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NATIONAL BUREAU OF STANDARDS REPORT

4875

SOME OBSERVED HEAT TRANSFER CHARACTERISTICS OF SEVEN TYPICAL REFRIGERATED SEMI-TRAILERS

Draft of September 28, 1956

by

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R. S. Dill
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U. S. DEPARTMENT OF COMMERCE

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NBS PROJECT | **NBS REPORT**

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Abstract

The performance of seven refrigerated semi-trailers of nominal 35-foot length was observed to obtain general information on the range of such characteristics as heat transmission, solar heat gain, temperature pull-down rate, warm-up rate and refrigerating unit capacity for equipment now on the market. Considerable differences were found between the specimens; 40 percent in heat transmission (75 to 107 Btu per hour (°F)), 340 percent in solar heat gain (230 to 1020 Btu per hour), 55 percent in warm-up time from 0F to 70F (9.6 to 14.7 hours), 460 percent pull-down time from 91F to 0F (2.7 to 15.1 hours), and 150 percent in refrigerating unit capacity (6,400 to 15,900 Btu per hour. These differences emphasize the need for prompt standardization of purchase requirements for trailers and trailer refrigerating units, including standardization of test methods and test apparatus.

1. BACKGROUND

Transportation of perishable foods in motor trucks and trailers has increased tremendously in recent years in both volume and importance, and among the several problems accompanying this rapid growth is the need for standard methods for testing and rating truck and trailer bodies for heat transmission characteristics, and refrigerating units for capacity. Formulation of such standards is a necessary first step to permit purchasers and suppliers of such vehicles and their components to reach an understanding concerning their mutual problems.

The problem is not simple. In addition to the basic methods of measurement which must be developed or adapted for the purpose, factors to be considered include solar heat, effect of moisture accumulation in the insulation, rain and increased air infiltration due to wind, motion and vibration.

Recognizing this, many organizations have been studying various aspects of the problem. Among them were the Committee on Transportation of Perishables by Motor Truck, Regular Common Carrier Conference and Irregular Carrier Conference, all of the American Trucking Associations, Inc., The Truck-Trailer Manufacturers Association, Truck Body and Equipment Association, Inc., truck refrigerating unit manufacturers, the American Society of Refrigerating Engineers, the U. S. Department of Agriculture and the National Bureau of Standards.

New truck bodies are usually free from excess moisture in the insulation and because of this can be tested for heat flow characteristics with a simple heating test. After they have been used for some time they may accumulate significant amounts of moisture in the insulation. To determine the heat gain (or loss) of these vehicles is more difficult. No satisfactory method for making the determination is in general use. Apparatus for making this determination needs to be developed.

A program to develop a standard method (and apparatus) for determining heat gain and air infiltration of refrigerated trailers, both new and used, in the laboratory and on the road, has been proposed by the Bureau of Standards and the Department of Agriculture to the Committee on Transportation of Perishables by Motor Truck, of the American Trucking Associations, Inc. A major part of this program would be the development of simple apparatus to establish heat gain ratings of trailers in the field. This proposal is currently under consideration by the A. T. A. committee.

The Regular Common Carrier Conference of the American Trucking Associations, Inc., in an attempt to focus attention on the necessity of adoption of standard ratings for trailers and units, requested members of the Truck-Trailer Manufacturers Association to submit insulated refrigerated semi-trailers for comparative tests to be conducted by the Department of Agriculture and the National Bureau of Standards. The tests proposed were to show the range in relative heat transmission, pull-down rates and warm-up rates of the trailers, and were to be held at the Edgewater Gulf Hotel, Edgewater Park, Mississippi, May 9-16, 1956.

Seven trailers were submitted and tests were conducted at Edgewater Park as scheduled. This report deals with these tests.

2. TEST SPECIMENS

Refrigerated, insulated, semi-trailers of 35-foot nominal length were submitted by the following seven manufacturers:

Name of Trailer	Manufacturer
Dorsey	Dorsey Trailers Inc., Elba, Ala.
Fruehauf	Fruehauf Trailer Co., Detroit, Mich.
Great Dane	Great Dane Trailers, Savannah, Ga.
Highway	Highway Trailer Co., Edgerton, Wisc.
Lufkin	Lufkin Foundary and Machine Co., Lufkin, Texas
Miller	Miller Trailers Inc., Bradenton, Fla.
Trailmobile	Trailmobile, Inc., Cincinnati, Ohio

Table I lists descriptive characteristics, as furnished by respective manufacturers, of each trailer. Figures 1 and 2 are aerial views of the trailers in position as tested. In

TABLE I

Trailer Specifications

Trailer Mod., Ser. No.	Dorsey RCT-18	Fruehauf FE 26718
Refrig. Unit Mod., Ser. No.	Thermo-King RL-30	Thermo-King RL-30,9361
Inside Dimensions		
Length	33'7"	34'0"
Width	6'9"	7'0"
Height	6'8"	7'1"
Volume, cu. ft.	1500	1700
Int. Surface	990	1055
Weight (incl. refrig. unit)	12460	12520
Insulation		
Roof--type, thickness	Ultralite,6"	Styrofoam,4"
Floor--type, thickness	Rubatex,4"	Styrofoam,5"
Walls--type, thickness	Ultralite,6"	Styrofoam,4"
Doors--type, thickness	Ultralite,6"	Styrofoam,4"
Surface		
Interior	Alum. ceiling,Plastic Walls	Plastic
Exterior	Aluminum	Aluminum
Extruded Alum. Grooved Floor	Yes	Yes
Int. Wall Air Channels	Yes	Yes
Door Air Channels	Yes	No
Meat Rails	No	No
Floor Drains	No	Yes
Other Features	Side door, air delivery duct	

TABLE I (Cont.)

