THE DESIGN AND PERFORMANCE OF A HEATING AND VENTILATING SYSTEM FOR THE BUTLER UNIVERSITY FIELD HOUSE

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By

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PREFACE.

Not many years ago the heating of any public room by recirculating even a small proportion of the air was looked upon with horror by most ventilating engineers and health authorities. Today public buildings are being heated and even ventilated by recirculating an increasingly greater amount of the air in the rooms.

The trend of modern ventilating practise is away from the old theory of thirty cubic feet of outside air per minute per person to the new idea that real ventilation is secured by controlling four factors,-TEMPERATURE, HUMIDITY, MOTION, REMOVAL OF ODORS. This new idea is based upon actual experiment and practical observations. It is rapidly being learned that these four factors can be dontrolled more easily to provide real ventilation by recirculating the air than by pumping in and conditioning large volumes of outside air.

For the past twenty years Mr. E. K. Campbell, president of the E. K. Campbell Heating Company, has advanced this idea and has successfully practised the heating and VENTILATING of public buildings by total recirculation, with the intermittent admission of outside air for temperature control and the removal of odors, only. This practise has been extensive over the entire middle and central west extending far north and south, and includes many of the finest public buildings in that territory.

Practical observations and repeated statements from occupants of these buildings that are heated and ventilated by total recirculation indicate without question that they are nearly perfectly ventilated according to modern standards and according to that standard of ventilation- the sense of comfort. Statements such as the following, from those who occupy the rooms in which air is totally recirculated but kept at the right temperature, humidity, and motion, are frequent, - "The sense of freshness in the air even when the church is crowded can be noted by anyone.", "The air always tastes good and smells good.", "The heat in the winter time is never stifling.", "It gives a refreshing heat."

Aside from the sensations of comfort and freshness, however, it is not the purpose of this paper to tell that which no one knows-- what qualities of the air or what elements in the air are the most beneficial,- but its purpose is to demonstrate how simple many of the problems of the heating and ventilating engineer become when recirculation is employed to produce these sensations of comfort and freshness.

This will be demonstrated by following thru the actual design of the heating and ventilating equipment in one of the largest auditoriums in the country, which seemingly would present the most difficult problems, and then in observing by test the performance of this equipment under actual operating conditions.

The building is the Butler University Field House, Indianapolis, Indiana, illustrated in figures 1 and 2, pages 6 and 7. It has a seating capacity of approximately fifteen thousand people. It was designed by Mr. Fermor Spencer Cannon, architect, and was erected under the supervision of Mr. Harry Phillip Bartlett, architect. The heating and ventilating system was designed and installed by the E. K. Campbell Heating Company. As engineer for this company, the writer was in charge of the design and installation of the equipment, and conducted the performance tests described in this paper.

John M. Robertson.

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PART 1. - DESIGN OF THE EQUIPMENT.

In the design of heating and ventilating equipment for a building such as the Butler University Field House, Figure 2, page 7, the engineer is faced with problems that might seem very difficult. Chief of these are, the problem of distributing the temperature evenly over so large an area, that of bringing the lighter warm air down from the high ceiling to the floor, and that of heating quickly the large volume of air and materials in the building since it is to be used only intermittently.

These problems, however, are very simple to the engineer familiar with recirculation in large volume. To him it is known that any size or shaped room may be heated evenly and quickly from one air inlet and one outlet if the air is circulated in sufficient volume. It is also known that the location of the one warm air inlet and the one cold air outlet in order to obtain even distribution of temperature, is immaterial except that the cold air outlet must be at the lowest level in the room, and that there must be no projection or object that might deflect the natural movement of the air.

The force of gravity combined with the opposite action of the fans that are used to cifculate the air make this phenomenon possible. Warm air is light. As soon as it is introduced into a room it rises to the ceiling. If it is pumped into the room in sufficient volumes it will cover the ceiling almost immediately. If the heavier cold air is pulled from the floors in the same volume, the warm air is pulled down to take its place. If this circulation is induced in sufficient volume the warm air will reach every corner of the room and will be pulled to the floor before its temperature has dropped below the degree of comfort.

Recirculation consists of drawing the cold air from the floors, passing it over heaters, moisteners, and any other conditioning equipment, then delivering it back to the rooms.

Thus, if the warm air inlet is located at a higher level than the heads of occupants of the room, the distribution will be above the heads, without drafts, and all distributing ducts or pipes within each room may be eliminated. The movement of air back to the cold air opening can be kept below a point that is perceptible by proportioning the size of the openings so the velocity will be low, or in the case of rooms of large size, by dividing the opening into several at different points.

With these facts in mind, the procedure in designing the heating and ventilating equipment for the Butler Field House is simple. For convenience this procedure is divided into three headings, Heat requirement, Air Movement, and Arrangement of Equipment.

HEAT REQUIREMENT.

For use as an athletic building, a temperature of 60 degrees F. was deemed most desirable for players and for spectators. The calculation of the heat required to provide a temperature of 60 degrees F. in zero weather is shown on Calculation Sheet No. 1, page 11. The temperature at various levels is taken in the calculation at exact temperatures that were found by tests described in Par 2 to exist. In fact the entire calculation of heat requirements is made to correspond with data obtained during the test, so far as is possible.

The factors of heat conductivity thru the various building materials, with the exception of the roof, are the average of various authorities which were compiled by Wm. R. Jones, Supt. Department of Buildings and Grounds, University of Pennsylvania, and repored in the Heating and Ventilating Magazine, October to December 1918 and January 1919. The heat conductivity factor for the roof was estimated. The roof consists of a "Truscon I-Plate" steel deck, 1 inch thick "Fibro-felt" insulation and 5-Ply "Johns-Manville" smooth surface roofing. The U. S. Bureau of Standards by test has determined the factor for 1 inch thick "Fibro-felt" as .32 B.T.U. per square foot per degree difference in temperature. Adding the value of the roofing and steel deck the factor of .27 B.T.U. for the heat conductivity of the entire roof wasarrived at.

Because of the tremendous weight of steel and concrete

Calculation Sheet No. 1.

Heat Loss Per Hour.

Glass above 50' level - 8990# x 1.1 B.T.U. x 70°	692,230 B.T.U.
Glass below 50' level - 6943# x 1.1 x 60°	458,238 B.T.U.
8" Brick wall above 50' level - 6342# x .42 x 70°	186,455 B.T.U.
12" Brick wall below 50' level - 14,166# x .32 x 60°	271,987 B.T.U.
16" Brick wall below 50' level - 20,102# x .26 x 60°	313,591 B.T.U.
20" Brick wall below 50' level - 3256# x .23 x 60°	44,933 B.T.U.
Roof - 1" Fibrofelt - 5 Ply Asbestos - 77,992# x .27 B.T.U. x 70°	1,474,048 B.T.U.
4" Cement floor - 28,258# x .38 B.T.U. x 15°	131,391 B.T.U.
Moist earth floor - 33,400# x .35 x 15°	175,560 B.T.U.
Wood floor with sleeper on earth - 6400# x .13 x 15°	12,480 B.T.U.
Leakage - 4,573,906 cu. ft. x .9896* x .019 B.T.U. x 60° x 1/4 change/hr.	1,290,006 B.T.U.
Total heat loss for Field House Main Room	5,050,919 B.T.U.
Glass in Gym. - 792# x 1.1 B.T.U. x 60°	52,272 B.T.U.
12" Brick in Gym. - 5368# x .32 x 60°	103,065 B.T.U.
Roof on Gym. - 12,000# x .27 x 65°	210,600 B.T.U.
Floor in Gym. - 12,000# wood on earth x .13 B.T.U. x 15°	23,400 B.T.U.
Leakage-Gym. - 384,000 cu. ft. x .9896* x .019 B.T.U. x 60° x 1/4	108,301 B.T.U.
Total Heat Loss for Gymnasium	497,639 B.T.U.
Glass in Pool - 1056# x 1.1 B.T.U. x 60°	69,696 B.T.U.
12" Brick wall in pool - 3474# x .32 B.T.U. x 60°	66,701 B.T.U.
Roof on Pool - 6000# x .27 x 65°	105,300 B.T.U.
Leakage - 192 000 cu. ft. x .9896* x .019 B.T.U. x 60° x 1/4 change	54,150 B.T.U.
Total Heat Loss for Swimming Pool	295,847 B.T.U.
Total Heat Loss for Building per Hour	5,844,405 B.T.U.

Heat Absorbed By Materials In Building.

Steel Roof deck above 50' level - 300,000 lbs. x .11 B.T.U. x 40°	1,320,000 B.T.U.
Steel Roof trusses above 50' level - 1,200,000 lbs. x .11 x 40°	5,280,000 B.T.U.
Steel roof trusses below 50' level - 464,000 lbs. x .11 x 30°	1,531,200 B.T.U.
Steel balcony trusses - 972,000 lbs. x .11 x 30°	3,207,600 B.T.U.
Gaurd rails & misc. steel - 60,000 lbs. x .11 x 30°	198,000 B.T.U.
Concrete in balconies & ramps - 4,484,660 lbs. x .21 B.T.U. x 30°	28,253 000 B.T.U.
Inside tile partitions - 620,000 lbs. x .195 B.T.U. x 30°	3,627 000 B.T.U.
Air in building - 5,149,906 cu. ft. x .9896* x .019 B.T.U. x 30°	2,904,880 B.T.U.
Ice melted & evaporated (.000917 lbs. x 38% r.h. - .000441 lbs. x 48% r.h.) x 5,149,906 x .9896* x (14 B.T.U. + 33 B.T.U. + 971.7)	809,144 B.T.U.
Total heat absorbed by materials in building	47,130,824 B.T.U.

Heat Required For 12 Hours - 0° Outside - 33° To 63° Inside.

Heat loss first hour - 5,844,405 ÷ 2	2,922,202 B.T.U.
Heat loss second hour - 5,844,405 x .7	4,091,085 B.T.U.
Heat loss third hour - 5,844,405 x .9	5,259,965 B.T.U.
Heat loss third to twelvth hours - 5,844,405 x 9	52,599,645 B.T.U.
Heat to raise temperature of materials inside 30°	47,130,824 B.T.U.
Total heat required for 12 hours	112,003,721 B.T.U.
Average heat required per hour	9,333,560 B.T.U.

*.9896 is correction factor for barometric pressure during test 2/1/29.

within the space to be heated, it is essential that the heat required to raise its temperature along with thatof the air be included. All concrete and steel materials are of thin members suspended in the air in such manner that a large surface of thin materials is in contact with the air that is circulated. During the test of the heating plant it was found that the temperature of the steel within the building rose approximately 3 degrees slower than the temperature of the air during the heating up period and that it dropped three degrees slower than the air when the fires were checked and the room allowed to cool. A calculation of the heat required to raise the temperature of the materials inside the building, but not including any outside walls, is shown on Calculation Sheet No. 1.

After calculating the heat required, the equipment to generate this heat was selected. For intermittent heating, direct fired furnaces are more efficient and quicker than steam coils. Furnaces manufactured by the E. K. Campbell Heating Company, because of their compactness, ruggedness of construction, and high efficiency, were selected. In order to keep down the number of fires three of the largest available units were used. This unit is illustrated in Figure 3, page 13, and its dimensions and capacities are given in Figure 4, page 14. Particular notice should be taken of the secondary heating surface or economizer in connection with the heater, and of the down draft arrangement for the smoke outlet. The large amount of second-

