thermocouples were distributed throughout the plenum space to measure temperatures of the unexposed ceiling face, air, and ductwork.

OBSERVATIONS

Significant observations were recorded during the fire test. At 3 min the ceiling panel surface had darkened and the expansion points on the main runners had operated. It was noted that the flange at one of these points had buckled upward instead of downward as the design intends. At about 10 min the ceiling panels had lightened again and the suspension system was deflecting slightly downward. This gradual deflection continued until the test was terminated. No panels dropped from the ceiling during the fire test.

No changes were observed on the unexposed surface, except that small quantities of smoke were generated during the early minutes. This was produced by the lighting fixture ballasts and the combustible content of the mineral fibre ceiling panels.

RESULTS

Because roof assemblies in Canadian buildings require a maximum fire resistance rating of 2 h, the fire test was terminated at 2 h 5 min. At this time no failure point, as prescribed in the test standard, had been reached. Accordingly, the fire resistance classification of the assembly is 2 h.

Information relating to temperatures developed in the furnace and in the test assembly is illustrated in Figures 10 to 16; they are labelled so as to be self-explanatory.

Deflections measured over each joist at the centreline of the assembly are shown in Figures 17 and 18.

COMMENTS

Provision of the 1-in. concrete cover (heat sink) changed the fire endurance time of the assembly from barely 1 h to over 2 h, as had been anticipated in the design. This test demonstrated once again (6) how effective a heat capacity remote from the fire-exposed surface can be in prolonging the fire resistance of a construction assembly. From the temperature charts it may be seen that "partial protection" (2) was quite effective in minimizing heat transmission through ductwork and lighting fixtures. It is recommended that this economical protection be used in place of lighting fixture protection boxes and fire stop flaps (ceiling dampers).

CONCLUSIONS

1. The fire resistance classification of the roof ceiling assembly tested is 2 h according to the criteria for acceptance of ULC S101-1975 (ASTM E119-73).

2. A 1-in. concrete topping on steel roof deck results in much improved fire endurance and structural quality, as compared to roof-deck without concrete topping.

3. "Partial protection" (that is, placing a ceiling panel on top of a lighting fixture) is satisfactory for this type of assembly and offers construction economy.

4. Protection of ceiling openings for air handling by "partial protection" (placing a ceiling panel on top of the duct over the header) proved to be satisfactory. This installation is a substitute for the rather costly fire-stop flap or ceiling damper normally used.

ACKNOWLEDGEMENT

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6. Stanzak, W.W. and T.Z. Harmathy, Effect of Deck on Failure Temperature of Steel Beams. Fire Technology, Vol. 4, No. 4, 1968, p. 265-270.