Trailer Specifications

Trailer	Great Dane	Highway	Lufkin
Mod., Ser. No.	AATR2 12915	TL35CR-3LV(OP),#17	ALV
Refrig. Unit	Thermo-King	Tru-Kooler	Transi-Cold
Mod., Ser. No.	RL-30	G-500R,#1919	161,#1608(Butane)
Inside Dimensions			
Length	33'5"	33'6"	33'4"
Width	6'10"	6'10"	6'8"
Height	6'10"	6'11"	6'8"
Volume, cu. ft.	1550	1600	1500
Int. Surface	1005	1020	960
Weight (incl. refrig. unit)	11970	13680	13140
Insulation			
Roof--type, thickness	Microlite, 6"	Microlite, 6"	Fiberglass, 6"
Floor--type, thickness	Rubatex, 4"	Styrofoam, 6"	Styrofoam, 5"
Walls--type, thickness	Microlite, 6"	Microlite, 6"	Fiberglass, 6"
Doors--type, thickness	Microlite, 6"	Microlite, 6"	Fiberglass, 6"
Surface			
Interior	Aluminum	Plywood	Plywood
Exterior	Aluminum	Aluminum	Aluminum
Extruded Alum. Grooved Floor	Yes	Yes	Yes
Int. Wall Air Channels	Yes	Yes	No
Door Air Channels	Yes	Yes	No
Meat Rails	No	No	Yes
Floor Drains	Yes	No	Yes
Other Features			Side door, front and rear ice hatch doors, temp. recorder-controller

TABLE I (Cont.)

Trailer Specifications

Trailer	Miller	Trailmobile
Mod., Ser. No.	FRL-22-35' Hi-Cube Full Reefer, #L-647	C-6222, #1-17126
Refrig. Unit	Columobile	Thermo-King
Mod., Ser. No.	2 Elec. Units, Gasoline Generator	RL-30, 9446
Inside Dimensions		
Length	33'6" *	33'9"
Width	6'9"	6'11"
Height	7'6" and 7'8"*	6'9"
Volume, cu. ft.	1700	1600
Int. Surface	1060	1015
Weight (incl. refrig. unit)	14300	13220
Insulation		
Roof--type, thickness	Ultralite, 6"	Ultralite, 6"
Floor--type, thickness	Styrofoam, 6"	Ultralite, 6"
Walls--type, thickness	Ultralite, 6"	Ultralite, 6"
Doors--type, thickness	Ultralite, 6"	Ultralite, 6"
Surface		
Interior	Plastic walls, Aluminum ceiling	Plywood
Exterior	Aluminum	Aluminum
Extruded Alum. Grooved Floor	Yes	Yes
Int. Wall Air Channels	Yes	No
Door Air Channels	Yes	No
Meat Rails	Yes	Yes
Floor Drains	Yes	Yes
Other Features	*6"-Stepdown floor; nose to step--9', step to rear door--24'6".	

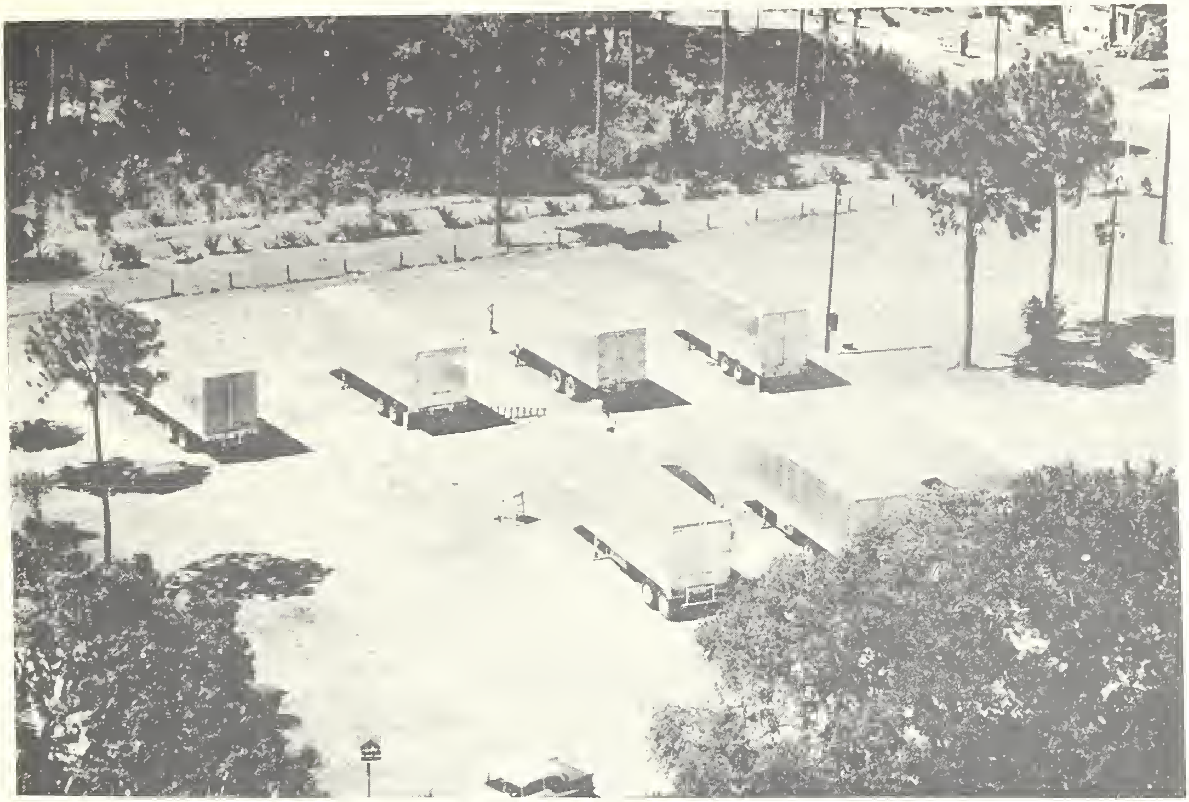


FIGURE 1.

FIGURE 2.

figure 2, the trailers are arranged as follows: front row, left to right, Miller, Great Dane, Trailmobile and Fruehauf; back row, left to right, Dorsey, Highway and Lufkin. Figure 3 shows, left to right, Miller, Great Dane, Trailmobile and Fruehauf trailers. Figure 4 shows in the same order Dorsey, Highway and Lufkin. Figure 5 is a schematic drawing of the trailer test layout.

The trailers were all of nominal 35-foot length and ranged in interior volume from 1,500 cubic feet for the Dorsey and Lufkin trailers to 1,700 cubic feet for the Fruehauf and Miller trailers. Weight ranged from 11,970 pounds for the Great Dane trailer to 14,300 pounds for the Miller trailer.