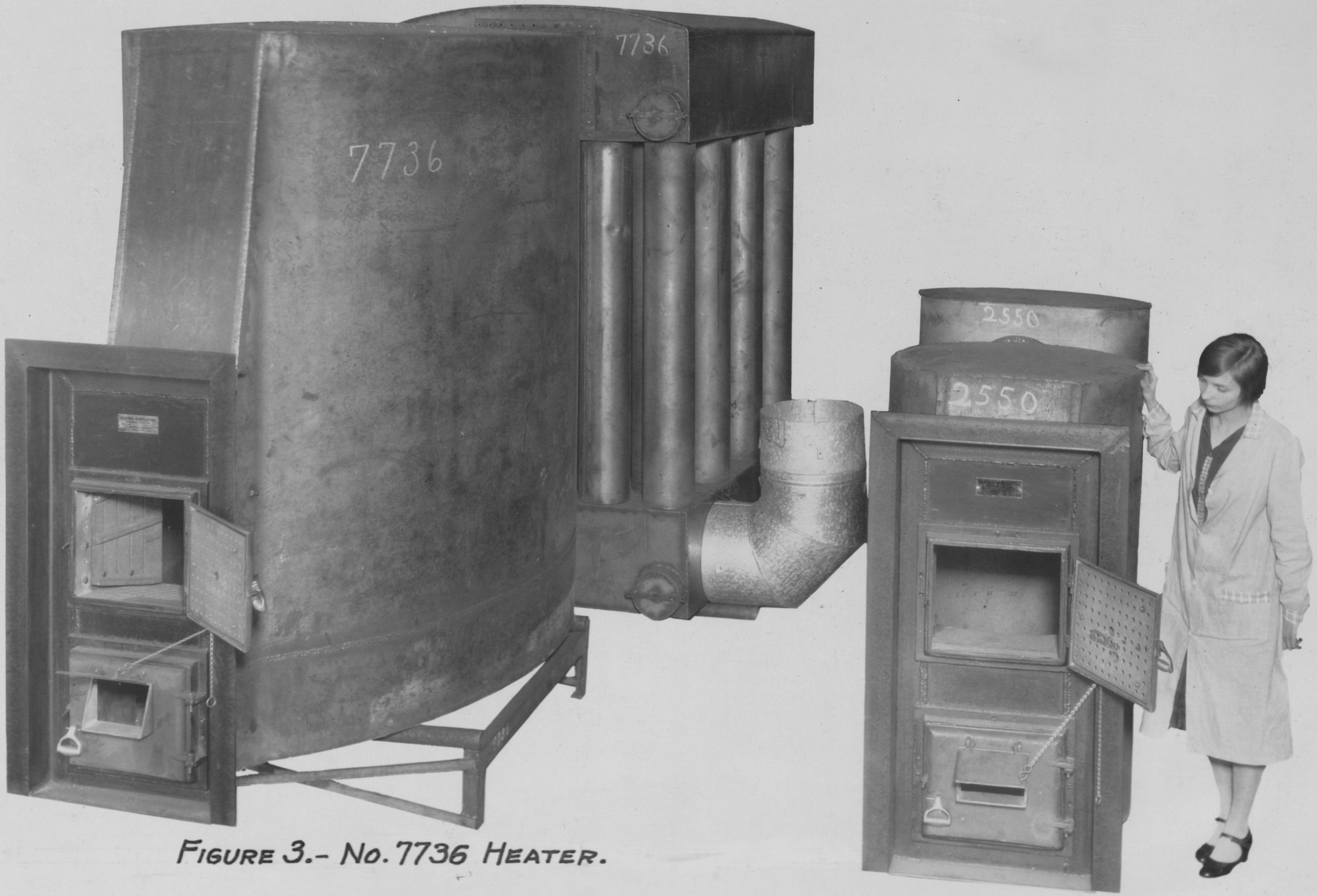
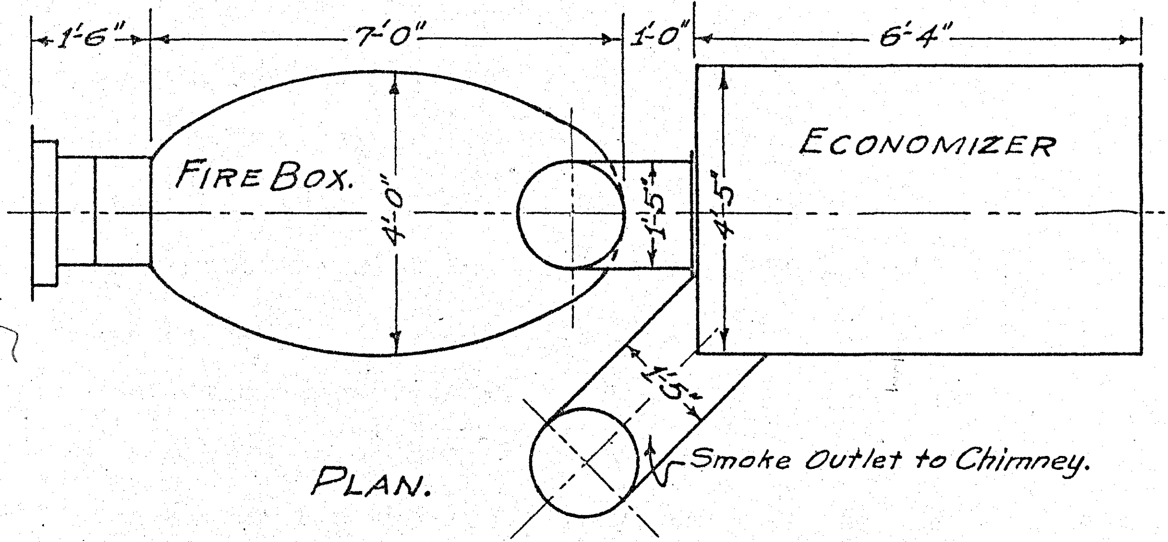
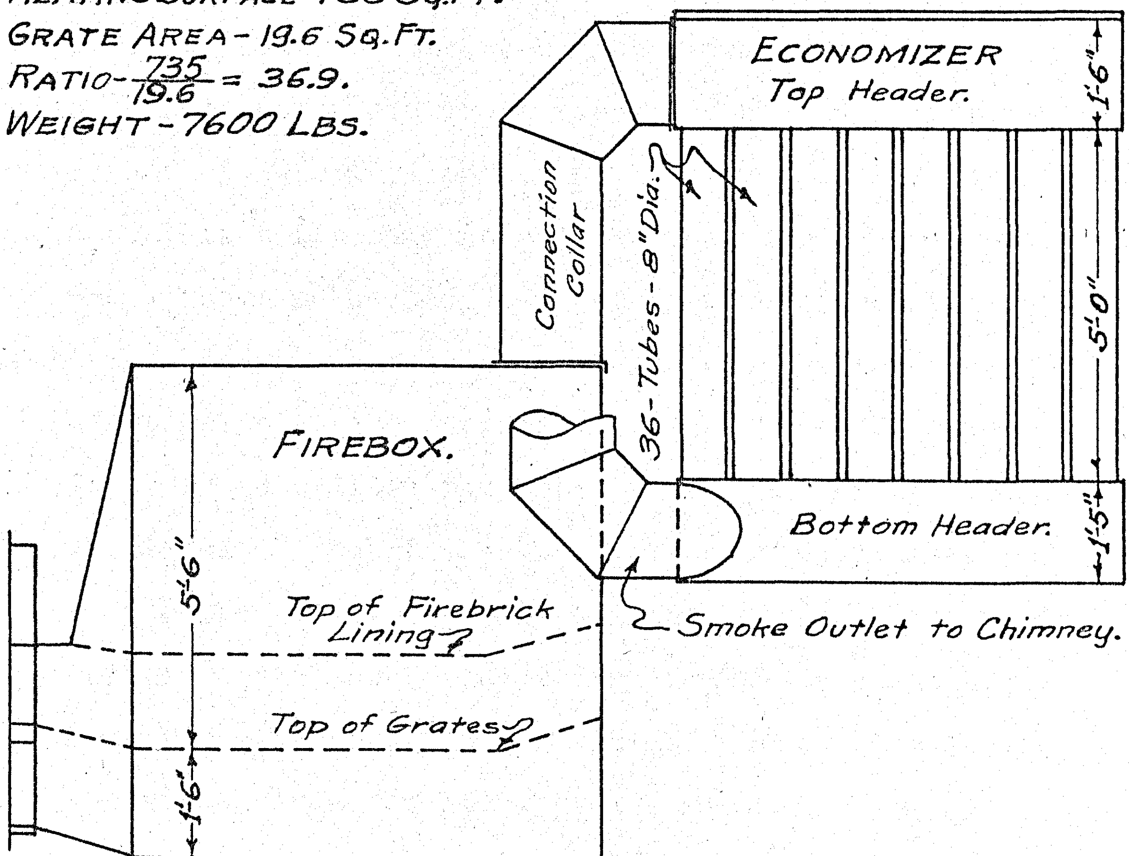


FIGURE 3.- NO. 7736 HEATER.



PLAN.

CAPACITY-3,000,000 B.T.U./HOUR.
HEATING SURFACE-735 SQ.FT.
GRATE AREA-19.6 SQ.FT.
RATIO-$\frac{735}{19.6}$ = 36.9.
WEIGHT-7600 LBS.



ELEVATION.

FIGURE 4 .- DETAIL OF HEATERS.
Scale-3/8"=1'-0"

ary heating surface and the arrangement of the smoke travel are responsible mainly for the high efficiencies obtained with these heaters during the tests described later.

In connection with the heating installation it was necessary to provide for the heating of 12,000 gallons of water per hour from 40 degrees F. to 80 degrees F. for the swimming pool, and 1875 gallons of water per hour from 40 degrees to 80 degrees for the showers and lavatories. For this purpose a No. 127 Heggie-Simplex boiler was selected. Steam from this boiler was used to heat the three main entrances to the Field House, four toilets, one locker room, and two office rooms. These rooms are remote from the heating plant and more easily and effeciently reached with steam pipes and radiators. No account is taken in this calculation, nor in the tests, of the small rooms so heated, since they have no bearing on the problems involved in this paper. Account is taken, however, of the boiler with its economizer in the heater room.

In order to utilize the waste heat from the steam boiler, it was placed in the plenum chamber with the furnaces and the smoke from the boiler was passed thru the economizer in the same chamber, the economizer being similar in construction to those on the furnaces. It was estimated that in mild weather the waste heat from the steam boiler while it was in use to heat the swimming pool and service water, the offices, toilets and locker rooms, would be sufficient to heat the swimming pool room and the gymnasium room.

AIR MOVEMENT.

It has been determined by experience that in order to distribute the temperature evenly in a large room from one point, one complete recirculation of the air should be accomplished each ten minutes. Fans with a rated capacity sufficient to provide this change of air were selected but in the actual test they produced a change of air each fifteen minutes, only. The fifteen minute change proved to be sufficient in this particular case because of the compact shape of the rooms and because of the extremely large air content in the rooms in proportion to the heat losses.

The usual practise in auditoriums where recirculation is employed is to provide a velocity of 600 feet per minute for the air in the ducts and a velocity of 400 feet per minute at the openings. With these low velocities and with low pressures in the ducts noise due to the rush of air is eliminated and drafts near the cold air openings are not perceptible. In the case of the Butler Field House, because of the volume of air to be handled and the resultant duct sizes a velocity of 1,000 feet per minute in the ducts was figured. However, the entire length of air travel from the cold air openings to the warm air openings was made of sufficient area and size that the velocity would not exceed 1,000 feet per minute at any point.

Since the ductwork was made comparatively short and all ducts were large a pressure within the ducts not exceeding .25

inch of water prevailed and it was possible to use a low pressure type of fan with a resultant large saving in cost of power to operate it. With the volume of air that must be moved, the cost of power to move it was a real consideration.

Because of its characterisic of large air delivery at low pressure with a minimum power requirement, a modified cone type of fan manufactured by the Parker Fan and Machine Works, was selected. A cut of the fan blades used at the Field House is shown in Figure 5, page 18, while a view of the complete fan assembly in the fan room is shown in Figure 6, page 19.

Again it was desirable to keep down the number of fans, yet the height of the furnaces and the space in the fan room limited the size of each unit. Four fans with blades ten feet in diameter were selected. The tested capacity of each fan at .25 inch pressure and 150 R.P.M. in actual operation at the Butler Field House is 85,443 cubic feet of air per minute. Each fan is driven by a 10 H. P., 1200 R. P. M. Century Electric Company Automatic Start Induction Three Phase Motor, belted to the fan with an endless leather belt.

ARRANGEMENT OF EQUIPMENT.

The location of the heater room in the Butler Field House resulted from a fortunate combination of natural conditions on the building site and consideration of space available in the building for ducts of large size to reach the three rooms, from the standpoint of both economy in construction and value of space to be used. A small gully extended thru the center

FIGURE 5.- PHOTOGRAPH OF FAN BLADES.

FIGURE 5A.- VIEW IN FAN ROOM.

of the site, and opened into a deep, wide out at about the center of the north side of the main room. From this point all three rooms could be reached with a simple duct system, and being at the rear of the building, this natural excavation was squared up and formed into the heater and boiler room with a minimum cost.

With space somewhat limited in the heater room by large foundations for the roof trusses, the ducts, heaters, boiler and economizer, and fans were arranged as shown in Figure 6, page 21 and in Figure 7, page 22. The heaters were placed directly under the main warm air riser in order to benefit by the natural gravity movement of the warm air straight up from the heaters. Considerable care and ingenuity was exercised to maintain enough area thruout the system to keep the velocity of the air at all points thruout the system below 1,000 feet per minute.

In view of the high efficiencies of the heaters described later, notice should be taken that the heaters are so arranged that the cooler air direct from the fans passes over the economizer or secondary heating surface first, then over the hotter firebox.

Dampered openings from the main warm air riser to the Field House proper were placed beneath the balcony as indicated on Figure 6, page 21. Such a provision is essential to insure a circulation of air and heat beneath the balconies.