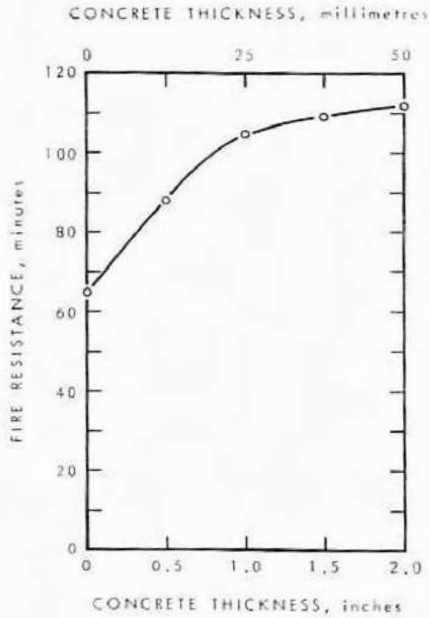

Figure 1 Dependence of fire resistance on thickness of concrete topping

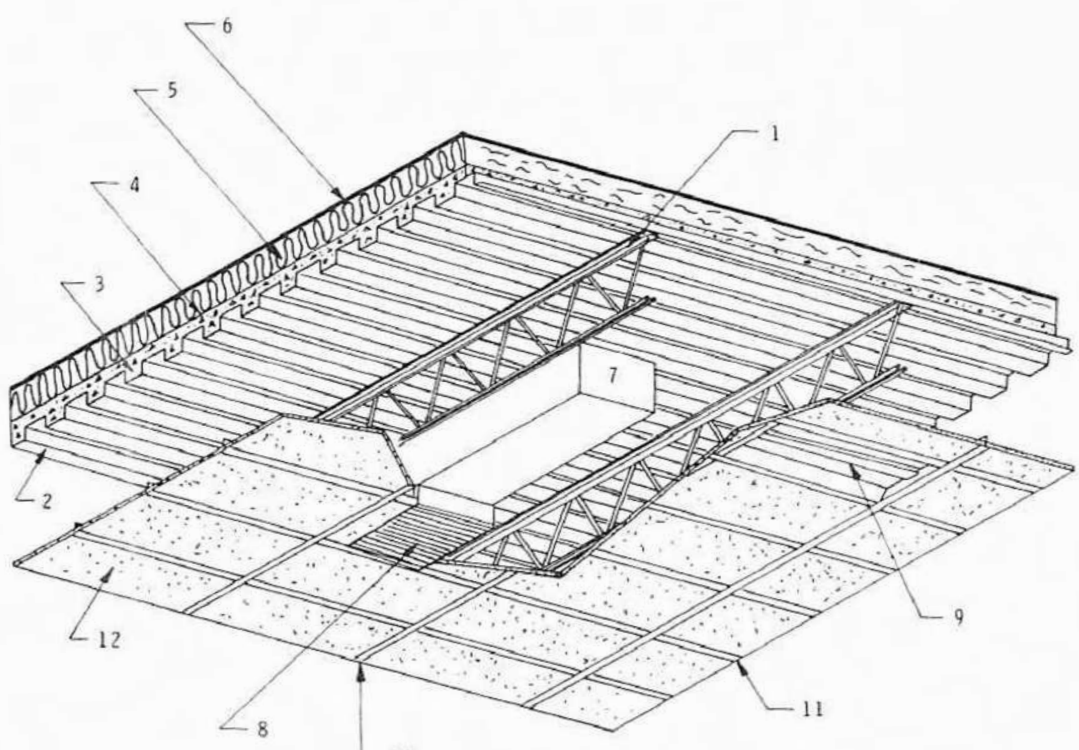

Figure 2 Construction details

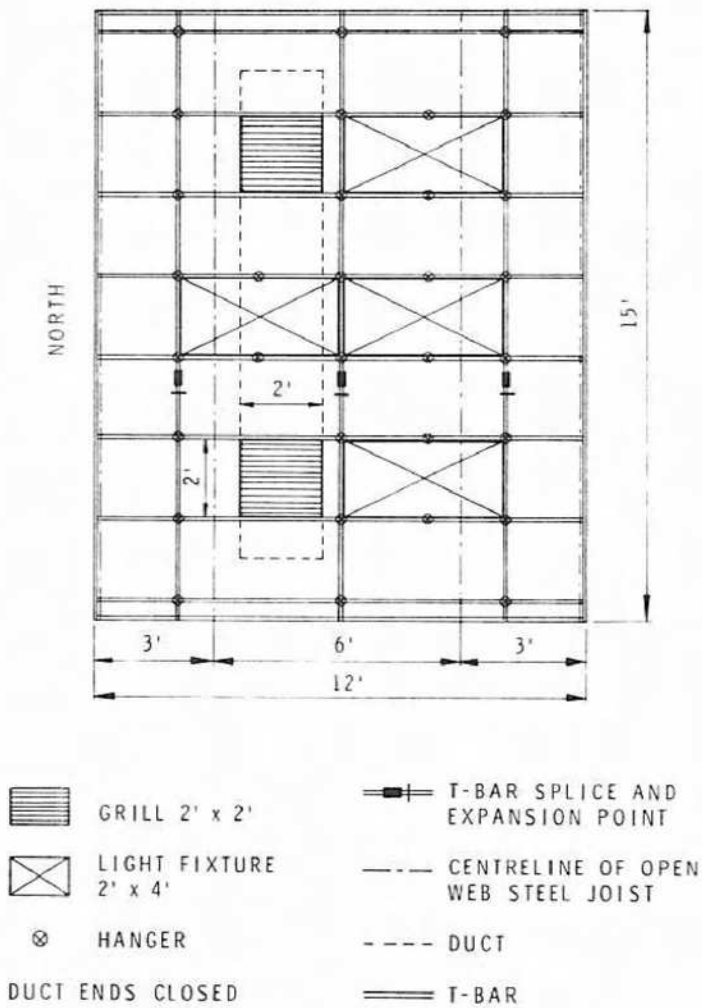