Four of the trailers, Fruehauf, Trailmobile, Great Dane, and Dorsey, were equipped with Model RL30 Thermo King gasoline-engine driven refrigerating units. The Miller Trailer was equipped with a Coldmobile electric unit-gasoline-engine-driven generator combination, and the Highway and Lufkin Trailers were, respectively, equipped with a Model G-500-R Tru Kooler, gasoline-engine-driven refrigerating unit and a Model 161 Transicold butane engine-driven refrigerating unit.

The Miller, Lufkin, and Trailmobile Trailers were equipped with meat rails. All trailers had tandem wheel assemblies.

Various materials were employed as interior wall and ceiling surfaces in the various trailers as shown in table I. All of the trailers were covered with bright aluminum on the exterior.

3. TEST EQUIPMENT AND PROCEDURE

Heat transfer characteristics of all seven trailers were observed as follows: (1) Approximate steady state heat loss; (2) Pull-down time; and (3) Warm-up time.

The trailers were tested in an open lot in the rear of the Edgewater Gulf Hotel in Edgewater Park, Mississippi, in May, 1956. They were exposed to the weather and were arranged as shown in figure 5.

Each trailer was equipped with five thermocouples (for remote measurement of temperature), an electric heater, and a 16-inch electric fan. These items were positioned as shown in figure 6. The heaters were all of the same model and were rated at 1650 watts at 115 volts and each was equipped with a small internal fan. The 16-inch electric fans were selected for comparable air delivery characteristics. An actual installation of the fan and heater is shown in figure 7.

The thermocouples were made of calibrated No. 30 copper and No. 30 constantan wire and temperature readings were taken with an electronic constant-balance potentiometer

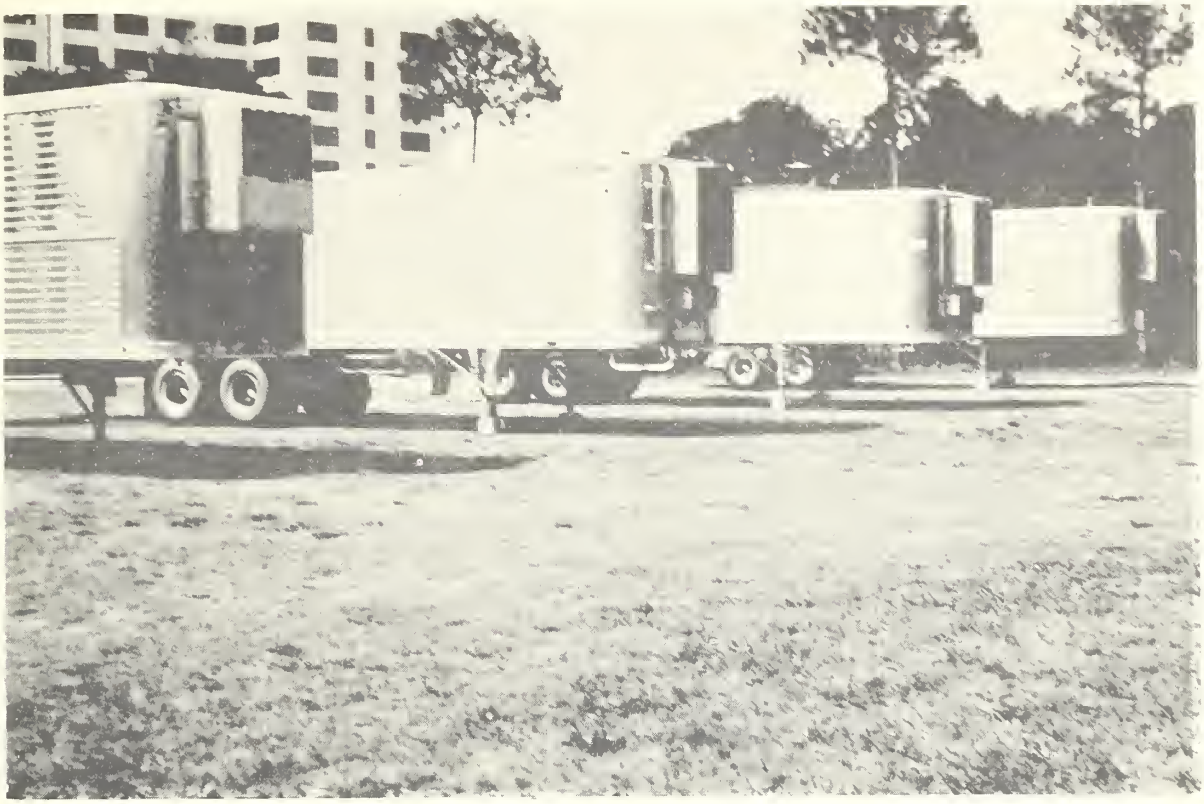


FIGURE 3.