In order to permit the heating and ventilating of any

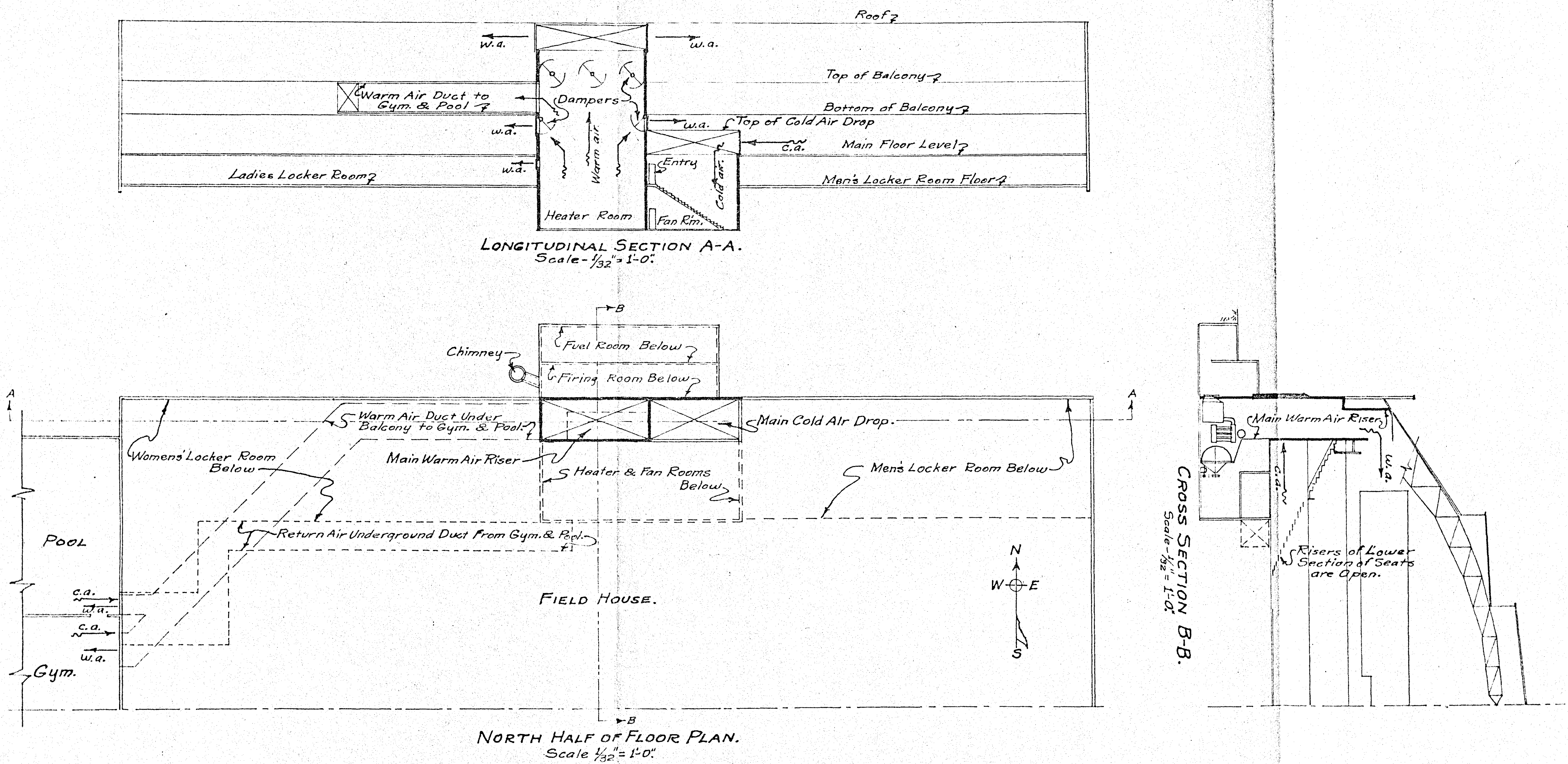


Figure 6. - Location of Heater & Fan Rooms, Ducts, Dampers & Openings.

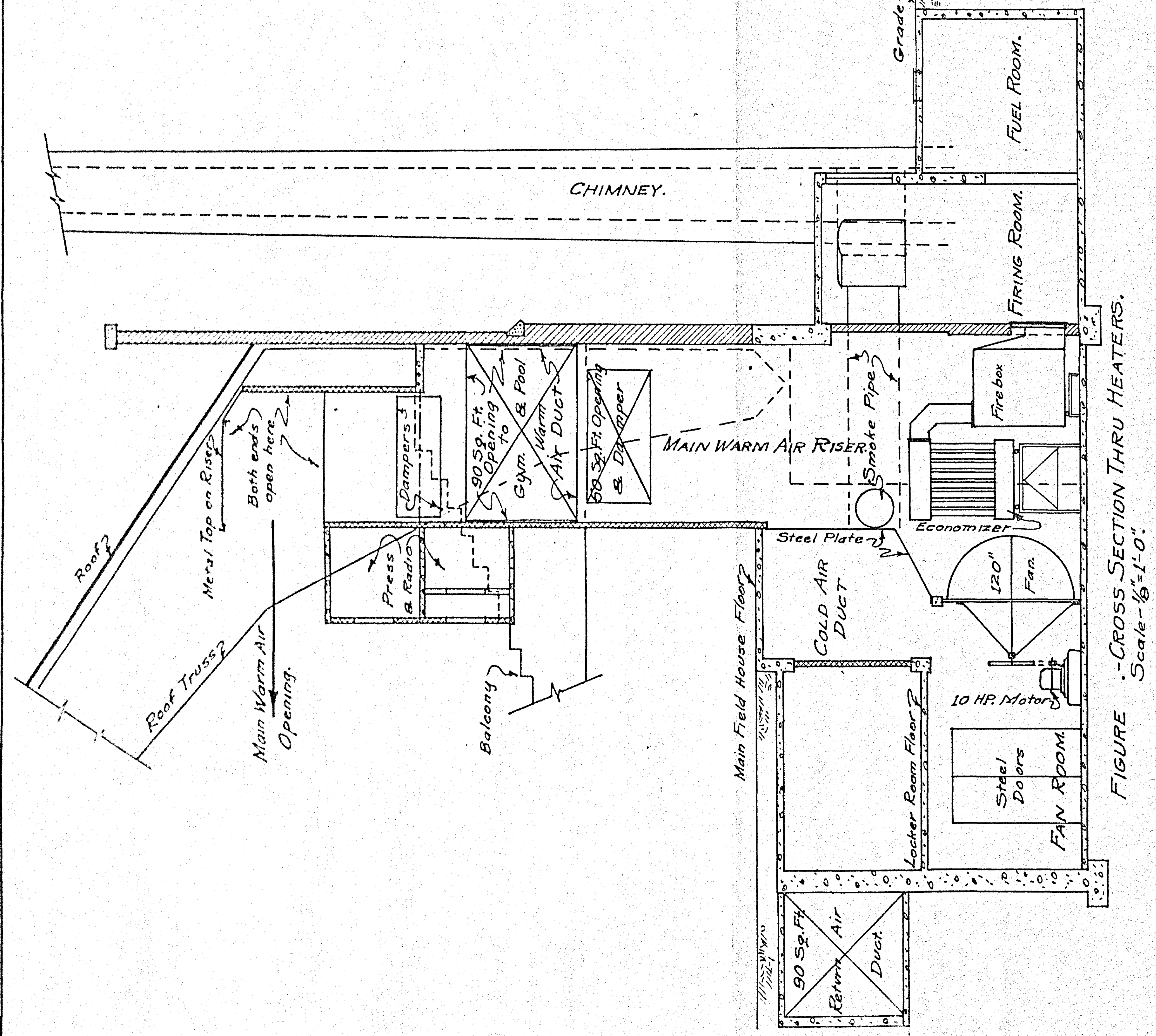


FIGURE -CROSS SECTION THRU HEATERS. Scale-1/8"=1'-0".

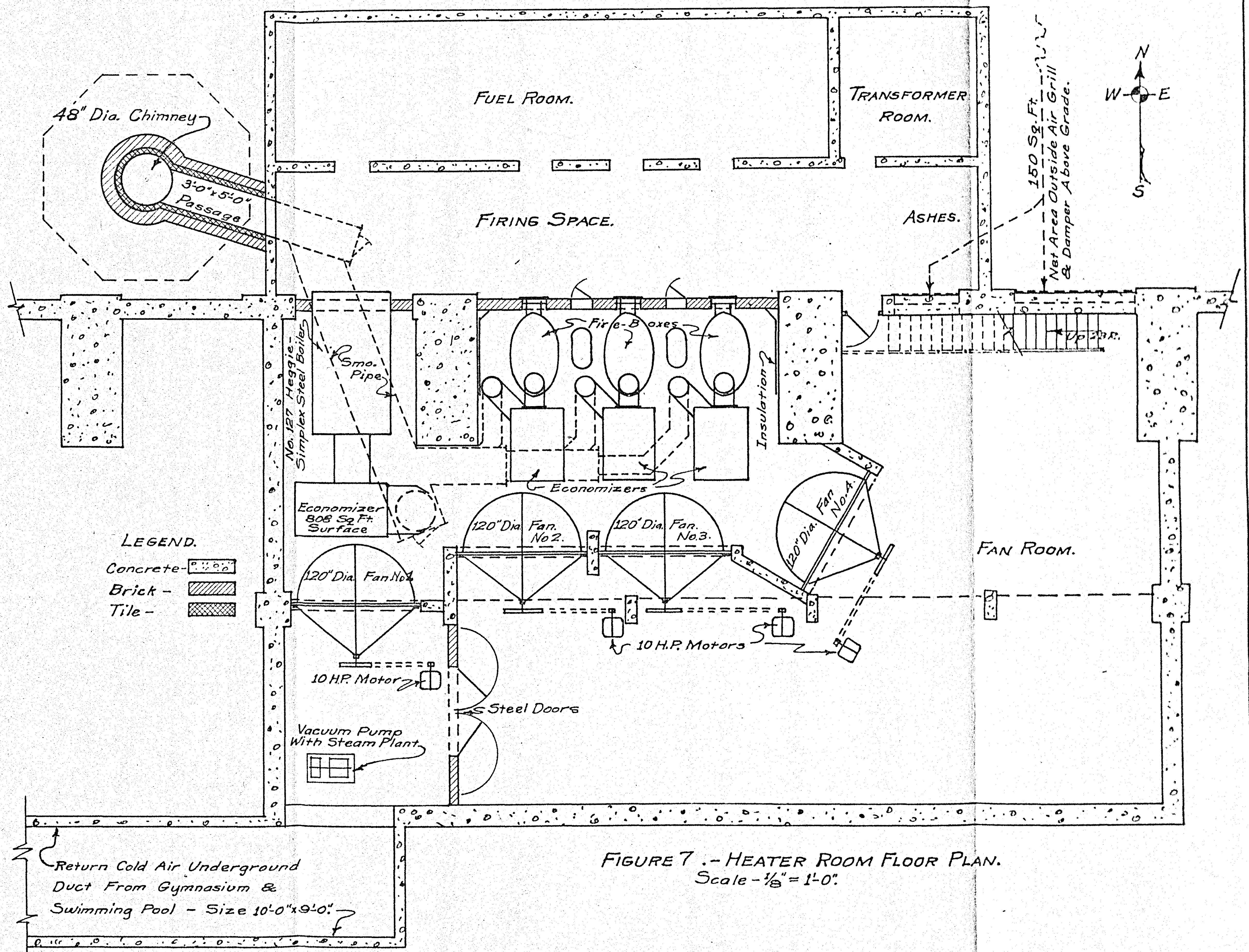


FIGURE 7. - HEATER ROOM FLOOR PLAN.
Scale - 1/8" = 1'-0".

one of the three rooms without heating others, dampers were provided at all warm air openings and between Fan No. 1 and Fan No. 2, Figure 7. This latter damper permits the circulation of air in the gymnasium and swimming pool with Fan No. 1 without drawing cold air from the Field House proper. By placing Fan No.1 directly behind the steam boiler and economizer it was contemplated that it would deliver all waste heat from the boiler to the gymnasium and pool and in mild weather this waste heat would be sufficient. In more severe weather any number of the direct fired heaters could be used.

Openings with grilles and dampers were also provided as indicated on Figure 7, page 22, for the admittance of outside air for temperature control and the removal of smoke, odors, or excessive moisture from the building.

PART 2. - PERFORMANCE TESTS.

Four performance tests were conducted on the heating and ventilating system at the Butler University Field House during the winter of 1928-1929. The first two on January 11 and January 12, 1929, were made primarily to check methods of testing, to discover unforseen obstacles, and to determine points in the warm air riser and the cold air drop that represented the average temperature of the air in these two ducts. The third test was made on January 25, 1929, but after all instruments were set up and the test commenced the Weather was not as severe as had been forecast by the Weather Bureau, so a final zero weather test of twelve hours duration was made on February 1, 1929.

This description covers the final test only, except that some results of the test on January 25, are included for comparison.

The purpose of the test is to determine how this particular installation performed in meeting the three principal problems the engineer is confronted with in designing equipment for a building of this type, namely,- Temperature Distribution, Quickness in Heating a Cold Building, and Economy of Operation or Efficiency. During the test these three results were determined simultaneously but they will be described in order.

Extreme accuracy was not attempted partly because of the limited facilities at hand, but largely because any greater accuracy than can be obtained with reasonable care and good commercial instruments, was not considered of any possible practical value. Reasonable precautions were taken thruout the test and all instruments were carefully calibrated and all readings listed herein were corrected.