Figure 3 Reflected ceiling plan

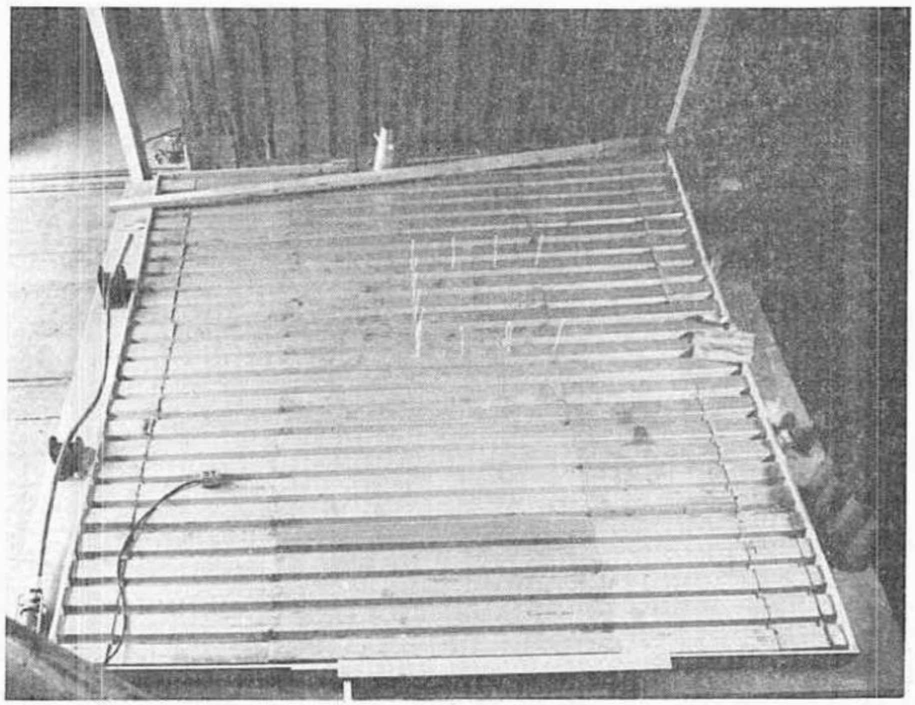

Figure 4 Steel assembly

Figure 5 Placing concrete fill

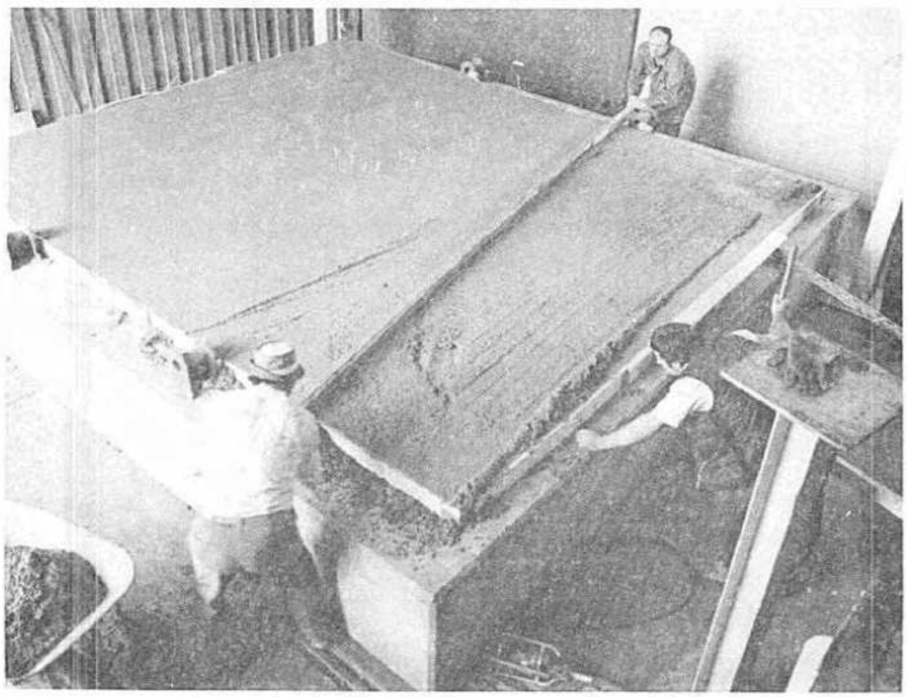

Figure 6 Concrete finishing