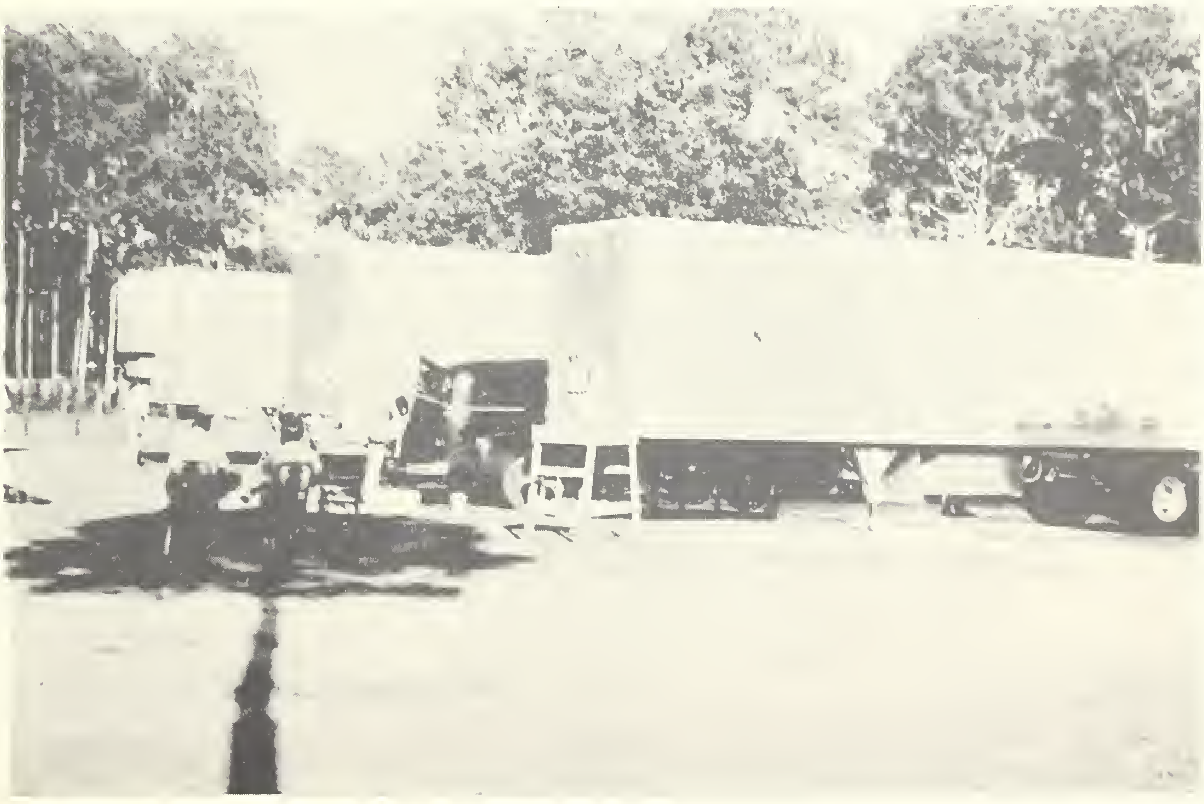
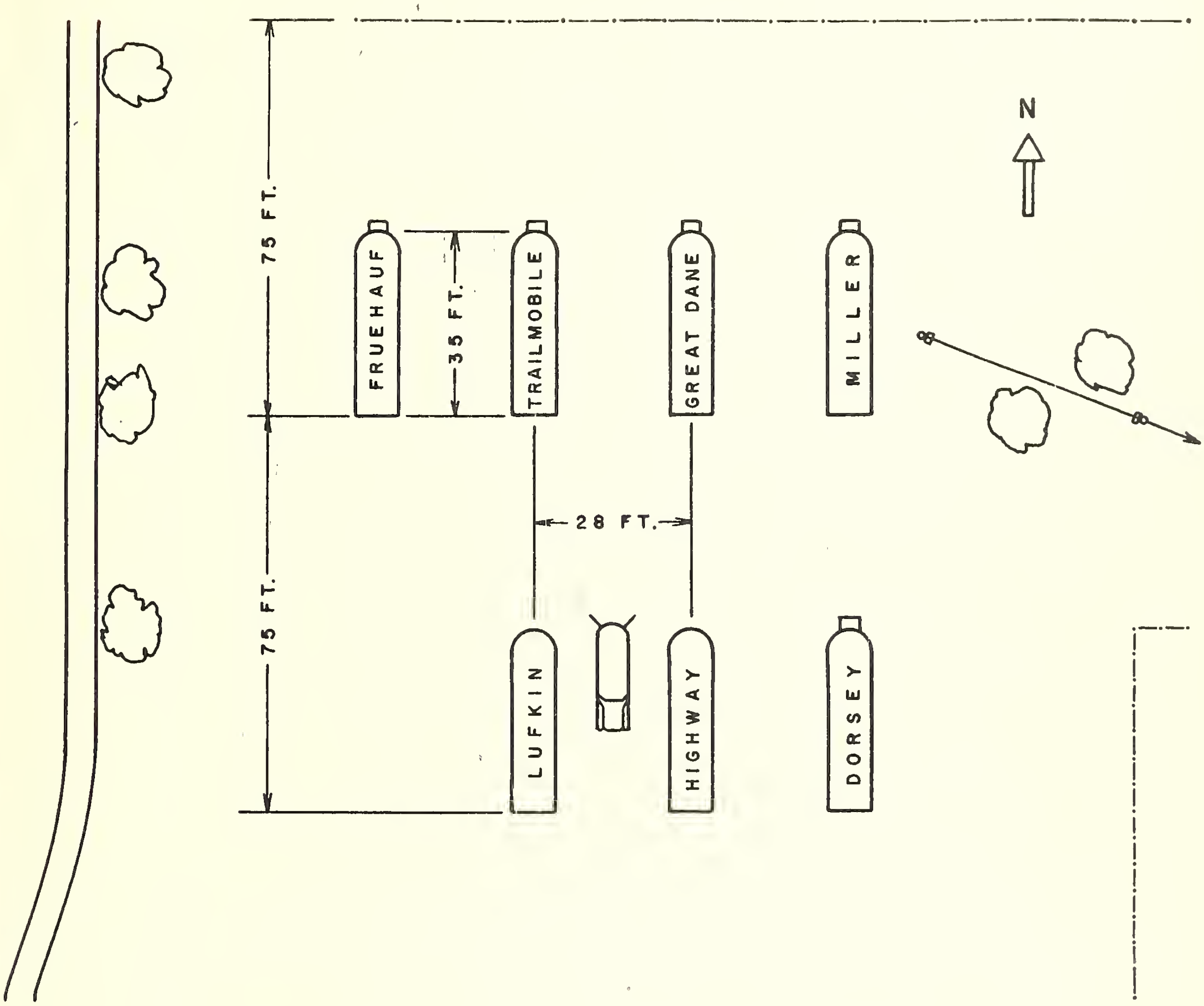


