NATIONAL BUREAU OF STANDARDS REPORT

5994

EXAMINATION OF THE TEMPERATURE DISTRIBUTION
WITHIN THE N.B.S. FLOOR TEST FURNACE

by

J. V. Ryan

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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ABSTRACT

The temperatures within the NBS floor test furnace are monitored by 12 thermocouples distributed symmetrically with respect to the furnace plan, and located 12 in. below the specimen. Extra thermocouples were included during several standard fire tests to give the temperatures at other positions within the furnace.

The mean temperature variation with moderate change in distance from the specimen surface was determined and compared with the variations among the individual standard thermocouples. The horizontal and vertical temperature distributions within the furnace chamber during typical tests are reported.

1. INTRODUCTION

Fire endurance studies of floors and roofs are made by the National Bureau of Standards, employing a floor furnace in which the specimen forms the top of the combustion chamber. The chamber height is about 6 ft but varies with the thickness of the specimen; the chamber width is 12 ft 8 in. and the length 17 ft 3 in. Premixed gas and air is fed to 9 burners along each side wall. The burners are at two levels, about 38 and 52 in. above the furnace floor; those at 52 in. are located in ports through the furnace wall, those at 38 in. are in brick piers that extend about 28 in. out from the wall and 50 in. up from the floor. The burners discharge horizontally, in the space from about 34 to 56 in. above the floor.

The individual fire tests are conducted in accordance with a Standard Test Method, ASTM E119 (1), that specifies the time-temperature curve to be produced, as closely as

feasible, in the furnace chamber, as indicated by thermocouples placed 12 in. below the exposed surface of the specimen. The thermocouples are encased in iron pipes of which eight are inserted through holes in the furnace walls, and the other four extend up from a central pier. The pipes for the latter may be cut to the necessary length to place the thermocouple junctions at the specified 12 in. below the specimen. However, the eight peripheral thermocouple pipes are essentially horizontal. The vertical distance below the specimen is adjusted in discrete steps by the choice of one of four holes at each location along the furnace walls. The positions of these holes permit the initial placement of the thermocouple junctions within 1 in. of the specified distance for specimens within the range of thicknesses normally found in buildings. Specimens of unusual designs could make it necessary to place the thermocouple junctions at distances below the specimen significantly different than 12 in.

As a means for exploring the effects of such misplacements as well as general temperature variations within the furnace, extra thermocouples were placed at various locations within the chamber during four tests.

2. THERMOCOUPLE LOCATIONS

The thermocouples in the first test were placed to permit evaluation of the effect of displacing the eight peripheral thermocouples 4 to 6 in. farther than the specified 12 in. from the specimen. Those in the second, third, and fourth test were placed to sample the horizontal and transverse temperature distributions.

The specific locations of the thermocouple junctions are shown in Figure 1. In the first test, with two levels of peripheral thermocouples, those at the standard 12 in. distance were supported with nichrome wires to minimize

sag. In the other three tests, the extra experimental thermocouples were mounted in a manner intended to minimize sag without introducing serious obstruction to the normal circulation of hot gases.

3. TEST METHOD

The test method requires that specimens be exposed to the furnace fires controlled to produce, as closely as feasible, the temperatures of the standard time-temperature curve (1). These include 1000°F at 5 min, 1300°F at 10 min, 1550°F at 30 min, 1700°F at 1 hr, 1850°F at 2 hr, 2000°F at 4 hr, and 2300°F at 8 hr.

Fire exposure severity is defined as the ratio of the area under the curve of average furnace temperatures to the area under the standard time-temperature curve for the same elapsed time, both taken above 20°C as a base line. The severity is expressed as a percent, and variation of ± 5 percent is allowed, in tests of over 2 hr duration.

4. TEST RESULTS

The first, second, and fourth tests were of six hour durations; the third of only 50 min duration. Therefore, most of the results and conclusions were derived from the data of the former group.

Some of the individual thermocouples ceased to function properly before the ends of the six hour tests. Hence the data were not complete for the full duration, in all cases.

4.1 First Test

For the sake of analysis, two groups of twelve thermocouples, and the mean values of the data therefrom were considered. The first group was composed of the thermocouples at the standard 12 in. from the specimen; the mean temperature indicated by this group was designated $\overline{T_5}$. The second group was composed of the eight peripheral thermocouples 4 to 6 in. below the standard position plus the four along the central pier; this group's mean temperature was designated $\overline{T_1}$.

The four thermocouples along the central pier, at the standard 12 in. from the specimen, were included in both groups because the furnace design is such that their junctions may always be placed at the standard position.