TEMPERATURE DISTRIBUTION.

The tests for temperature distribution were confined to the main Field House room which is 333 feet long inside, 206 feet wide, and 85 feet high in the center. It is undoubtedly the largest single room from the standpoint of cubical contents, that has ever been heated from one point.

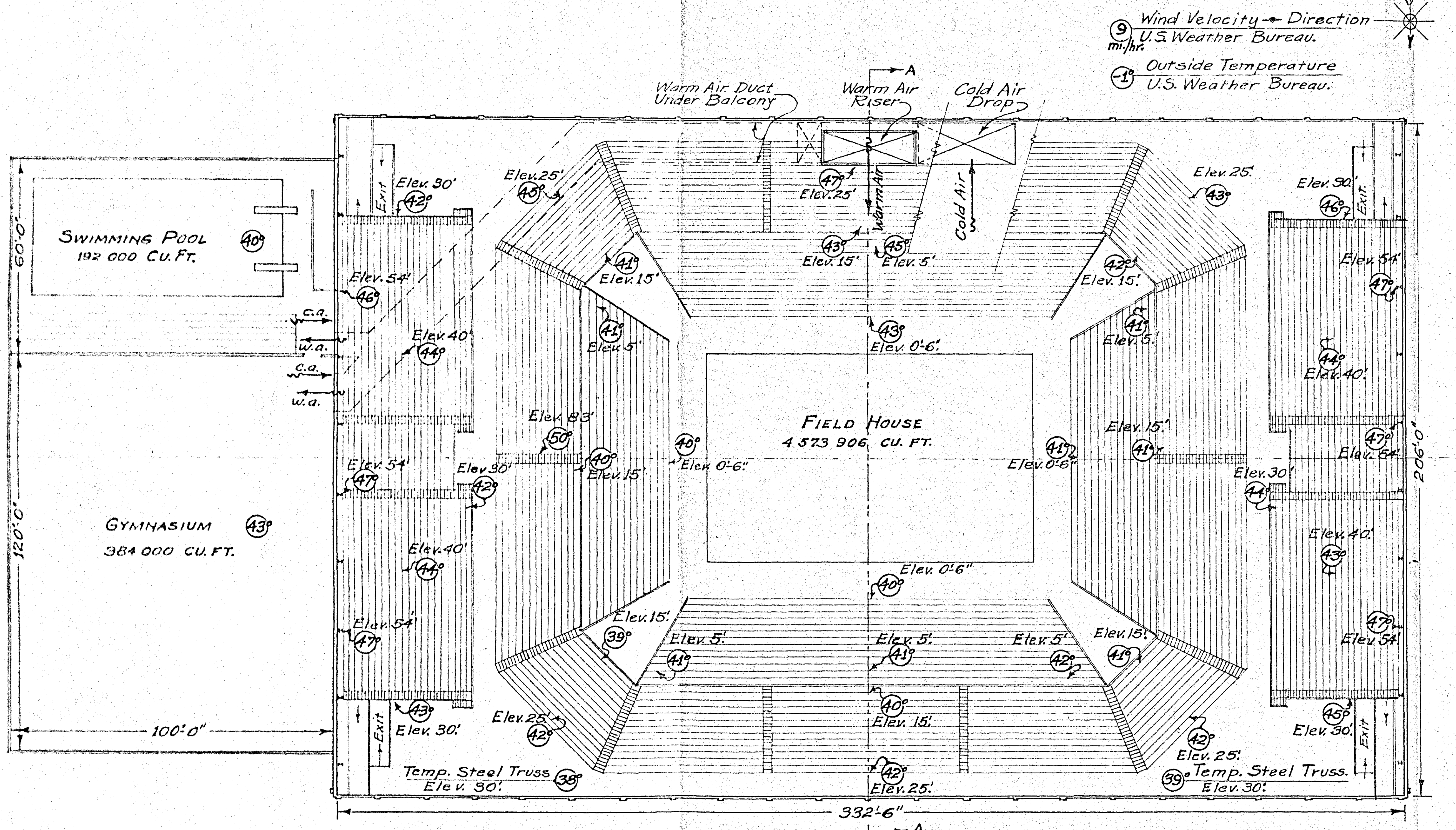
Forty room thermometers were placed in a glass case and calibrated to read within one-half of one degree of each other between the ranges of 60 degrees F. and 70 degrees F. These forty thermometers were then distributed over the room at various points and elevations as indicated on Figure 8, page 27. The point of each arrow on Figure 8 represents the location of a thermometer, while the elevation of each thermometer above the floor of the room is given in figures.

All distribution tests were made with the room vacant but thruout the time there were a number of students, employees, etc., in and out of the building, and it was found necessary to fasten the thermometers securely to the seats or to some permanent fixture in order to keep them in place or even to keep the thermometers. This accounts for the particular elevations at which they are placed, or rather at which there was something to which they could be fastened; also, it accounts for the fact that the bulb of every thermometer was within 2 inches of woodwork, concrete or steel. It was discovered, however, that the temperature of all materials in the building followed that of the air very closely as the room was heated, hence the proximity of the thermometers to any material had little if any effect on the temperature readings, other than on the four thermometers within 6 inches of the main floor of damp earth. The cooling of the air by evaporation of moisture and by the absorbtion of heat into the damp floor undoubtedly produced a cooling effect on the lower thermometers. Special care was taken that thermometers close to the outside walls were carefully insulated from the walls and protected from any infiltration or leakage thru windows or openings.

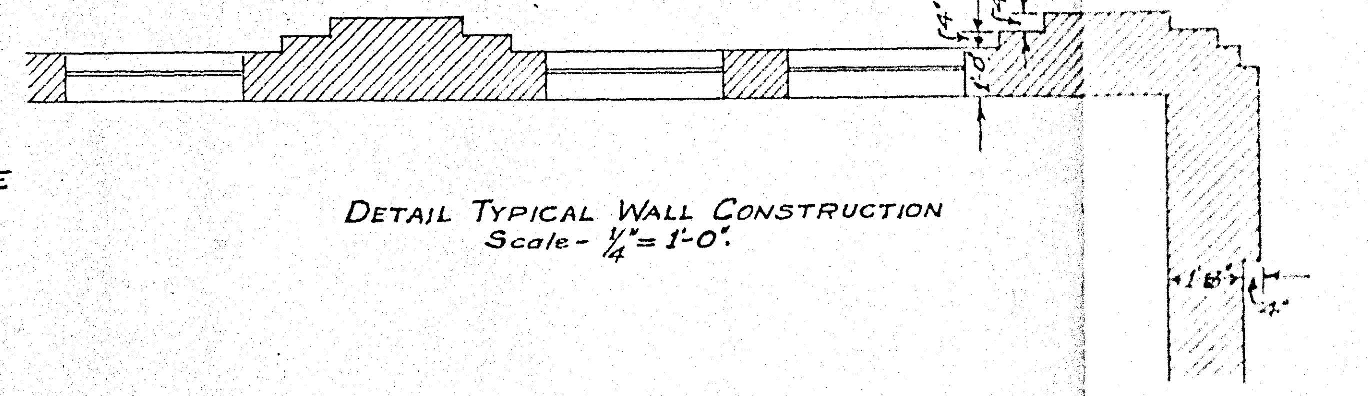
A "Bristol" Model 146 Recording Thermometer was placed 83 feet above the main floor level at the point indicated on Figure 8, page 27.

A reading was made of every thermometer at the beginning of and at intervals of one hour thereafter thruout the test and all readings were recorded. Temperatures thus recorded at each point at various time intervals are indicated on Figure 8, 9, and 10 , pages 27,28 and 29. Variations in temperatures thruout the test at each level are given on Calculation Sheet No. 2, page 32.

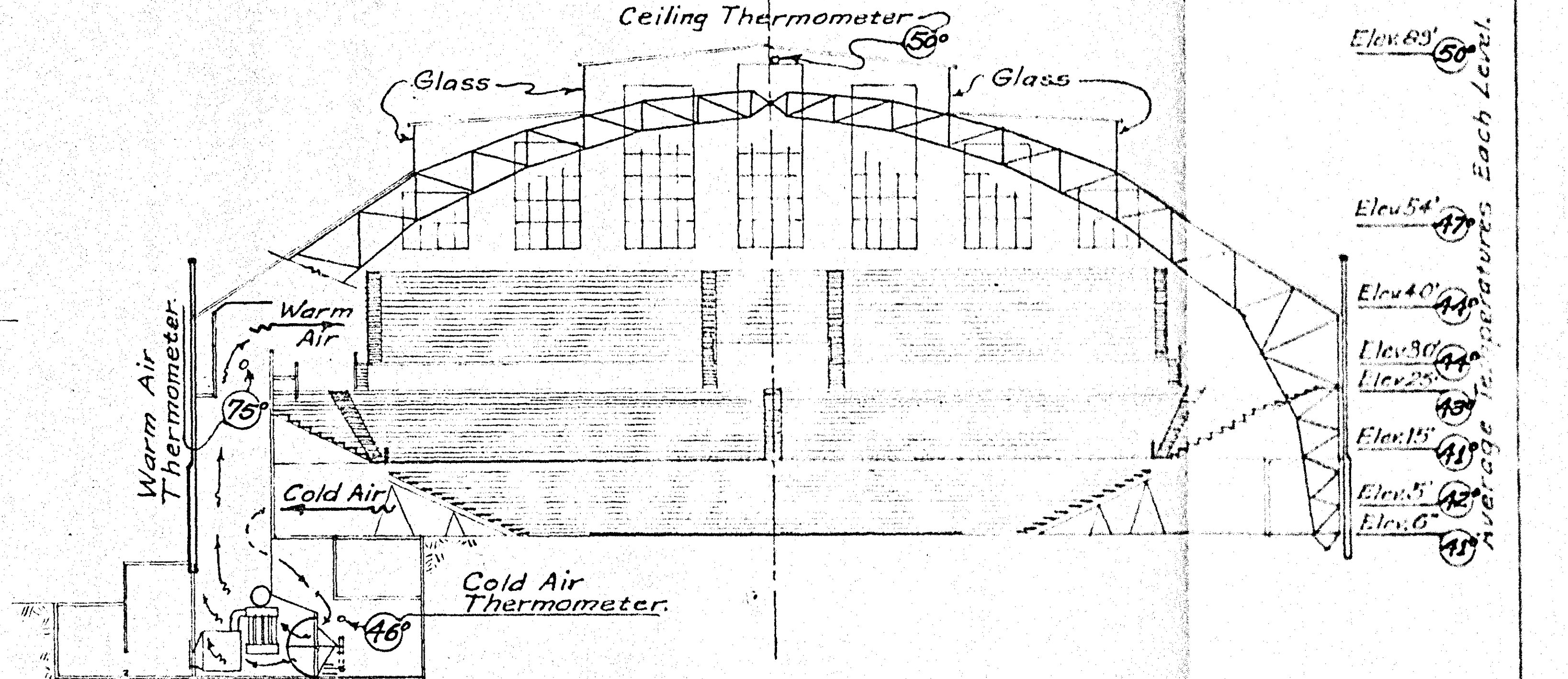
A record is also included on Figure 11, page 30, of the temperature distribution data obtained during the test on January 25, 1929. These data are interesting for comparison



Balcony Plan.
Scale - 1/32" = 1'-0".