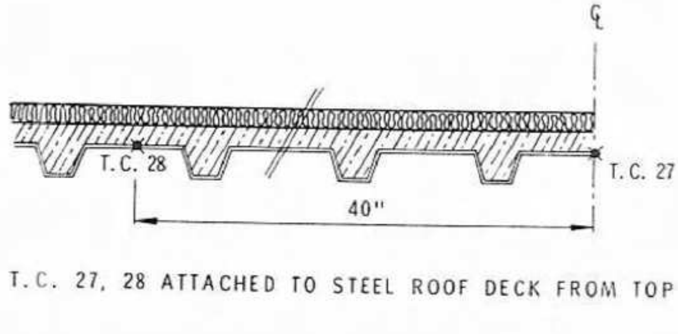

Figure 7 Steel deck thermocouples

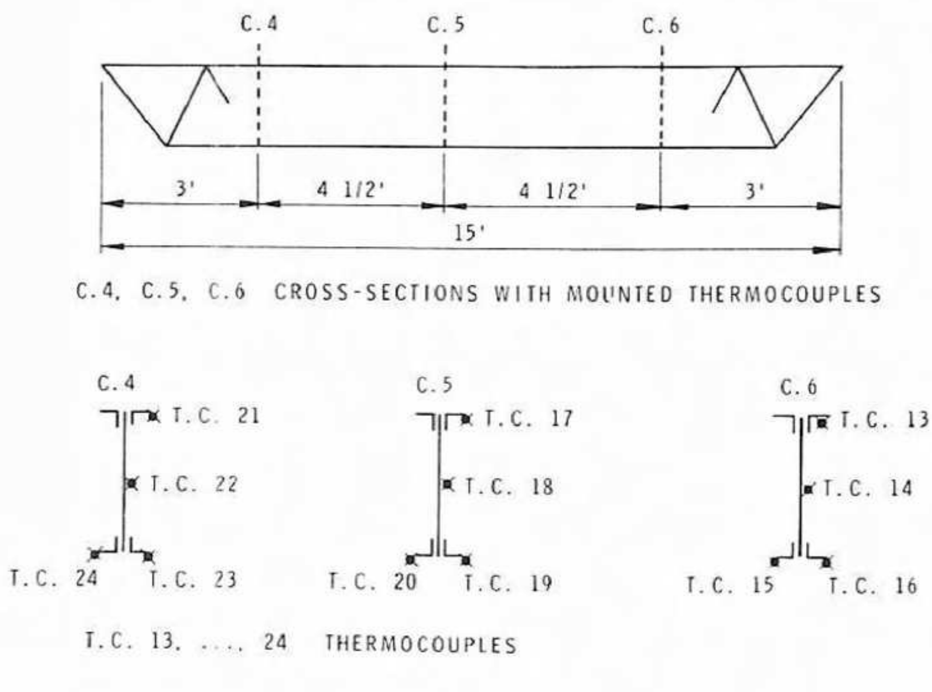

Figure 8 Thermocouples - south joist

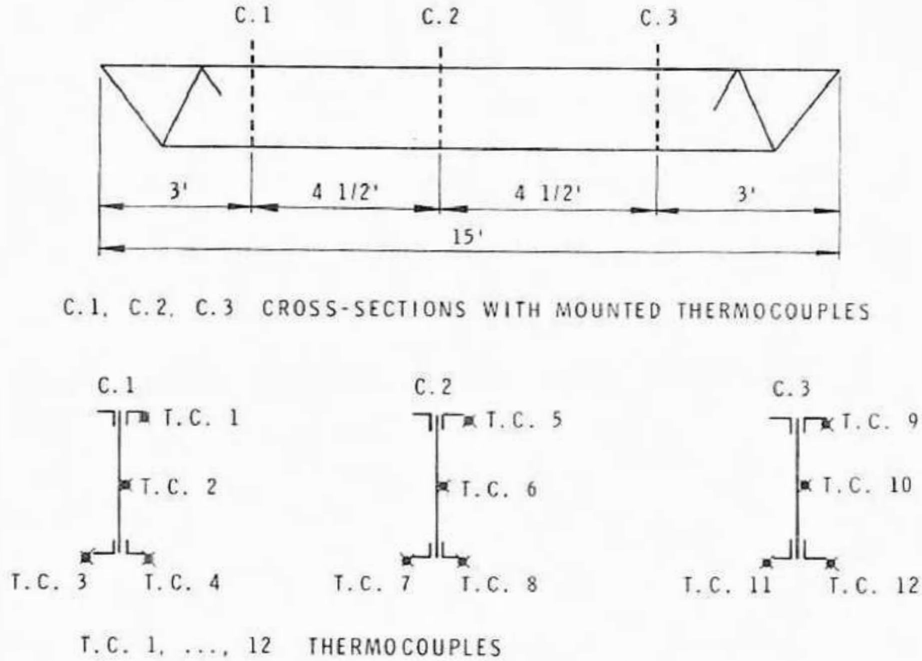