The mean temperatures were determined at 10 min intervals. The difference, $\Delta = \overline{T}_1 - \overline{T}_s$, reached a maximum of 8 deg C at 20 min and decreased more or less uniformly to 1 deg C at 4 hr 40 min. The root-mean-square values of the deviations from the mean among the data from the twelve standard thermocouples were in the range of 20 to 40 deg C over the 4 hr 40 min period.

The effect of the difference in elevation on the fire exposure severity was estimated by determining the ratio of the accumulated Δ to the accumulated mean from the standard thermocouples, expressed as a percent:

$$\phi = \frac{\Sigma \Delta}{\Sigma \overline{T}_s} \times 100 = \frac{\Sigma (\overline{T}_1 - \overline{T}_s)}{\Sigma \overline{T}_s} \times 100$$

The values of ϕ ranged from 0.99 percent at 20 min to 0.42 percent at 4 hr 40 min. The effects of difference in thermocouple location on fire exposure would thus be less than 1.0 percent.

4.2 Second Test

The results of the second test are presented as graphs of temperature vs distance above the furnace chamber floor, at a given distance from the side wall (that of the standard thermocouple positions), and of temperature vs distance from the side wall, at two elevations above the furnace chamber floor. Each graph has a family of curves, each curve corresponding to a specific time. These graphs are given in Figures 2, 4, and 6.

4.3 Third Test

The floor specimen under test failed at 52 min, much earlier than anticipated. Therefore, the data cover a much smaller time than those from the other tests. They do not appear to contradict those from the other tests, and are not presented.

4.4 Fourth Test

The results of this test are presented as graphs similar to those for the second test. These graphs are given in Figures 3, 5, and 7.

5. DISCUSSION

The first test showed that the 12 in. spacing of the furnace thermocouples from the specimen surface might be exceeded by as much as 6 in. without introducing a serious difference in the actual exposure to the specimen. Since the peripheral thermocouple pipes at the standard 12 in. were supported and those at greater distance were not, the distance between increased as the latter pipes softened and bent down under the effects of the fire. Despite this increase in separation, the temperature differences between the mean values decreased. This test also indicated that near the specimen the mean furnace temperature decreased slightly with decrease of distance from the specimen. This should be expected due to the heat absorption by the specimen, plus the fact that the direct flames from the burners are concentrated somewhat below the standard thermocouple position.

The direction of the temperature gradient near the specimen was confirmed by the other tests. This may be seen in Figures 2 and 3, showing the vertical temperature distribution in the second and fourth tests.

Figures 4 and 5 show the horizontal temperature distribution at a level 54 in. above the floor, and slightly above the burners. As expected, the curves are reasonably flat. Figure 4, covering distances from 12 to 77 in. from the furnace wall, (the latter distance being at the centerline) shows the cooling effect of the furnace wall to be fairly slight. The temperature observed at the centerline (77 in.) was consistently lower than that at 60 in. for the same time. This may have been due to overheating at the latter distance due to a feature of the furnace geometry. The temperature difference was more pronounced for the lower pipe and the cause is discussed in connection with Figure 6.

Figures 6 and 7 show the horizontal temperature distribution at a level 36 in. above the furnace floor. Here the geometry of the furnace causes significant interference in the circulation of the furnace atmosphere. Figure 6 indicates a high temperature condition persisting at about 60 in. from the furnace wall. This is believed due to the deflection of the flames from one burner by the support for one of the thermocouple pipes from the central pier. This appears to be born out by Figure 7. In the later test, the thermocouple junctions were on the opposite side of the centerline, and no localized hot spot is indicated by the data.

6. CONCLUSIONS

The graphs indicate that: The horizontal temperature distribution near the specimen is fairly uniform. The piers in the furnace chamber cause some local hot spots but the overall temperature distribution is still reasonable at about 3 ft above the furnace chamber floor.