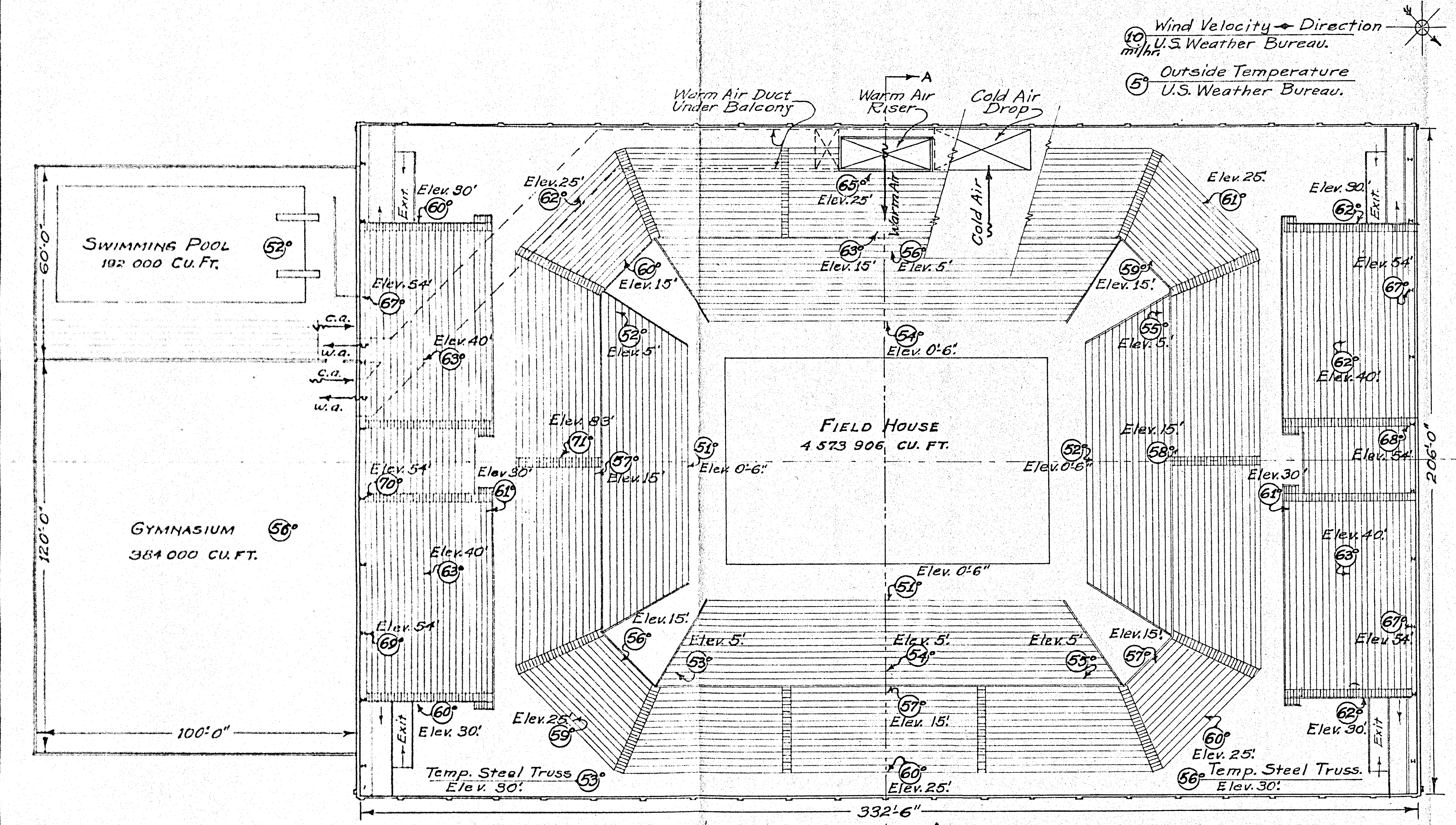
Detail Typical Wall Construction
Scale - 1/4" = 1'-0".



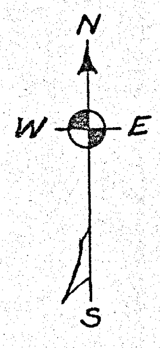
Cross Section A-A.
Scale - 1/32" = 1'-0".

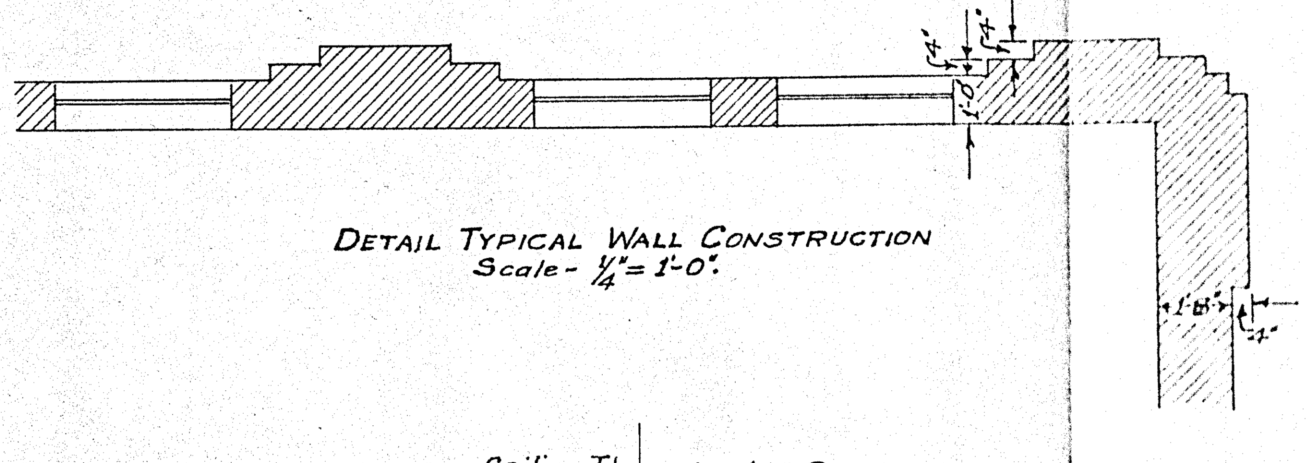
The Butler University Field House.
Indianapolis Indiana.
Efficiency & Temperature Distribution
Test of Heating Plant.

Date of Test 2/1/29. Time 9:00 AM. (1 Hour After Starting Fans.) Sky Cloudy.
Dry Bulb 46°. Wet Bulb 38°. Rel. Humidity 49 %.
Highest Temp. 50°. Lowest Temp. 39°. Average Temp. 43°.

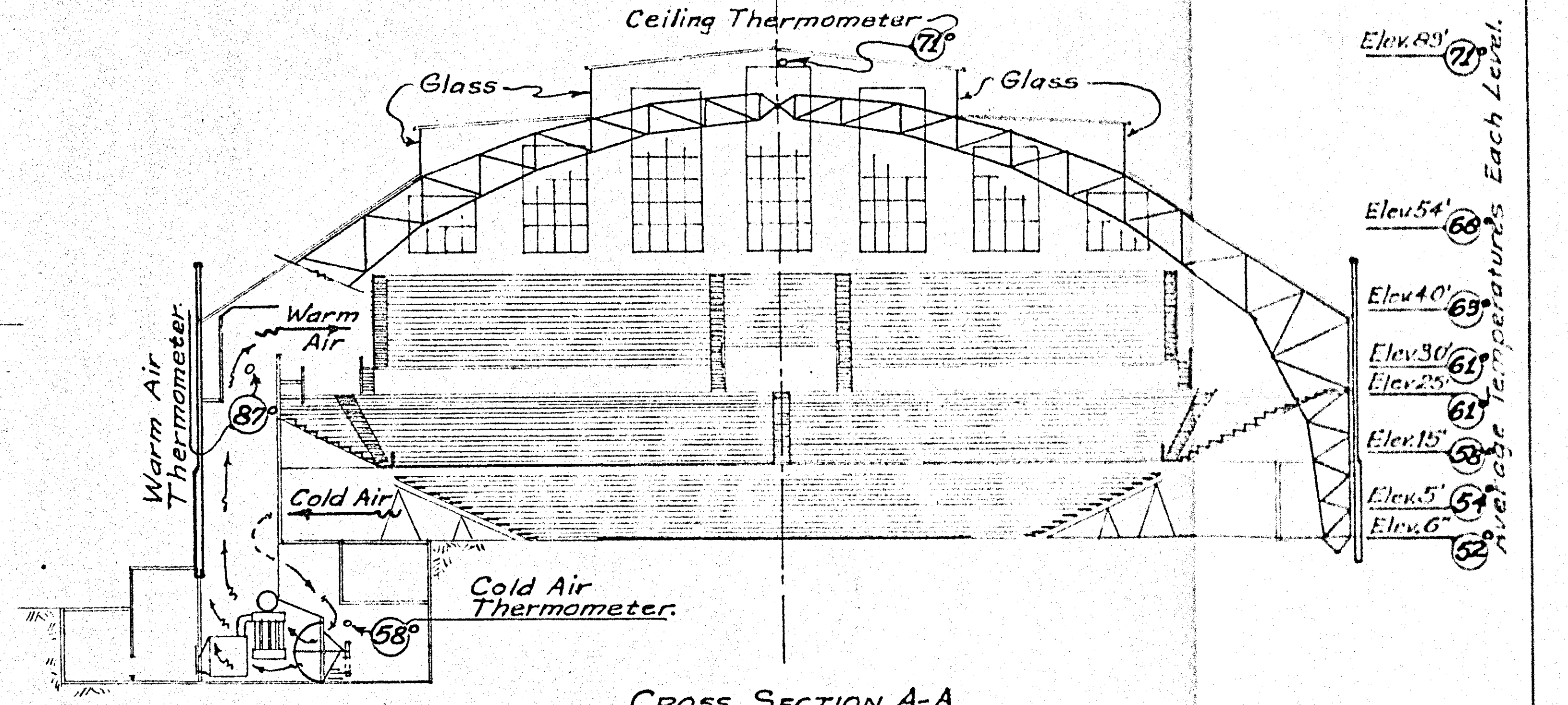


Balcony Plan.
Scale - 1/32" = 1'-0".





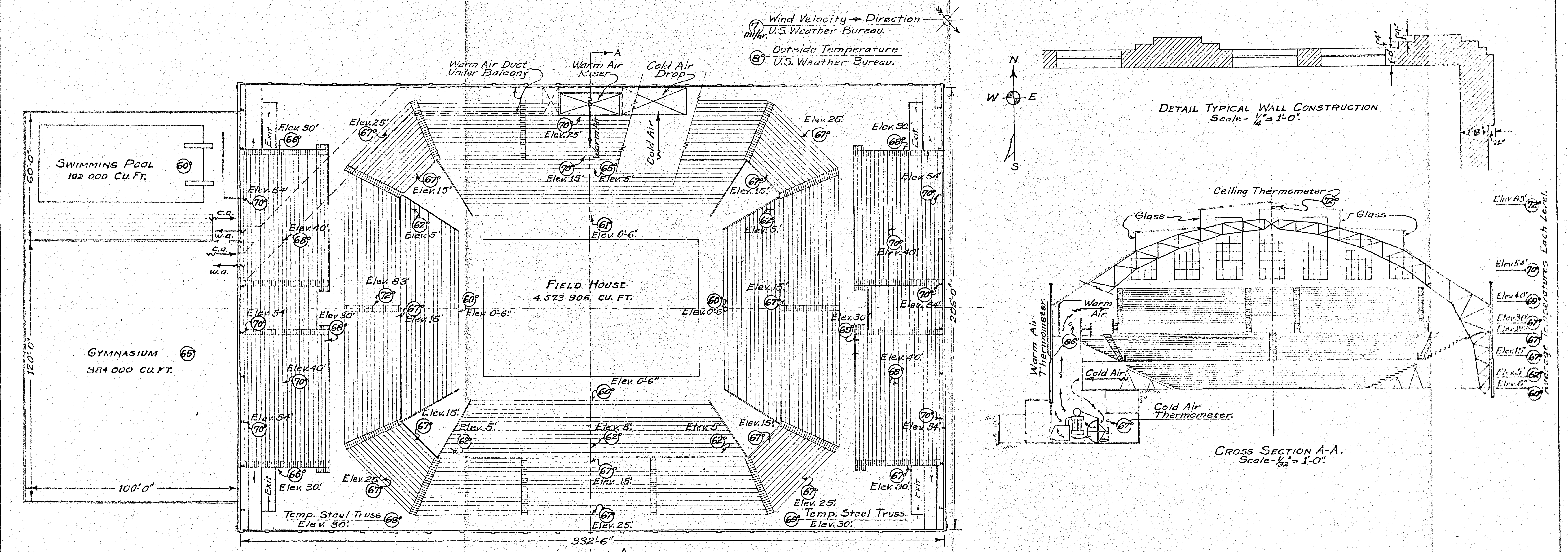
Detail Typical Wall Construction
Scale - 1/4" = 1'-0".



Cross Section A-A.
Scale - 1/32" = 1'-0".

The Butler University Field House.
Indianapolis Indiana.
Efficiency & Temperature Distribution
Test of Heating Plant.

Date of Test 2/1/29. Time 12⁰⁰M. Sky Clear.
Dry Bulb 57°. Wet Bulb 48°. Rel. Humidity 41 %.
Highest Temp. 71°. Lowest Temp. 51°. Average Temp. 60°.