Figure 9 Thermocouples - north joist

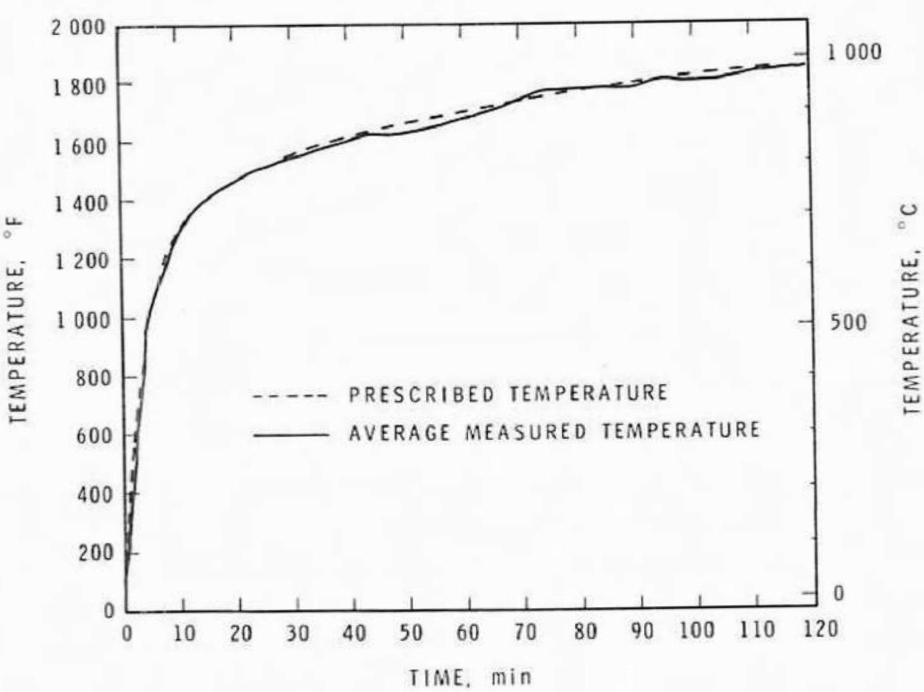

Figure 10 Furnace temperatures

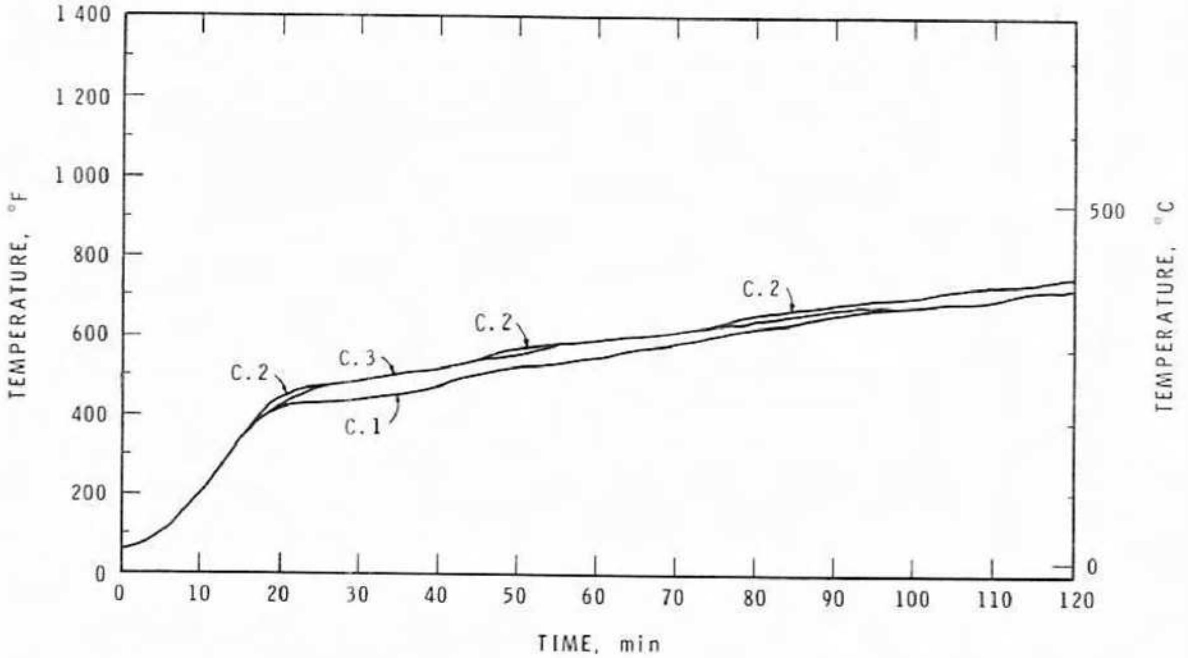

Figure 11 Temperatures on north joist (average at cross-section C.1, C.2, C.3)