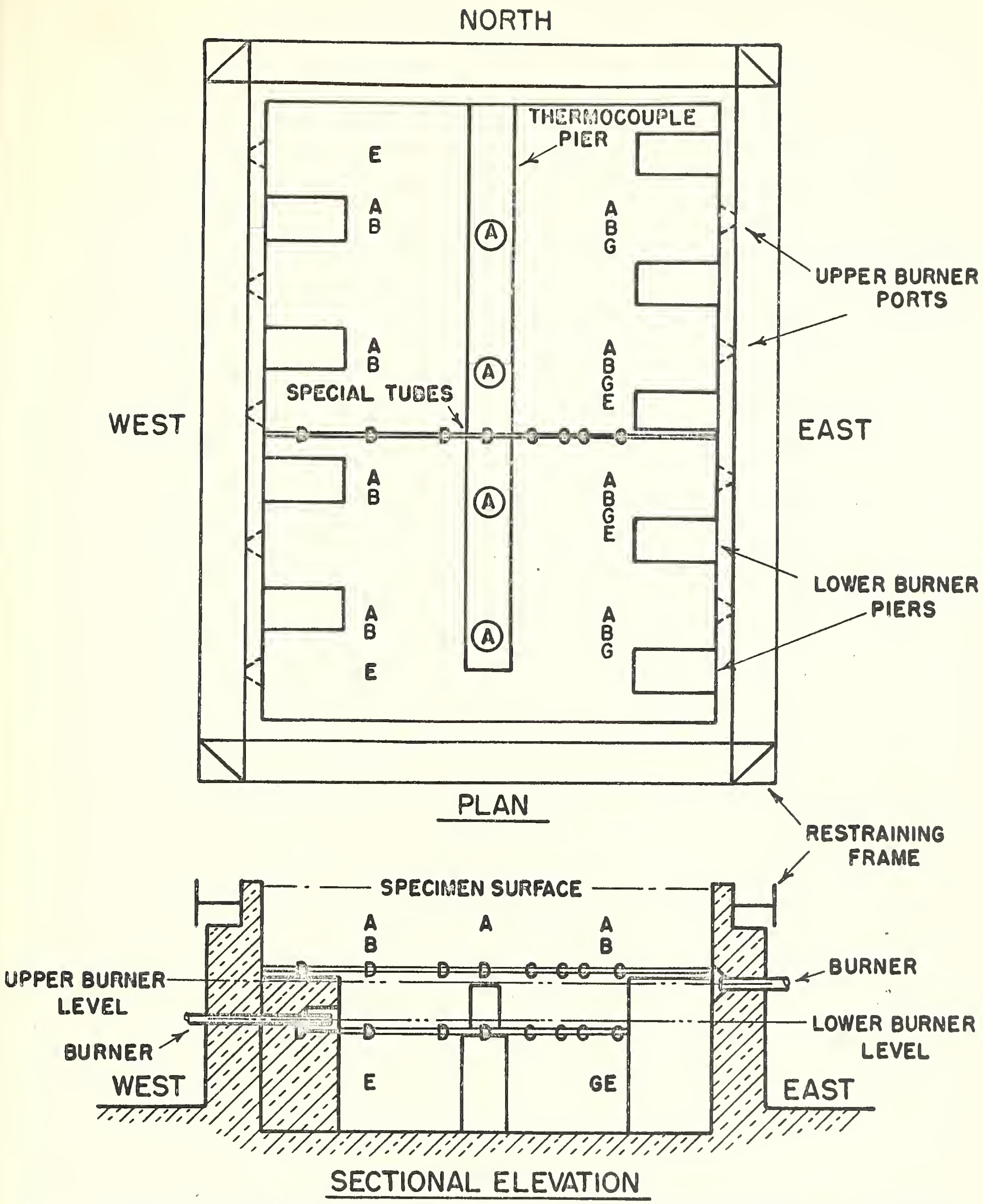
The vertical temperature distribution is much less nearly uniform than the horizontal distributions.

The temperature gradient within 18 in. of the specimen is such that the temperature decreases as the specimen surface is approached.

The deviations from uniformity, both horizontal and vertical, decrease significantly as the test duration increases.

REFERENCES

1. "Standard Method for Fire Tests of Building Construction and Materials", American Society for Testing Materials, designation E119.