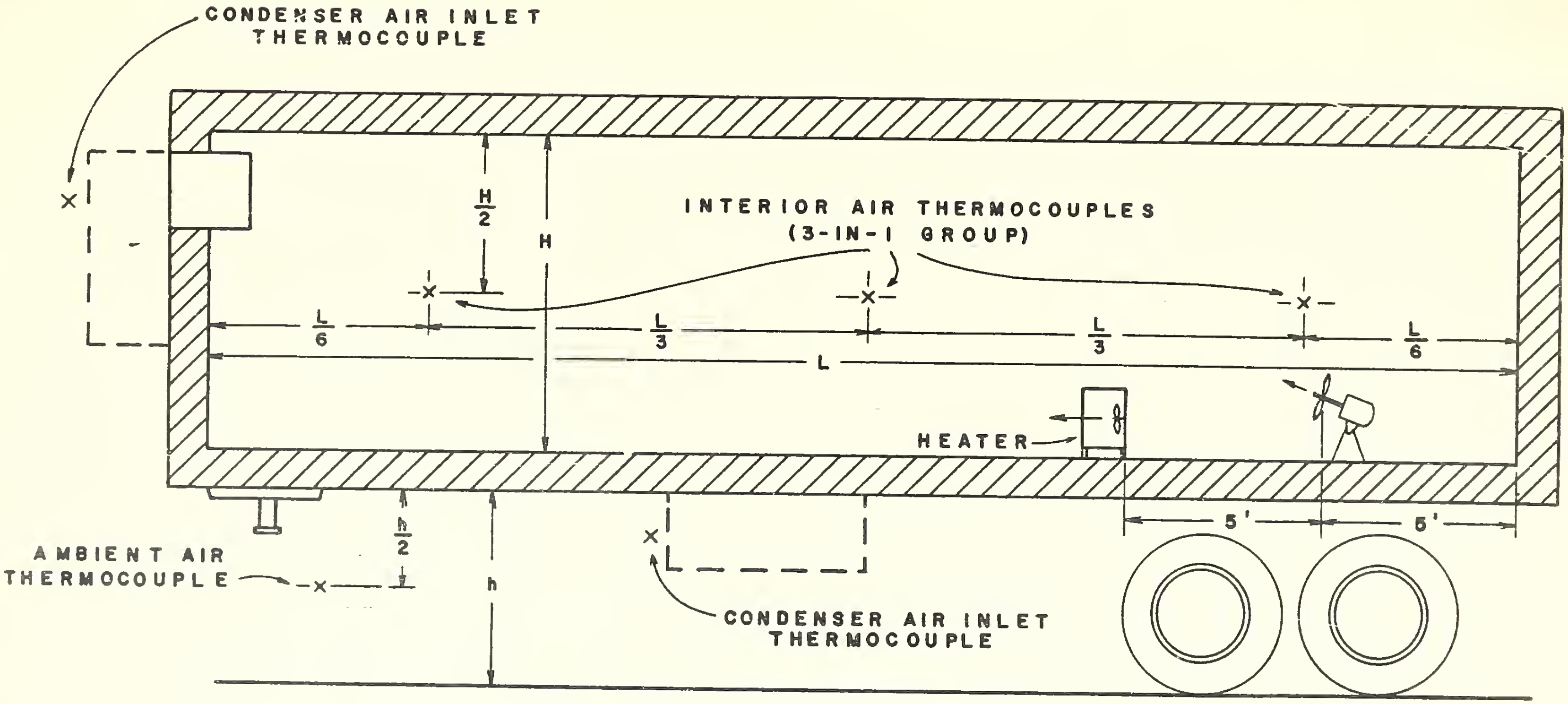
FIGURE 4.



PARKING LAYOUT OF TEST TRAILERS
USDA-NBS-TTMA-ATA
EDGEWATER GULF HOTEL
MAY 7-20, 1956

0 10 20 30 40 FEET

Fig. 5



LOCATION OF THERMOCOUPLES
AND
POSITION OF FAN AND HEATER

Fig. 6

using the null-flow principle which equalized the effect of thermocouple length. In each trailer three equal-length thermocouples used for measuring interior air temperature were parallel-connected and read as a single average temperature. A thermocouple was attached to the roof surface of two of the trailers and the instrument truck for indication of comparative day and night thermal radiation effects. All ambient, condenser inlet, and interior air thermocouples were checked for proper performance after installation and again before the pull-down test. Figure 6 shows the 3-in-1 group couple being checked in one of the trailers by immersion in crushed ice. The performance of the potentiometer was monitored at the time of each observation by reading the temperature of both high and low temperature reference baths. To reduce likelihood of accidental damage, all thermocouple leads were carried overhead between trucks.

The electric input for heating each trailer was measured by a calibrated watt-hour meter. All watt-hour meters used had a correction of less than ±1%. Performance of each of the watt-hour meters was monitored by voltammeter readings throughout the tests. The power leads to each truck were the same length and of such size (#12-2 wire AC) that resistance loss differences were negligible. The resistance of each power lead, including attachment fittings was checked after installation. Power for the tests was supplied by transformers installed for the purpose and was 3 phase 3 wire nominal 230 volt service with one center tap provided for 115 volt lighting use. Voltage to each trailer was adjustable to permit balancing heat input between vehicles.

All equipment for the test was transported to the test site from Washington, D. C., in a one-ton panel truck equipped with an instrument panel, as shown in figure 9, constructed for this test. To facilitate reading of instruments, a seat was equipped with casters permitting the operator to move easily along the 8-foot length of the panel. Figure 9 shows the physical lay-out of major items in the instrument truck. In figure 10 can be seen the two fans, one mounted in each window of the instrument truck cab, which provided ventilation of the vehicle.

Installation of all instrumentation at the test site and all observations were made by C. W. Phillips, NBS, W. H. Redit and Harold D. Johnson, U. S. D. A., shown in figure 11.

Data from all tests was coded to prevent accidental or improper release of competitive information.

The first test conducted was to determine relative heat leakage of the several trailers when the same amount of heat was added to each. All fans and heaters were checked

FIGURE 7.

FIGURE 8.

FIGURE 9.

FIGURE 10.

FIGURE 11.

for satisfactory performance eight hours before the start of the test at 9:00 A.M. May 11. The doors were closed at 9:00 A.M. and the fans and heaters were turned on at 9:30 A.M. One trailer was late in arriving and was started on test at 3:00 P.M. the same day. The test was concluded at 6:00 A.M. on May 14, an elapsed time of 69 hours. Power and temperature observations were made at 30-minute intervals throughout the test. Effect of daytime, sun and nighttime conditions were observed. No rain fell during any of the tests. Relative solar heat gain observations were made as a part of this test.