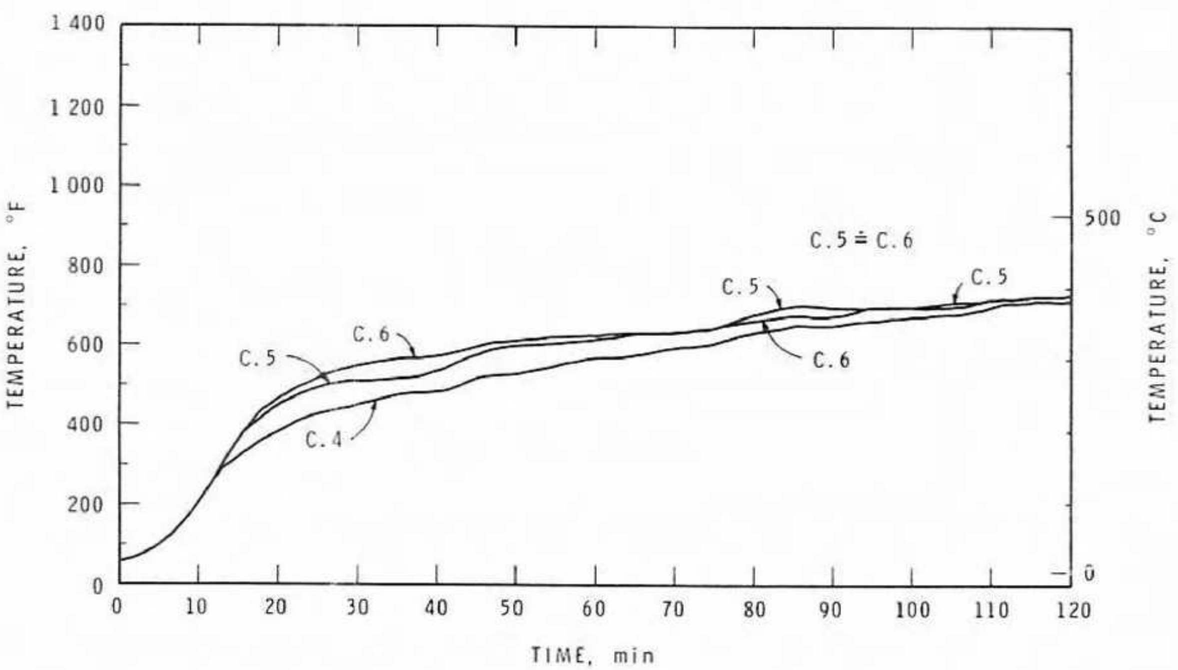

Figure 12 Temperatures on south joist (average at cross-section C.4, C.5, C.6)