A– 12 STANDARD THERMOCOUPLES 36" FROM WALLS AND IN CENTER PIER, ALL 12" BELOW SPECIMEN

B– 8 THERMOCOUPLES 16" TO 18" BELOW SPECIMEN IN TEST NO. 1

C– THERMOCOUPLES IN SPECIAL TUBES 32", 44", 50" AND 62" FROM EAST WALL IN TEST NO. 4

D– THERMOCOUPLES IN SPECIAL TUBES 12", 36", 60" AND 77" FROM WEST WALL IN TEST NO. 2

E– 4 THERMOCOUPLES 16" ABOVE FLOOR 36" FROM WALL IN TEST NO. 2

G– 4 THERMOCOUPLES 16" ABOVE FLOOR 36" FROM WALL IN TEST NO. 4

FIG. 1 – THERMOCOUPLE LOCATIONS

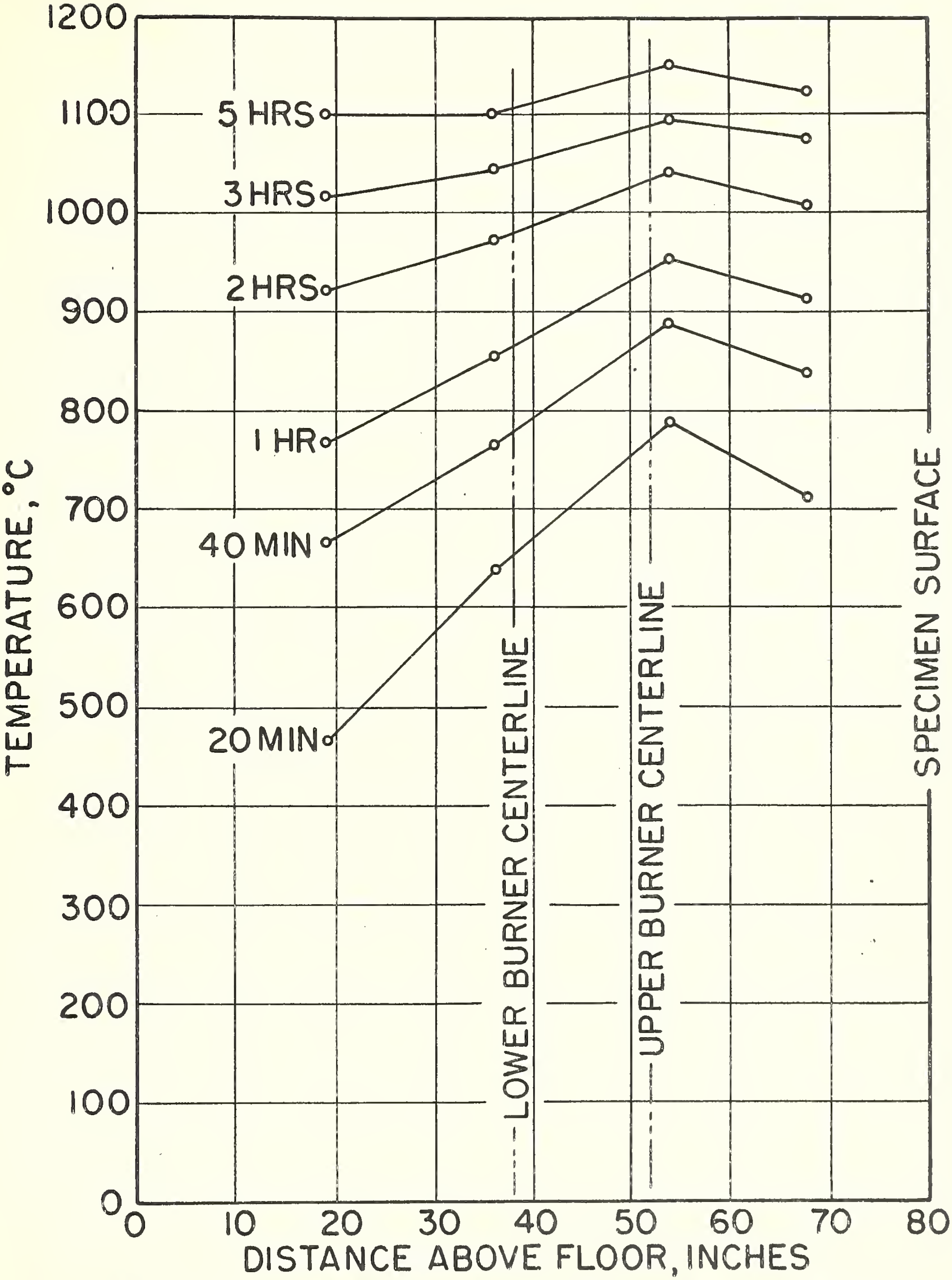


FIG. 2–TEMPERATURE DISTRIBUTION ABOUT 36 INCHES FROM SIDE WALL
(TEST NO. 2)