The second test conducted was to determine the relative temperature pull-down rate of each trailer and the relative capacity of the refrigerating units. Prior to the start of this test the doors of all trailers were opened and the interiors ventilated by fan for three and one-quarter hours. The trailer doors were closed 30 minutes before the refrigerating units were started, and sufficient observations of interior temperatures were made to adequately determine the initial temperature for this test. After starting the refrigerating units, temperature observations were made at 15-minute intervals until each trailer was at or below OF for at least four hours. The pull-down test was started at 9:45 A.M., May 14, a time when the trucks were exposed to strong sunlight. Industry personnel in attendance were permitted to make any desired adjustments to their respective units during the first 30 minutes of the test, and to remain at the site for the entire test. All thermostats were set well below OF to assure continuous operation of the units during pull-down. Tests for refrigerating unit capacity began after each trailer reached -1 F. As each trailer reached -1F, the heater in that trailer was energized. As each trailer reached -3F, the manufacturer's representative was requested to set the thermostat for cyclic operation at OF. Because of variation in reserve refrigerating capacity, in four cases after the trailers reached -1F, the refrigerating units cycled on thermostat with the heaters energized continuously, and in two cases the refrigerating units operated continuously and the heaters were cycled by test personnel. In one case the heater was not energized. All units were operated at about OF for at least four hours at the end of the pull-down portion of the test. Refrigerating unit capacity was computed from data recorded during this four-hour period. Observations were made of the area and of the extent of condensation or sweating on the trailer exteriors. Automatic or manual defrosting of unit evaporators was permitted.

The final test conducted was a "warm-up test." After each trailer had been operating at 0F for four hours or longer, the unit, the heater, and the fan were turned off and the trailer allowed to warm up with temperature measurements made at ten-minute intervals during the first hour, 15-minute intervals during the second hour, and 30-minute intervals for the remainder of the test. The warm-up test was started for all trailers between midnight and 3:00 A.M., May 15 and was concluded at 5:00 P. M. the same day.

4. TEST RESULTS

Test results reported in this section are presented in the following order:

1. Heat transmission
2. Relative solar heat gain
3. Warm-up rate
4. Comparison of heat transmission, solar heat gain, and warm-up rates
5. Temperature pull-down rate
6. Refrigerating unit capacity
7. Sweating of trailer exteriors

All phases of the test series were conducted with the trailers exposed to the weather. No rain fell during the tests and a slight on-shore breeze blew almost constantly. For the most part, days and nights were clear, and bright sunlight gave excellent opportunity to observe solar effects. Ambient dry bulb temperatures were relatively constant, ranging from a low of 75F to a high of 86F.

Heat Transmission

The observed heat transmission rates ranged from 75 Btu per hour (°F) to 107 Btu per hour (°F), a variation of 40 percent. In this test heat was added to the interior of each of the seven trailers and the heat loss coefficients were determined by observing the resultant differential between ambient and interior temperatures. The values reported, shown in figure 12, were computed by the equation:

$$HTC = \frac{\text{Heat Input}}{T_1 - T_2} \qquad \text{Eq. 1}$$

when HTC = Heat transmission coefficient, Btu/hr (°F Temperature difference between ambient and trailer)

Heat Input = Heat equivalent of electric input for each trailer, Btu/hr

T_1 = Average trailer temperature, °F

T_2 = Average ambient temperature, °F

RELATIVE HEAT TRANSMISSION

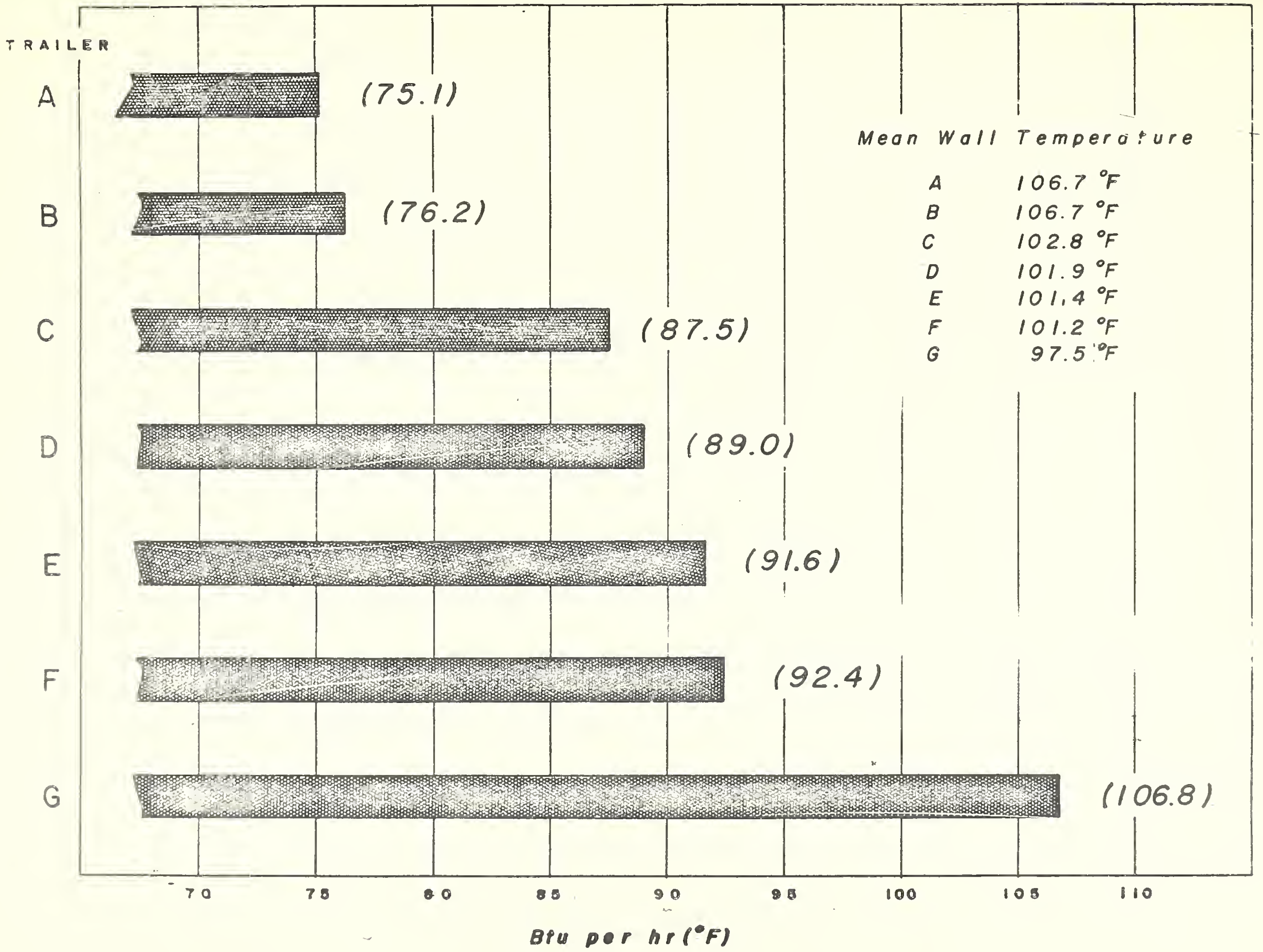


Fig. 12

All values are average for those observed from 3:00 A.M. to 6:00 A.M. on May 12 and 13, when trailer temperatures were at a nighttime minimum for a significant portion of the time most nearly free of sun effects. The average heat input to all trailers was 4535 Btu per hour with individual averages ranging from 4466 to 4582 Btu per hour. The outdoor ambient temperature averaged about 76.6F and the temperature rise of the trailers above ambient ranged from 41.8 to 60.3 degrees F. The actual temperature in the trailers ranged from about 118F to 137F.