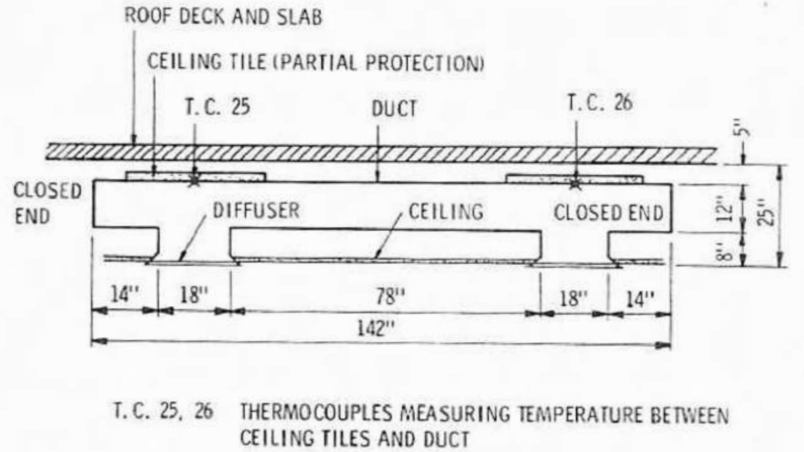

Figure 13 Thermocouples on air-conditioning duct

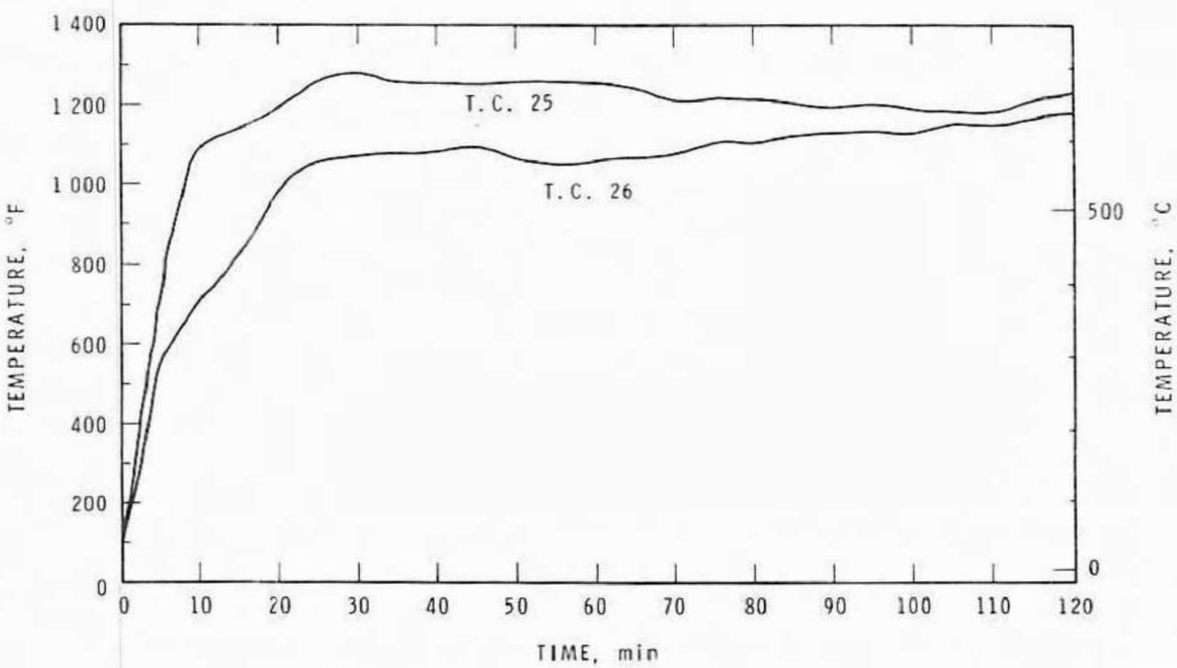

Figure 14 Temperatures on air-conditioning duct

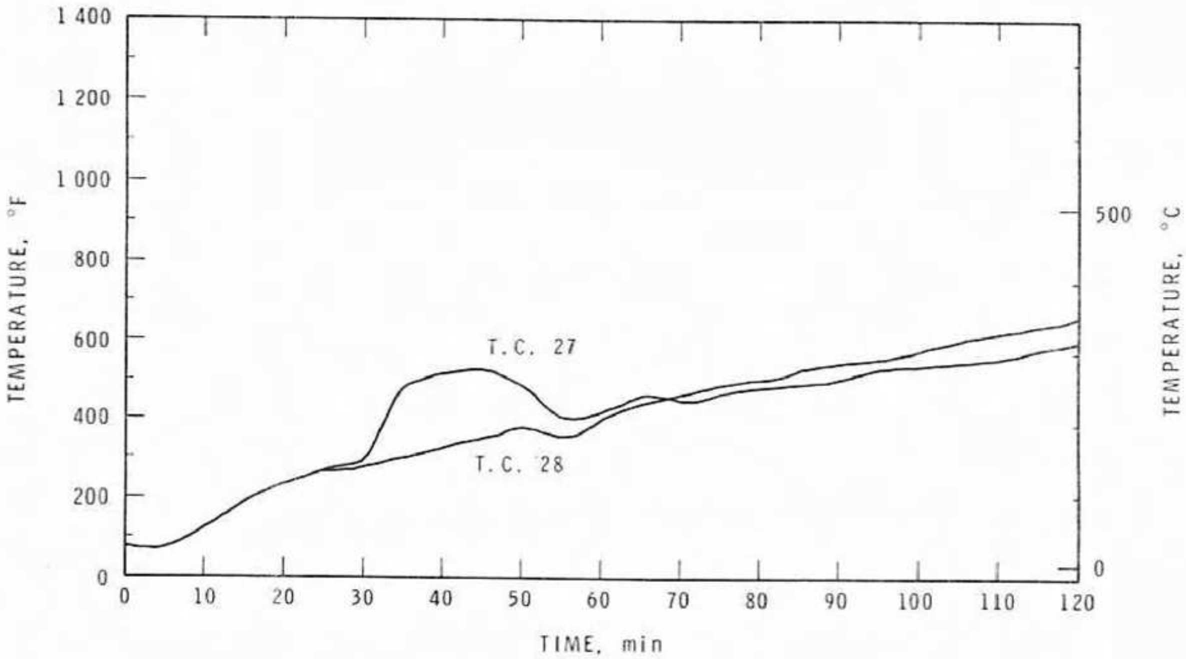

Figure 15 Temperatures on steel roof deck