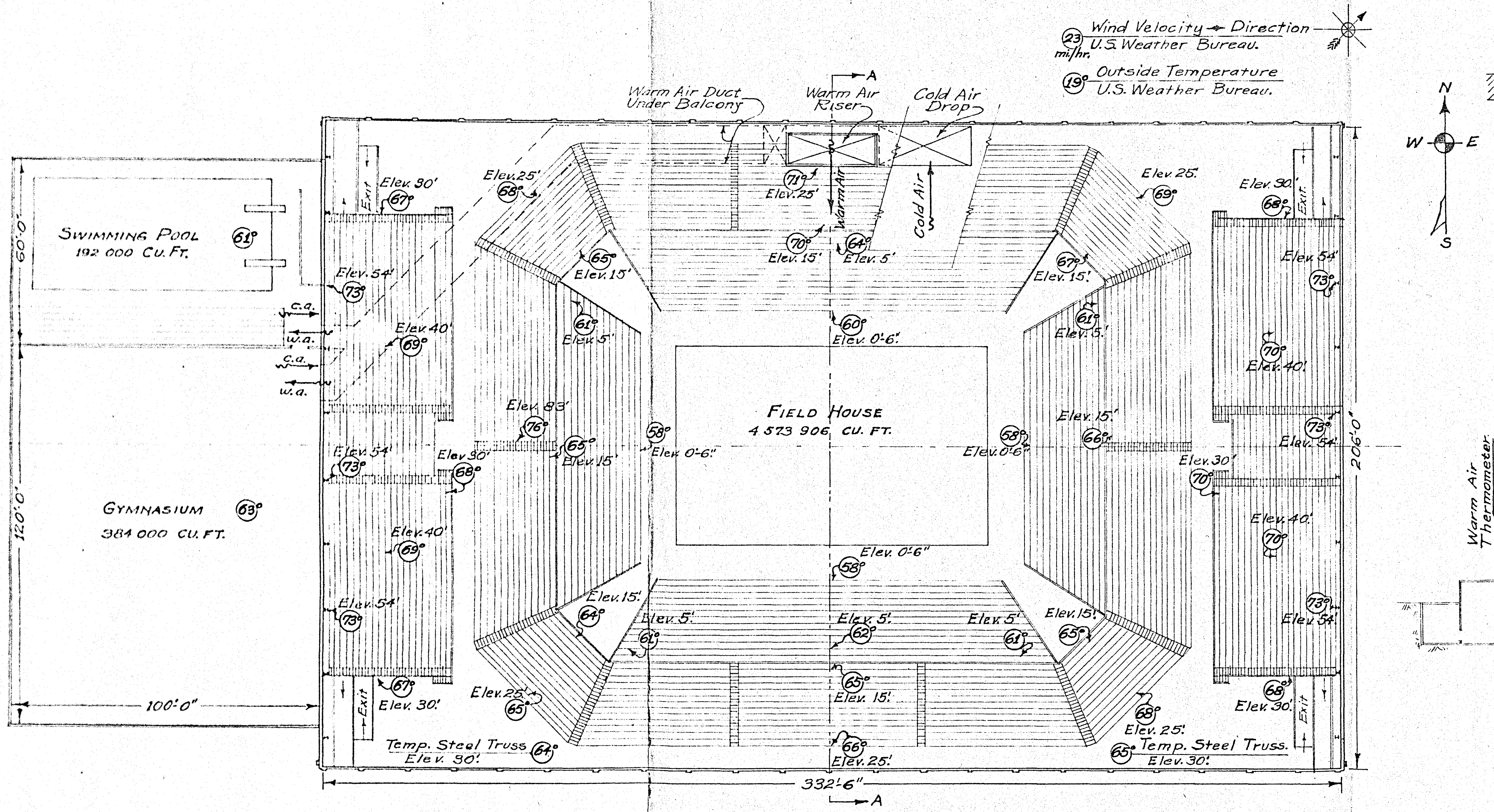


Balcony Plan.
Scale - 1/32" = 1'-0".

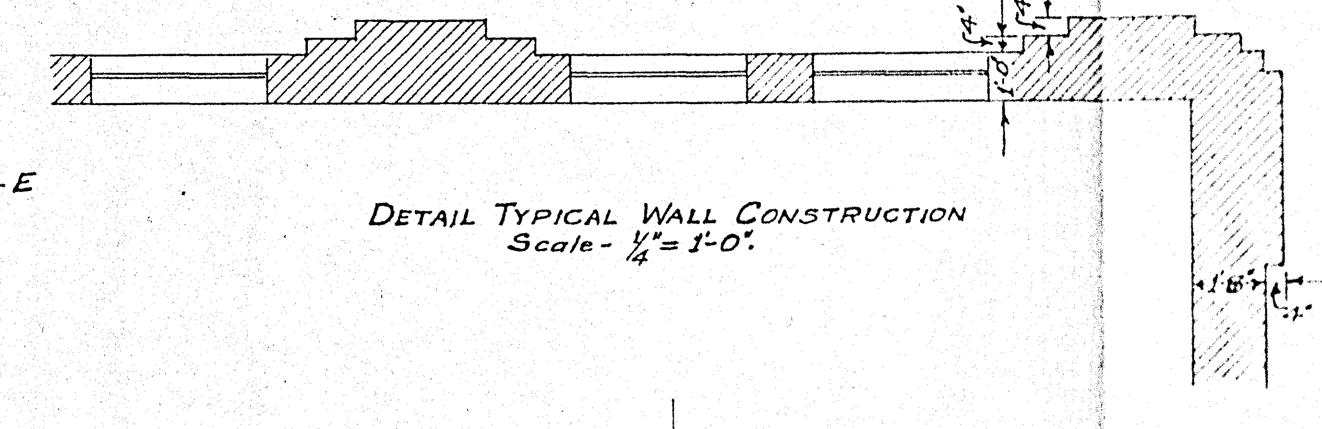
Cross Section A-A.
Scale - 1/32" = 1'-0".

The Butler University Field House.
Indianapolis Indiana.
Efficiency & Temperature Distribution
Test of Heating Plant.

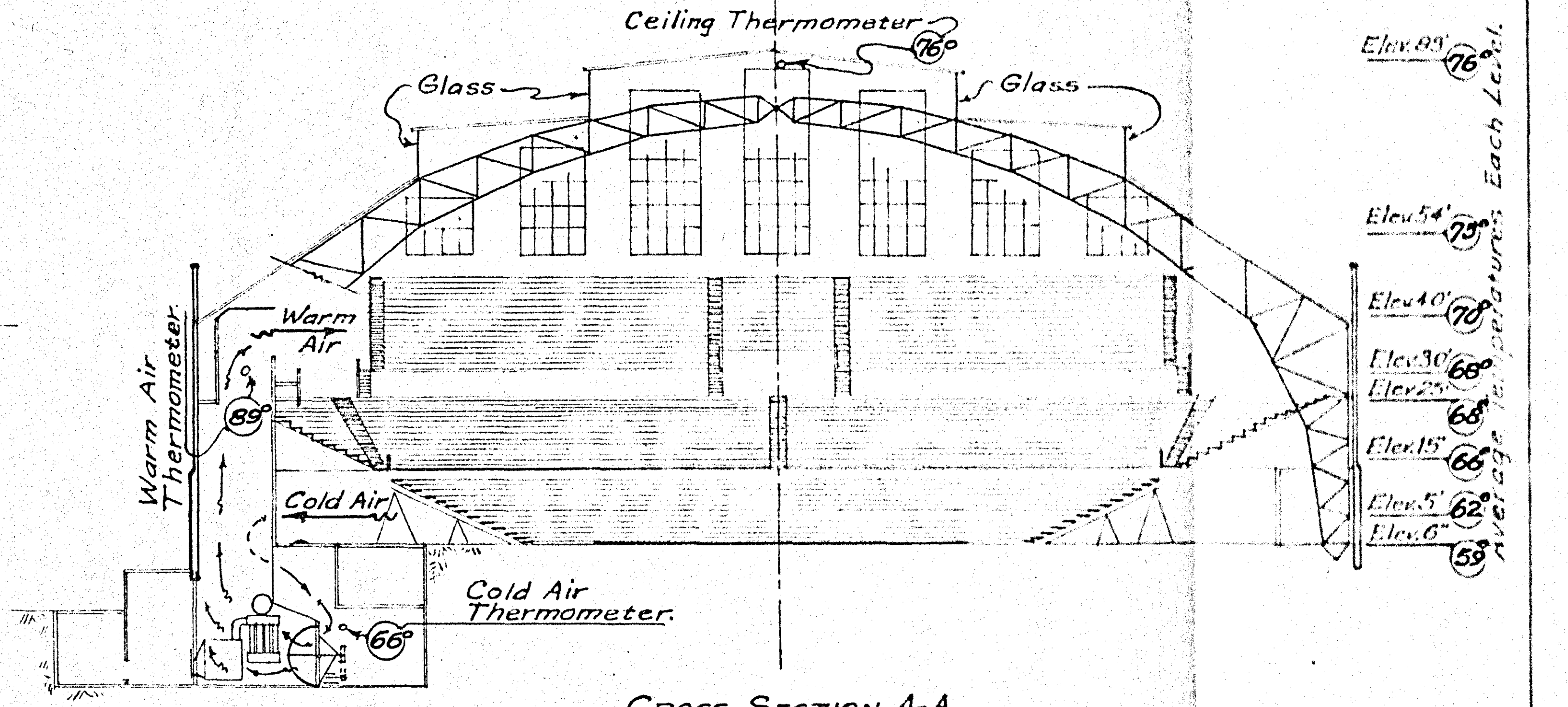
Date of Test 2/1/29. Time 8 00 P.M. Sky Cloudy.
Dry Bulb 63°. Wet Bulb 50°. Rel. Humidity 38%.
Highest Temp. 72°. Lowest Temp. 60°. Average Temp. 67°.



Balcony Plan.
Scale - 1/32" = 1'-0".



Detail Typical Wall Construction
Scale - 1/4" = 1'-0".



Cross Section A-A.
Scale - 1/32" = 1'-0".

The Butler University Field House.
Indianapolis Indiana.
Efficiency & Temperature Distribution
Test of Heating Plant.

7 Hours After Starting Fires.
Date of Test 1/25/29. Time 3^00 P.M. Sky Cloudy __.
Dry Bulb____. Wet Bulb____. Rel. Humidity____%.
Highest Temp. 76°. Lowest Temp. 58°. Average Temp. 67°.

since the outside wind velocity on January 25, was much higher than that on February 1.

Mention should be made here of the fact that all outside weather conditions shown are those of the U. S. Weather Bureau Station, Indianapolis, Indiana. Unofficial thermometers were placed outside the Field House and in every case registered approximately 5 degrees lower than the Weather Bureau record. The Field House is located at the edge of the city where it is exposed to the full sweep of the wind and is not protected by other buildings nor by city smoke. However, U. S. Weather Bureau records are accepted to avoid any possible question as to the weather conditions.

A further study of the temperature distribution and air movement was made with smoke bombs released at various points in the room. Attempts were made to photograph the movement of the smoke but the silver grey color of the ceiling and the balcony did not offer enough contrast with the smoke, and it diffused thruout the room too quickly. Figures 12, 13 and 14, page 33 illustrate the location of the bombs and the movement of the smoke from them. The bombs burned for 5 minutes and the smoke was evenly diffused thruout the room within ten minutes after they were released.

TIME REQUIRED TO HEAT THE COLD BUILDINGS.

It was intended that the Butler Field House should be used intermittently and previous to the test conducted on February 1, it had not been heated for six days. During that time the air and all materials in the building dropped to an average

Calculation Sheet No. 2.

Chart of Time Required to Heat The Butler Field House – Feb. 1st. 1929.

Outside Temperature U.S.W. Bureau.	Condition of sky.	Movement of Wind U.S.W. Bureau.	Average Inside Temperature.	Temperature of Steel Roof Trusses.	Central Standard Time.
−4° F.	Cloudy.	8 mi/hr. N.	33° F.	34° F.	8:00 AM.
− 1°.	Cloudy.	9 mi/hr. N.	43°	38°	9:00 A.M.
+ 2°.	P. Cloudy.	6 mi./hr. N.	49°	44°	10:00 AM.
+ 4°.	Clear	9 mi/hr. NW.	55°	52°	11:00 AM.
+ 5°.	Clear	10 mi/hr. NW.	60°	55°	12:00 M.
+ 8°.	Cloudy	9 mi/hr. NW.	63°	62°	1:00 PM.
+ 9°.	Cloudy	8 mi/hr. NW.	68°	66°	2:00 PM.
+ 11°.	Cloudy	8 mi/hr. NW.	70°	68°	4:00 PM.
+ 8°.	Cloudy	7 mi/hr. NW.	67°	68°	8:00 PM.

Note – Fires were lighted 7:30 A.M. – Fans were started 8:00 A.M. – Furnaces were fired at capacity 8:00 A.M. to 4:00 P.M. then checked. – Building had not been heated for 7 days.

Summary of Temperature Distribution 8:00 P.M.

Highest temperature (at ceiling) — 72°.
Lowest temperature (at floor) — 60°.
Average temperature of 41 thermometers — 67°.
Temperature variation over room at level 6 inches above floor — 1°.
Temperature variation over room at level 5 feet above floor — 3°.
Temperature variation over room at level 15 feet above floor — 3°.
Temperature variation over room at level 25 feet above floor — 3°.
Temperature variation over room at level 40 feet above floor — 2°.
Temperature variation over room at level 54 feet above floor — 0°.
Temperature difference 6 in. above floor & 5 ft. above floor – 2°.
Temperature difference 6 in. above floor & 15 ft. above floor – 7°.
Temperature difference 6 in. above floor & 25 ft above floor – 7°.
Temperature difference 6 in. above floor & 30 ft above floor – 7°.
Temperature difference 6 in above floor & 40 ft. above floor – 9°.
Temperature difference 6 in above floor & 54 ft. above floor – 10°.
Temperature difference 6 in above floor & 83 ft. above floor 12°.
Average temperature difference per 7 feet elevation — 1°.