Relative Solar Heat Gain

Solar heat gain observations were made during the heat transmission test when trailer temperatures were at a daytime maximum due to sun effects. The relative heating effects due to the sun, as shown in figure 13, ranged from 233 to 1015 Btu per hour and were computed by the equation:

$$HG_s = (T_3 - T_4)\ HTC - \text{Heat Input} \qquad \text{Eq. 2}$$

when HG_s = Relative solar heat gain, Btu/hr

T_3 = Average daytime maximum trailer temperature, °F

T_4 = Average ambient temperature, °F

HTC = Heat transmission coefficient Btu/(hr)(°F Temperature difference), equation 1

Heat Input = Electrical input for each trailer, Btu/hr

All values in the above equation, except HTC, are average for those observed from 3:00 P.M. to 6:00 P.M. on May 12 and 13. HTC, from equation 1, was computed from observations made from 3:00 A.M. to 6:00 A.M. on May 13 and 14. The time periods 3:00 A.M. to 6:00 A.M. and 3:00 P.M. to 6:00 P.M. were selected because the lowest and highest temperatures, respectively, in the trailers were observed at those times.

The average heat input to each trailer during the periods 3:00 P.M. to 6:00 P.M. on May 12 and 13 was 4537 Btu per hour, with individual averages ranging from 4506 to 4579 Btu per hour. The average ambient temperature during these periods was 80.4F. The maximum temperature observed in each trailer ranged from 151.6F to 132.6F as shown in table II.

Table II

Maximum Trailer Interior Air Temperature

Trailer	Temp.
A	145.1F
B	151.6
C	141.0
D	137.3
E	138.9
F	138.6
G	132.6

(These capital letter designations refer to trailers similarly referenced in figures 12, 13, and 14 and in tables III, IV, V, VII, and VIII.)

RELATIVE SOLAR HEAT GAIN

(Observed During Heat-Transmission Test)

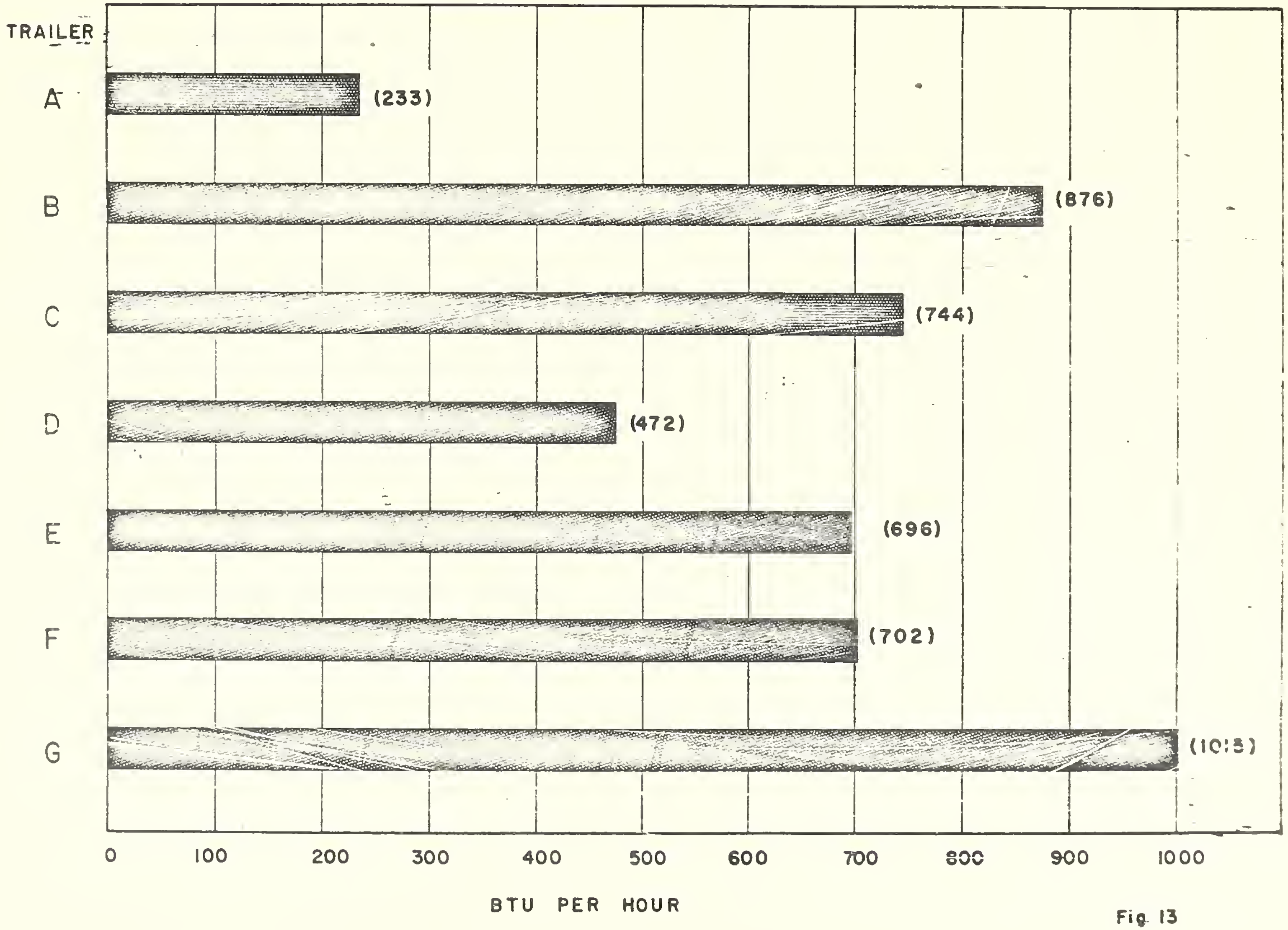


Fig. 13

For the periods 3:00 P.M. to 6:00 P.M. on May 12 and 13, the additional temperature rise of the trailers above ambient caused by the solar heating effect over and above that due to the electrical input, is shown in table III.