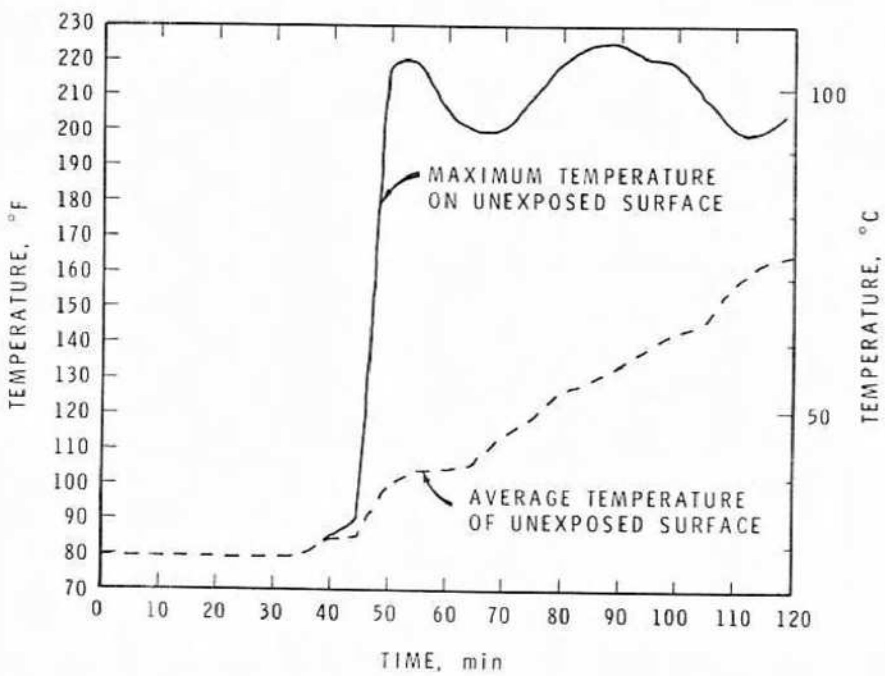

Figure 16 Temperatures on unexposed surface

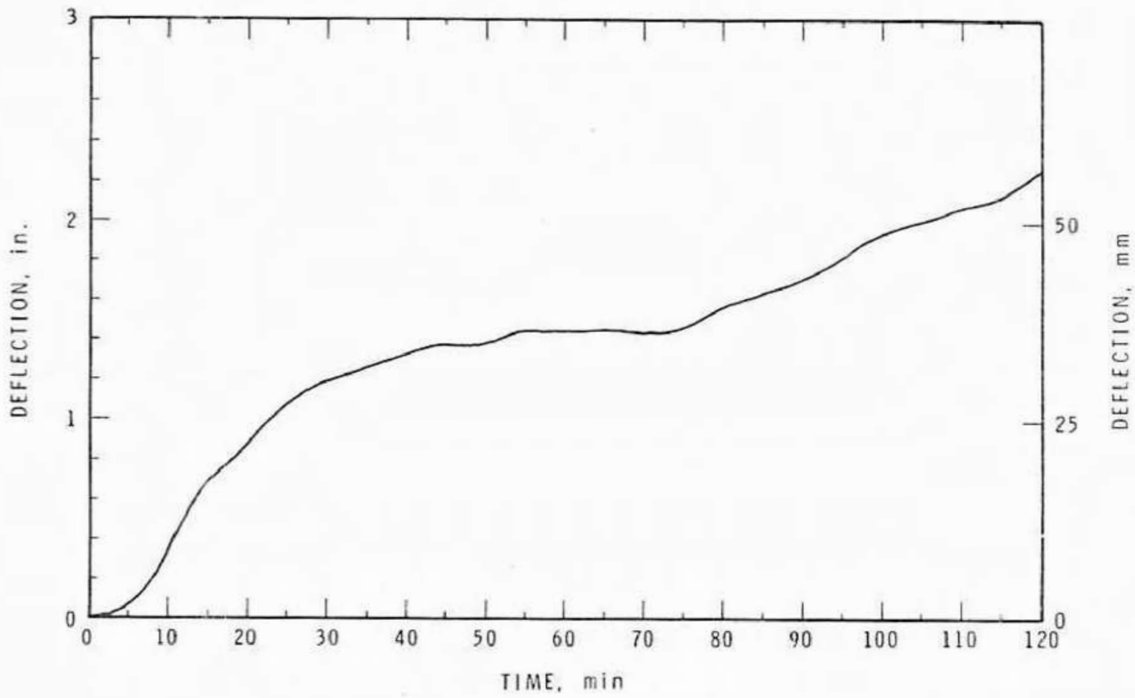

Figure 17 Mid-span deflection of north joist

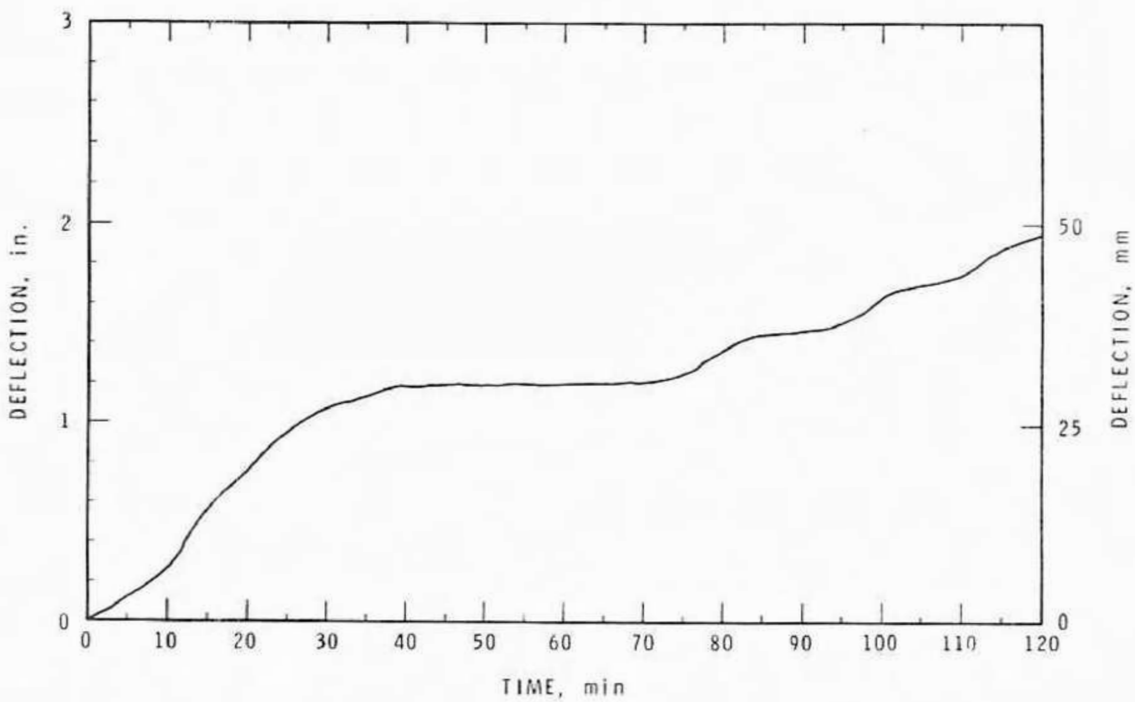

Figure 18 Mid-span deflection of south joist