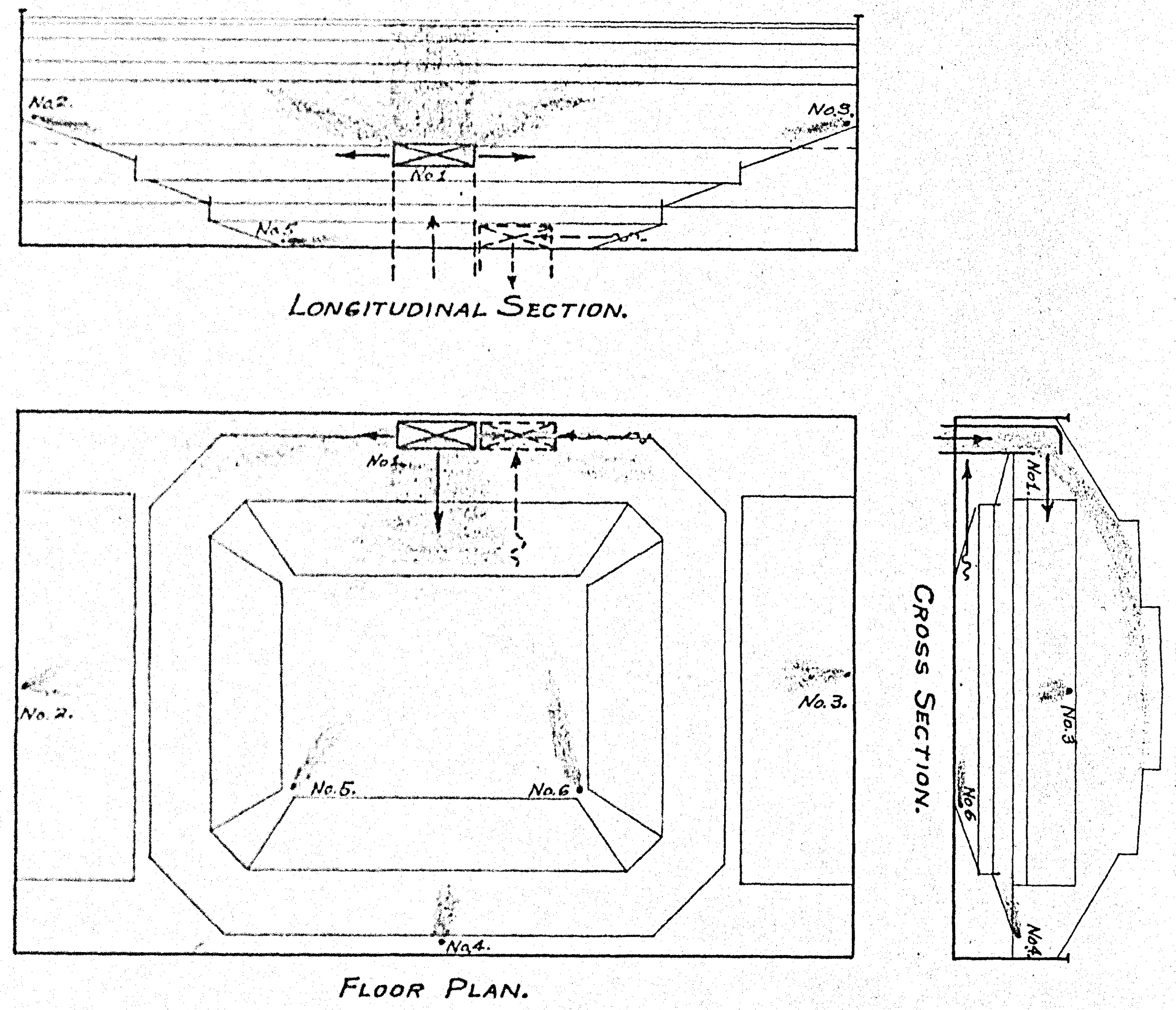


Figure 12. - Position of Smoke
One Minute After Lighting Bombs.

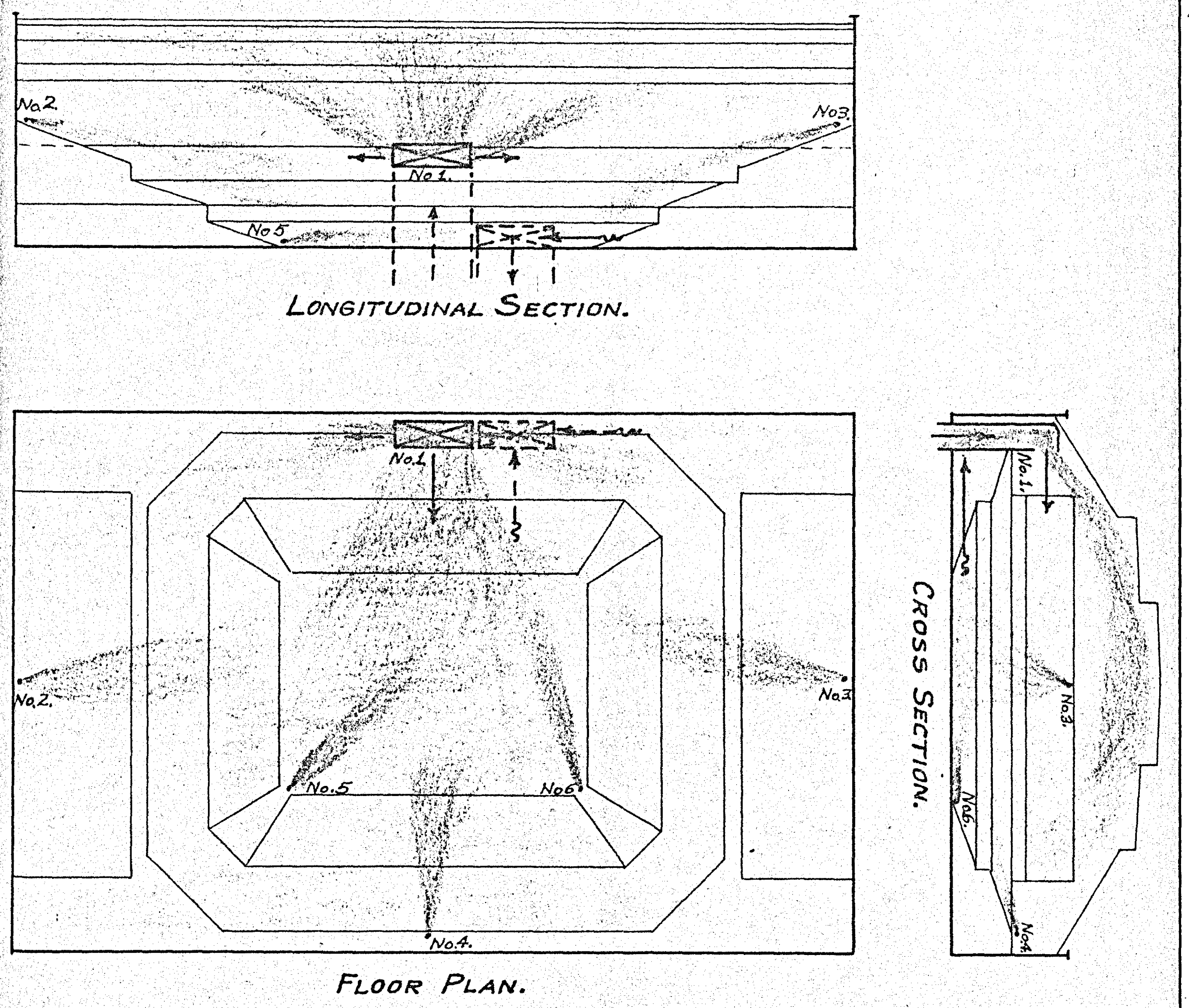


Figure 13. - Position of Smoke
Five Minutes After Lighting Bombs.

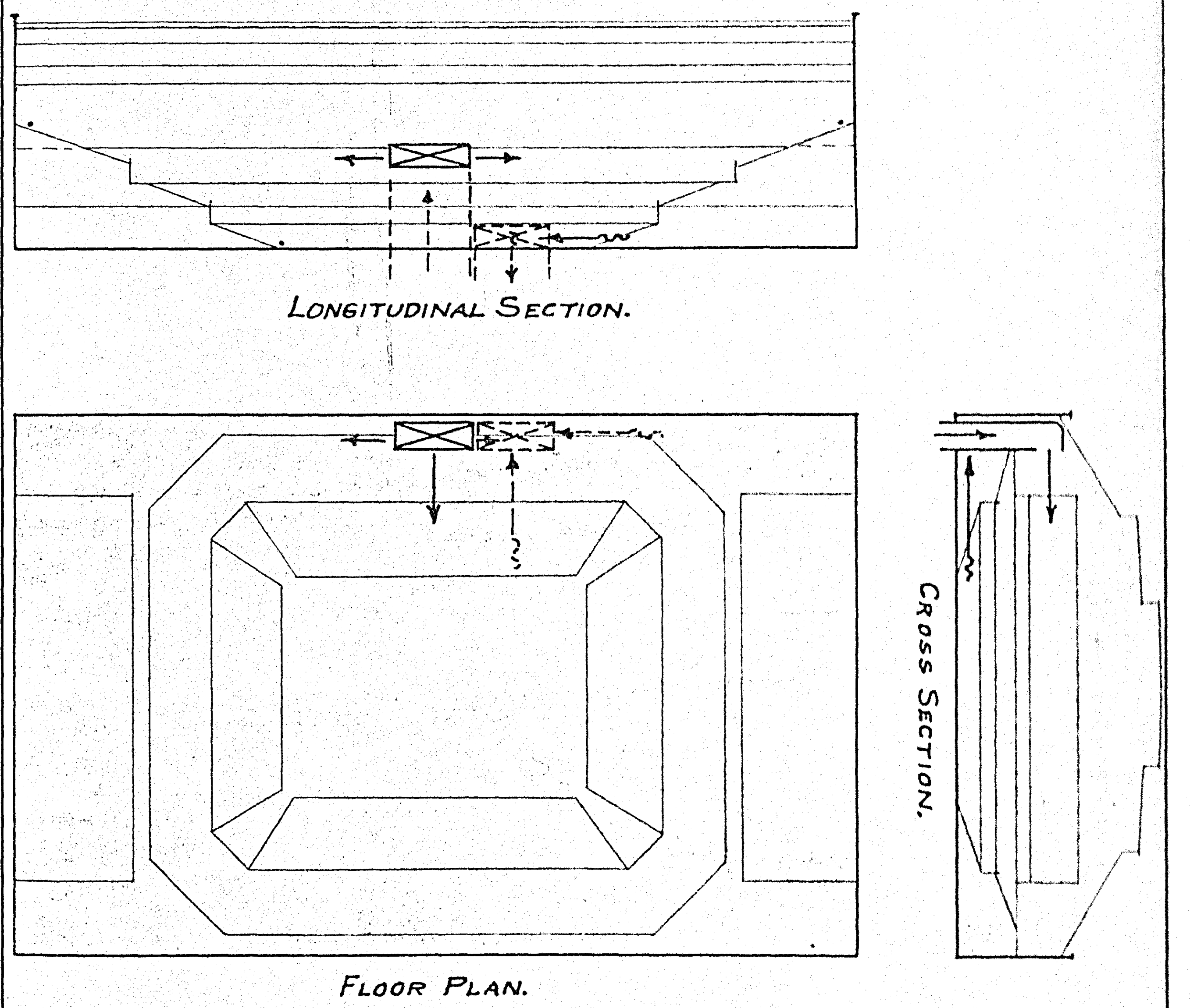


Figure 14. - Position of Smoke
Ten Minutes After Lighting Bombs.

temperature of 33 degrees. The heating of the materials in the building represented a real problem. The quantites of steel and concrete to be heated from 33 degrees to an average of 65 degrees are listed on Calculation Sheet No. 1, page 11. The steel consists largely of trusses and columns built up of I beams and Angle Irons the members of which are thin and offer the greatest possible radiating surface to the air. The concrete consists of 6 inch thick ramp floors and 2 inch thick floors on the balcony steps, all of which are suspended in the air heated and circulated.

The determination of the time required to heat the building was made from a study of the hourly room thermometer readings. These data are recorded on Figures 8,9, and 10, and a tabulation of the average temperatures that prevailed in the room at the end of each hour after starting the plant is set out on Calculation Sheet No. 2, page 32.

Further information regarding the speed at which the heat was absorbed by the materials in the building was obtained by sealing thermometers to the steel roof trusses in the locations indicated on Figure 8. The bulb of each thermometer was sealed against a 3/4 inch thick flange of an I beam, with 1 inch of asbestos cement. Over the asbestos cement was placed 2 layers of 1 inch thick loose felt, then the entire covering coated and made air-tight with 1 inch of asbestos cement. The temperatures indicated by the thermometers sealed in such manner to the steel roof trusses rose about 3 degrees slower than the temperature of the air surrounding the trusses as the room was being heated, then as the fires were checked and the temperature of the air allowed to drop, the temperature of the steel dropped about 3 degrees slower than that of the air.