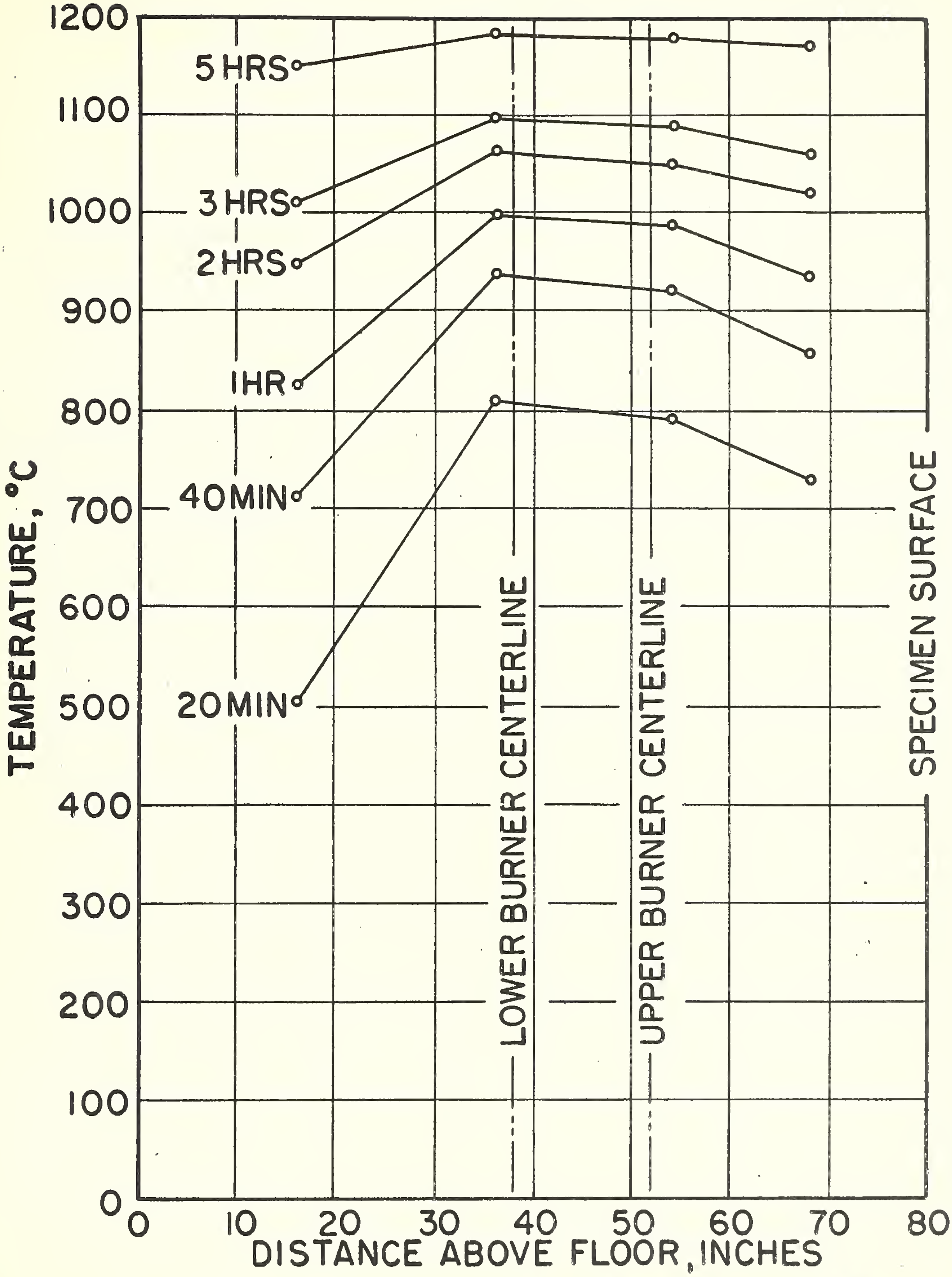


FIG. 3–TEMPERATURE DISTRIBUTION ABOUT 36 INCHES FROM SIDE WALL

(TEST NO. 4)

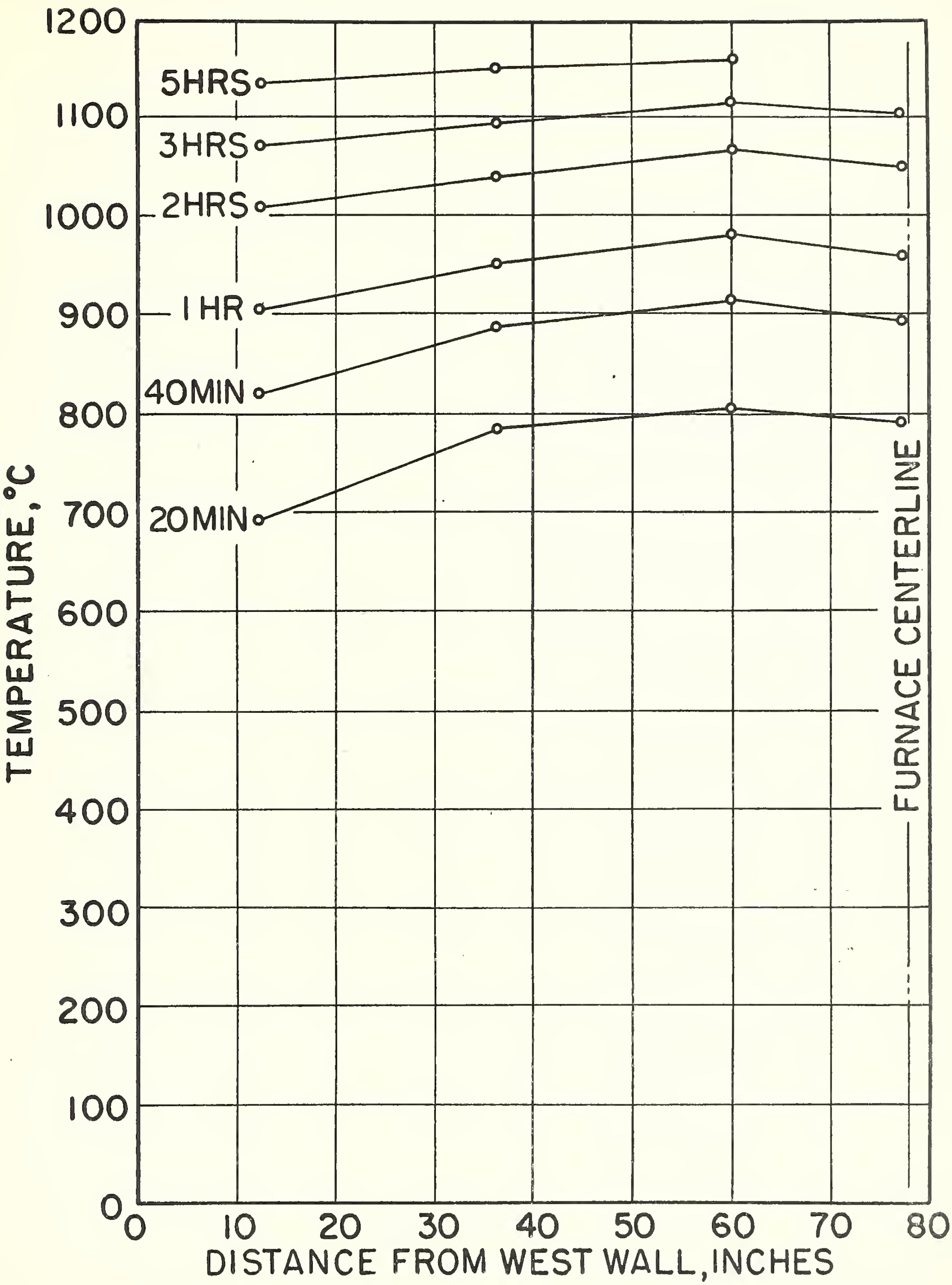


FIG. 4 - TEMPERATURE DISTRIBUTION
54 INCHES ABOVE FLOOR
(TEST NO. 2)