Each time the building was heated then allowed to cool, the moisture in the air condensed on the windows and froze into a thick coating of ice over all the windows. For the sake of economy, gutters for the drainage of moisture from the windows had been omitted by the owners of the building, and as it was heated up the ice melted and dripped down to the concrete balcony floors. All ice was melted within the first two hours of firing on February 1, then during the next two hours all moisture that had dripped down was evaporated and the floors were dry. A calculation of the weight of water melted and evaporated during the test was made by comparing the weight of water in the air as indicated by the relative humidity of the air at the end of the test with that at the beginning of the test. No moisture was supplied to the air by the humidifers in the furnace chamber, therefore all moisture added to the air was evaporated within the building. It was not possible to measure the moisture lost by leakage of air from the building and the infiltration of cold air with a small moisture content. The calculation of the weight of water evaporated and the heat required is given on Calculation Sheet No. 1, page 11.

EFFICIENCY OF HEATERS.

From a study of the temperature distribution and time data with the low temperature difference between ceiling and floor, the high efficiency of the recirculating method of distribution is apparent.

Further data were obtained to determine the efficiency of the method that was employed at the Butler Field House to generate the heat and supply it to the air that was circulated.

The input of available heat units to the heaters was measured by weighing the coal fired, then correcting the total weight for moisture content. The moisture content was determined by weighing 50 pound representative samples of the coal at frequent intervals before and after being heated to dry out the moisture.

The total output of the heaters was obtained by measuring the volume and thus the weight of air passed over the heaters during the 12 hour test, and measuring the rise in temperature of this air from the cold air openings to the warm air openings.

The volume of air circulated was measured with a Kueffel and Esser Number 9556 Anemometer. Altho the anemometer method of measuring air velocity is subject to considerable dispute as to accuracy, the anemometer used was carefully calibrated before the readings were taken and again afterward. Considering the volume of air handled, the size of openings, the number of readings taken, and the velocity range encountered, it is felt that this method is sufficiently accurate for all practical purposes.

Calculation Sheet No. 3, page 38, gives the corrected velocities obtained in the openings and a calculation of the volume of air circulated. Each figure given in the sub-dividions of Openings No. 1 and No. 2, is the average of 3 velocity readings taken in that space in the opening.

The temperature rise of the air passed over the heaters was determined by placing a Bristol Model 146 Recording Thermometer in the fan room immediately behind the fans and a similar instrument, both calibrated, at the junction of the warm air outlet ducts. Careful preliminary tests were made with ten room thermometers in each opening to determine the point at which the average temperature of the air at each opening prevailed. It was found, however, that there was not over 3 degrees variation at any point in the cross section of either opening, largely because of the volume and velocity of the air and the extreme turbulence or twisting motion imparted to the air by the particular type of fans used. The points at which the recording thermometers were located is shown on Figure 8, page 27. Care was taken to shield both thermometers from any possible radiant heat from the furnaces.

The original charts obtained durihg the test on February 1 are reproduced by photostat on Figure 16, page 39. The chart

Opening No. 1

10'-6" × 12'-0" (with 3'-0" × 2'-0" extension)

			1230
1084	1076	913	1119
1020	990	1027	650
972	966	1021	712
740	775	840	650

Opening No. 3.

9'-0" × 10'-0"

310	382	491	460
363	416	510	436
328	420	483	544
296	391	460	580

Opening No 2

10'-6" × 12'-0" (with 3'-0" × 2'-0" extension)

762	907	951	494
905	1080	1008	1006
678	998	1011	981
698	1080	1030	1006
			1224

Opening No. 1.
Av. Velocity - 928.5 Ft./Min.
Area - 162 Sq. Ft.
Volume - 150,417 Cu. Ft./Min.

Opening No. 2.
Av. Velocity - 942.3 Ft./Min.
Area - 162 Sq. Ft.
Volume - 152,653 Cu. Ft./Min.

Opening No. 3.
Av. Velocity - 430 Ft./Min.
Area - 90 Sq. Ft.
Volume - 38,700 Cu. Ft./Min.

Total Volume = 341,770 Cu. Ft./Min.

Note - Openings No. 1 & No. 2 are cold air ducts from field house. Opening No. 3 is cold air duct from gym. & Pool.

Calculation Sheet No 3. - Volume of Air Delivered By Fans.

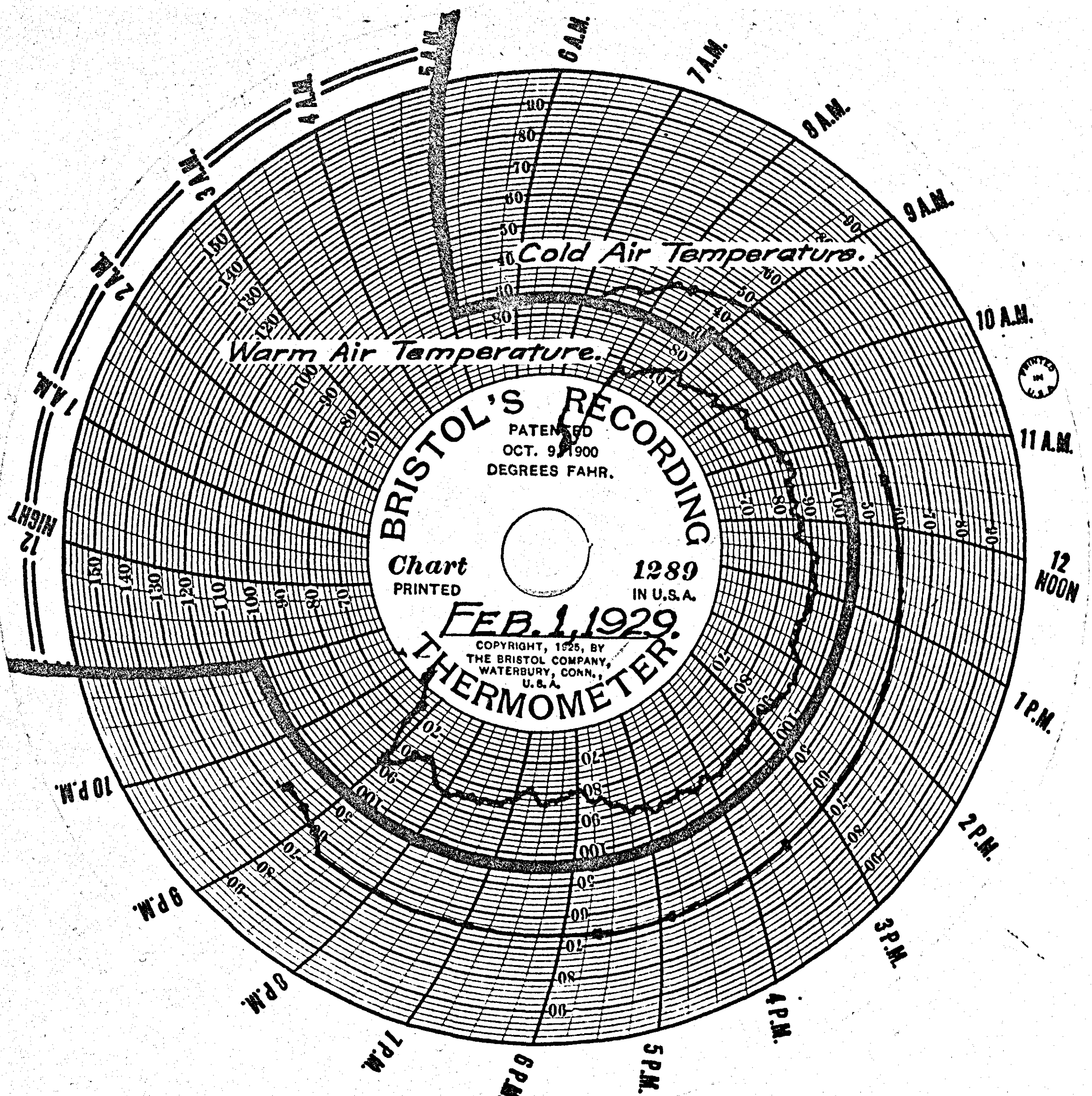


FIGURE-16 :ACTUAL CHARTS OF TEMPERATURES RECORDED.

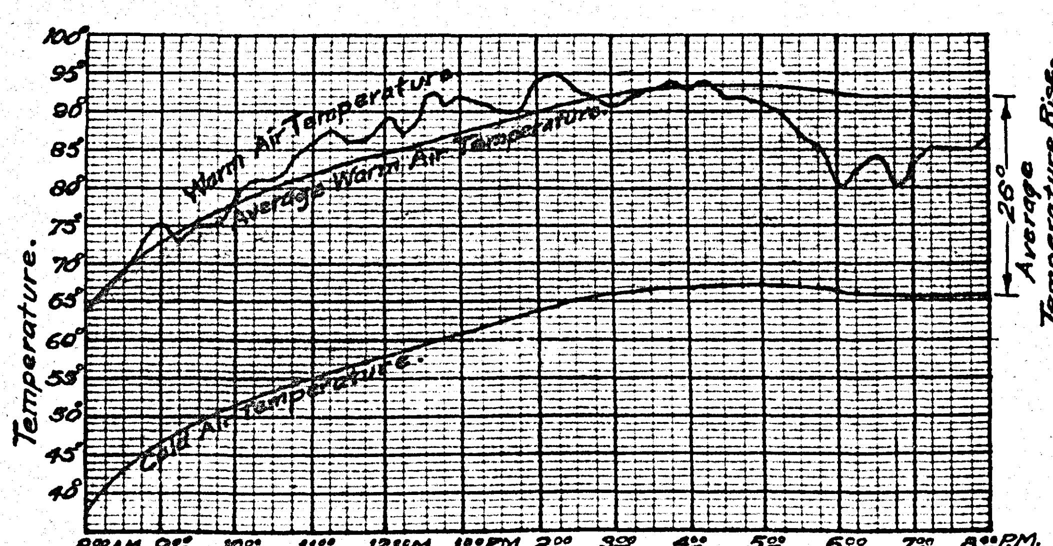


FIGURE 15.- PLOT OF ACTUAL AND AVERAGE TEMPERATURES.

of warm air temperatures has been cut away at the heavy black line and pasted over the chart of cold air temperatures so that the time coincides. Since the warm air chart is for high temperatures and at a different temperature scale, the line of warm air temperatures is inside the line of cold air temperatures.

By taking temperature readings at five minute intervals thruout the 12 hour test from these two charts, and averaging the differences between the cold air and the warm air from all readings, an average temperature rise of 26 degrees F. was determined. This calculation is illustrated graphically on Figure 15, page 39.

With the data obtained in this manner, the calculation of the overall efficiency of the heaters was completed as shown on Calculation Sheet No. 4, page 41.

CALCULATION SHEET No.4.

OVERALL EFFICIENCY OF HEATERS.

Input = 9,000 lbs. "Loredo" W.Va. coal. Htg. value per pound dry 14500 B.T.U.
Net Input = (9,000 − 180 lbs. water) × 14,250 B.T.U. ——— 125,685,000 B.T.U.
Output = 341,770 cu. ft. air × 720 min. × .01777 B.T.U. × 26° — 113,691,294 B.T.U.
.01777 is B.T.U. to raise 1 cu. ft. dry air at 29.61" pressure
1°F at average temperature of 75°F. or
Wt. at 75° × C_p × 29.61 ÷ 29.921.
Heat Furnished by boiler & economizer = 108,864 B.T.U. × 12 hrs 1,306,368 B.T.U.
Net output of furnaces ——— 112,384,926 B.T.U.
Overall Efficiency of furnaces = Input ÷ Output = 89.4 %.

ANALYSIS OF DATA.

Total heat supplied to building for 60° rise for 12 Hours 113,691,294 B.T.U.
Estimated heat requirement for same period ——— 112,003,721 B.T.U.
Heat loss unaccounted for ——— 1,687,573 B.T.U.
Error in estimating heat loss in ratio to heat actually supplied 1.4 %.
Heat supplied by each furnace per hour ——— 3,121,803 B.T.U.
Coal burned per furnace per hour — 245 lbs.
Coal burned per Sq. Ft. grate area per hour — 12.5 lbs.

PART 3. - CONCLUSIONS.

The test described herein on the heating and ventilating system in the Butler University Field House indicate,-

1.- The factors of heat conductivity employed and the methods of calculating heat loss from the building are approximately correct.

2.- In a building of this character that is heated intermittently, it is essential that the heat required to raise the temperature of the building materials be included. To raise the temperature of the materials in the building required 2/3 as much heat as to supply the heat loss from the building for 12 hours.

3.- The temperature can be evenly distributed thruout a room the size of the Butler Field House from one point, when the air is recirculated in sufficient volume.

4.- The heat is pulled from the ceiling to the floor with an average temperature difference between floor and ceiling of 1 degree per 7 feet of elevation.

5.- The building can be heated uniformly and thoroughly from 33 degrees to an average temperature of 65 degrees in zero weather in less than 12 hours time.

6.- The efficiency of the method of distributing the heat to the building and the efficiency of the method of generating heat and supplying it to the air, are higher than with any other known existing methods of heating.