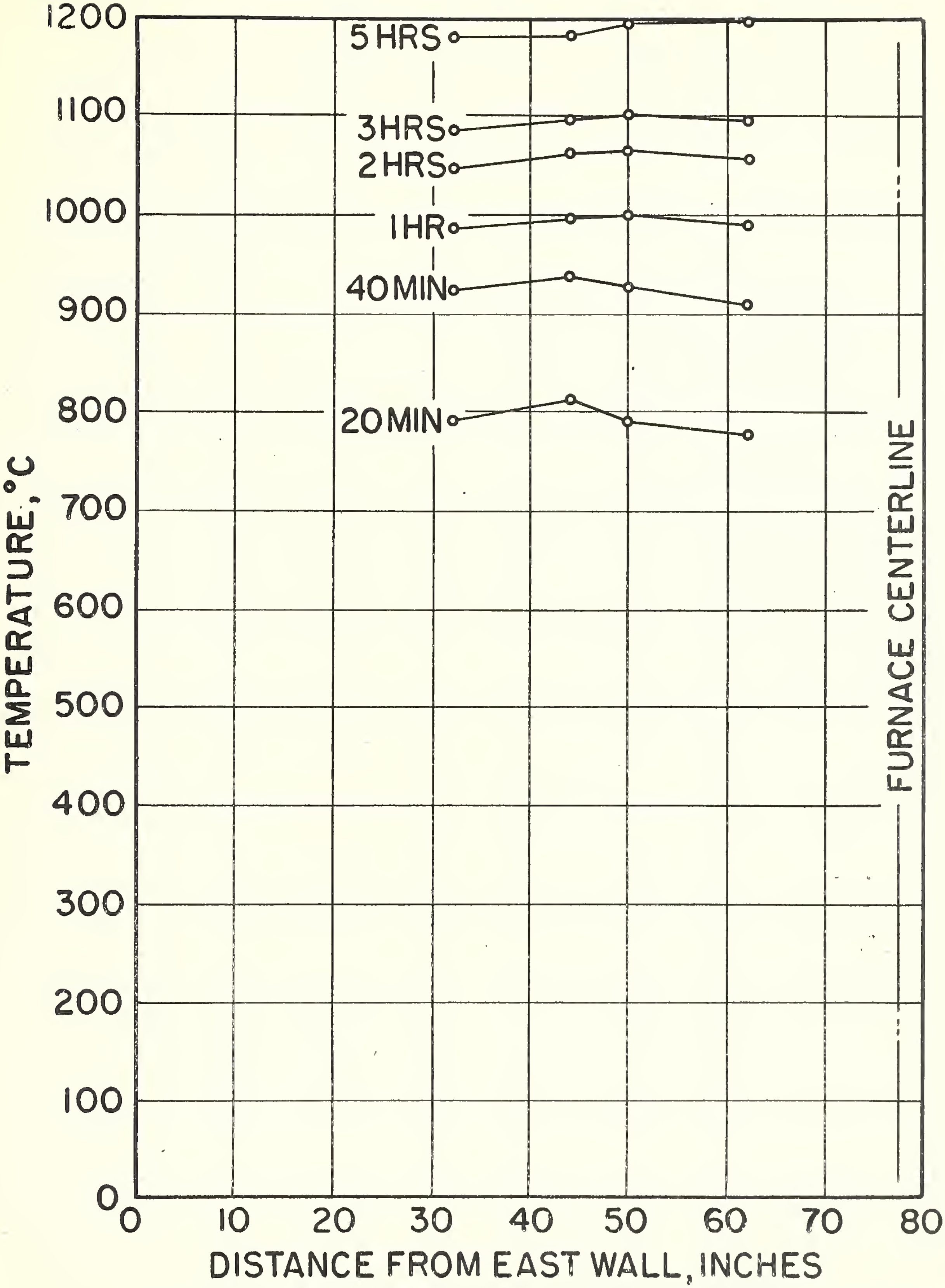


FIG. 5 - TEMPERATURE DISTRIBUTION 54 INCHES ABOVE FLOOR

(TEST NO. 4)

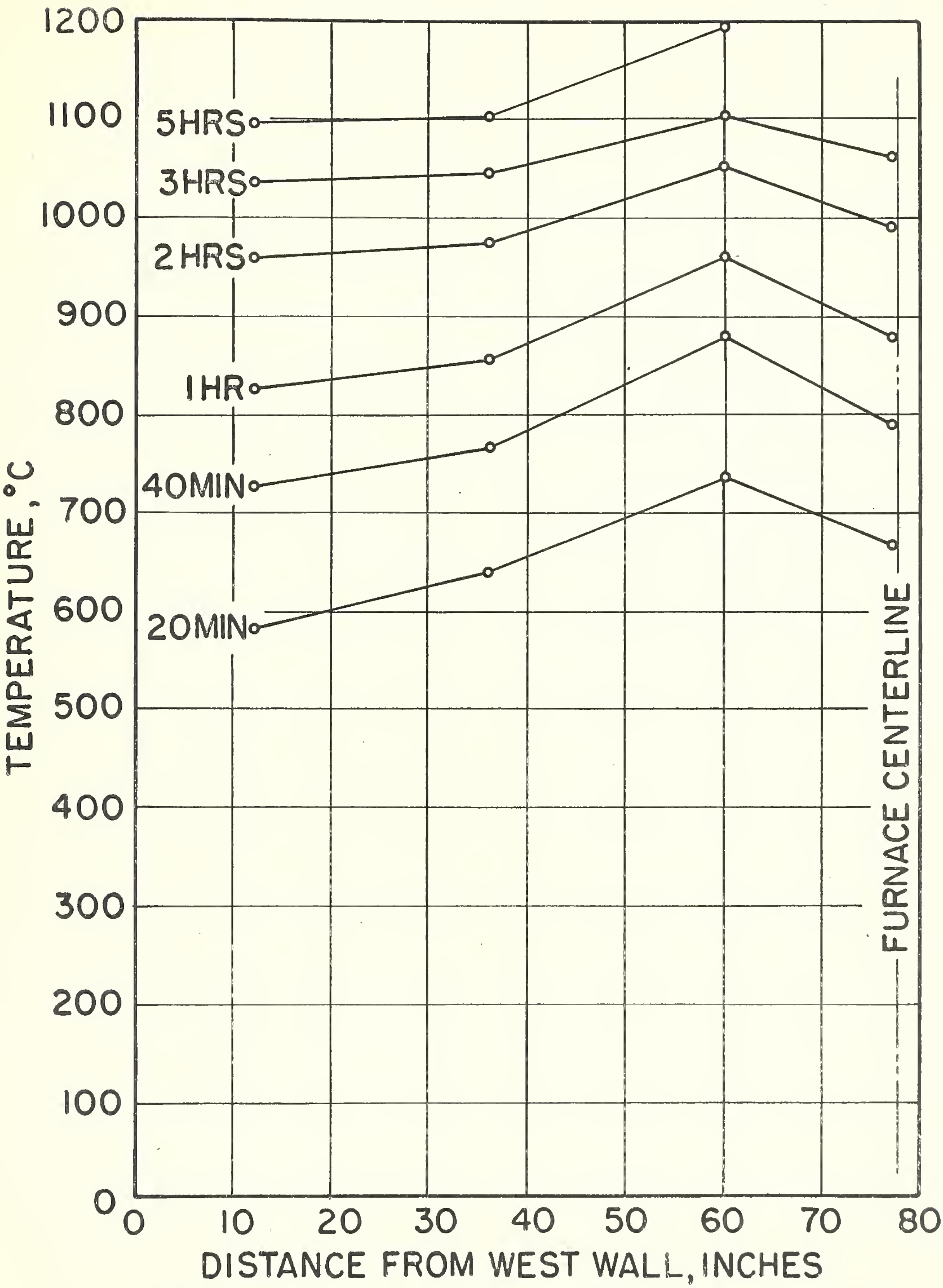


FIG. 6 – TEMPERATURE DISTRIBUTION 36 INCHES ABOVE FLOOR

(TEST NO. 2)

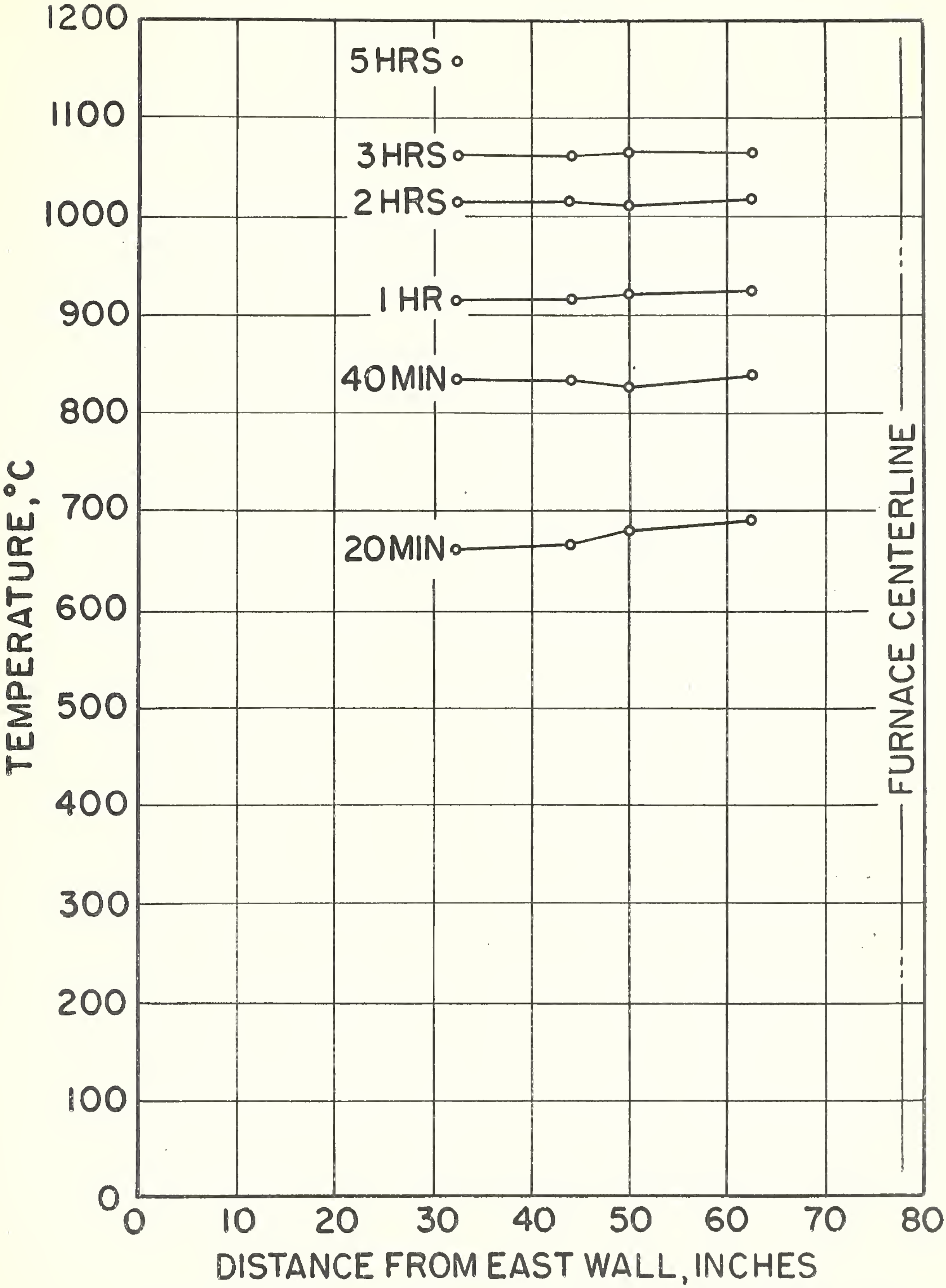


FIG. 7 - TEMPERATURE DISTRIBUTION 36 INCHES ABOVE FLOOR

(TEST NO. 4)

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