Table III

Effect of Solar Energy on Internal Heating of Trailers

Trailer	Temperature rise above ambient due to electrical heat input	Electrical Heat Input Btu/hr	Additional temperature rise due to solar heat	Btu/hr equivalent of solar heat
A	60.4	4539	3.1	233
B	59.2	4511	11.5	876
C	51.5	4506	8.5	744
D	51.0	4575	5.3	472
E	49.5	4514	7.6	696
F	49.1	4536	7.6	702
G	42.5	4579	9.5	1015

The surface temperature of the roof of one of the trailers, (roofs of all the trailers were of bright aluminum), was 145F during exposure to the sun. This was approximately 60 degrees F above ambient temperature. At night surface temperatures on the roof as much as 10 degrees F below ambient were observed.

Warm-up Rate

Figure 14 shows the time required for each empty trailer to warm up to 40F and then to 70F, with no internal heating, after being held at 0F for at least four hours.

The time required for the trailers to warm up from 0F to 70F under the test conditions ranged from nine and one-half to more than 14½ hours.

Although the warm-up test of one of the trailers (other than A) was started 3 hours later than the other six, this is purposely not indicated in figure 14 to prevent identification. Test data recorded beyond 70F trailer temperature is not shown in figure 14 because one of the trailers was inadvertently opened after it had reached 70F. Its temperature position, relative to the other trailers, did not change, however, because of the opening. The warm-up test was continued for 17 hours for six trailers and 14 hours for one trailer. The temperatures in the trailers and the ambient temperature at the conclusion of the test at 5:00 P.M. on May 15 are given in table IV.

TIME REQUIRED for TRAILERS to WARM UP from 0°F to 70°F

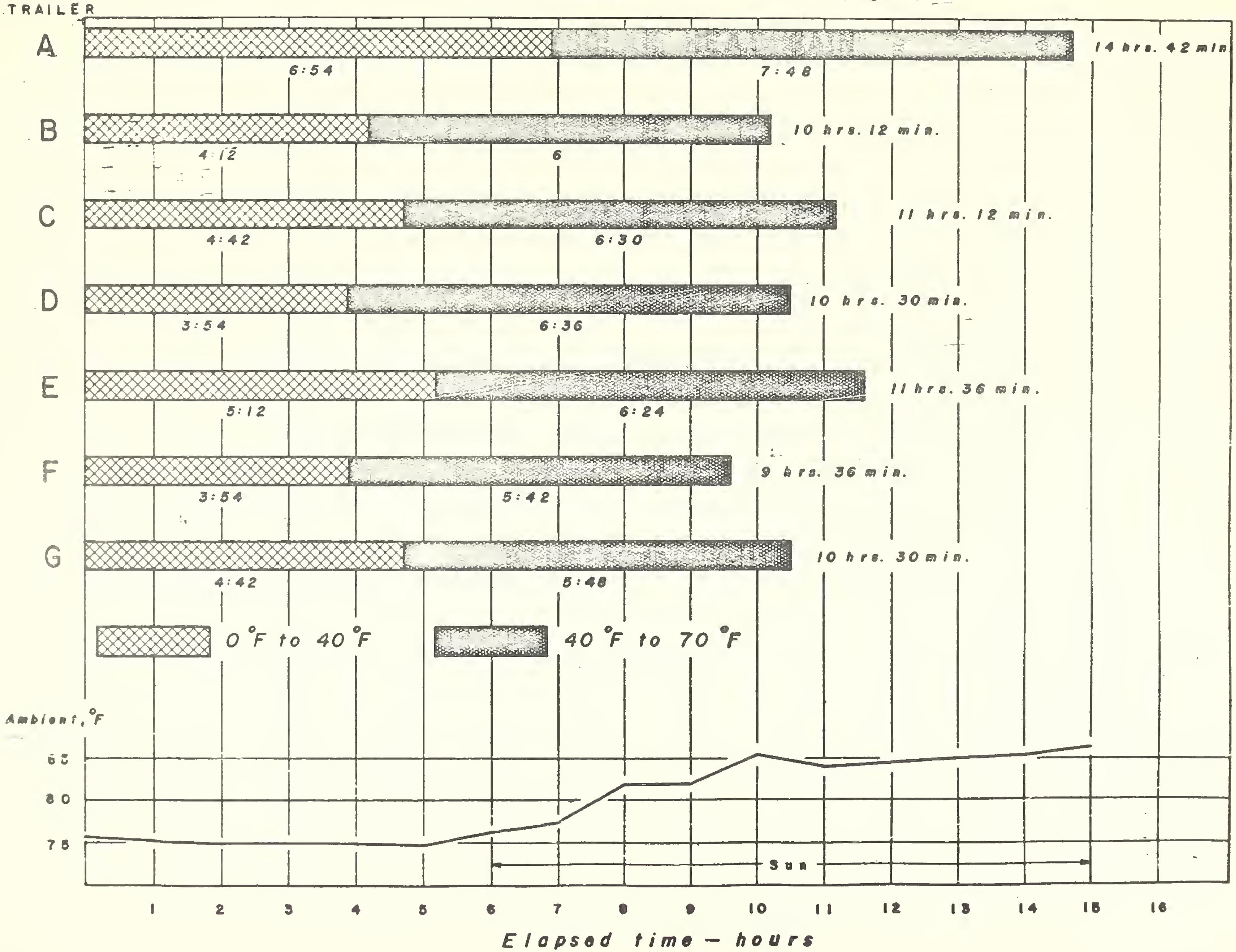


Fig. 14

Table IV

Trailer Temperatures and Ambient Temperature at Conclusion of the Warm-up Test

Trailer	Temperature
A	74F
B	88
C	84
D	87
E	86
F	82
G	88
Ambient	83.4

Comparison of Heat Transmission, Solar Gain, and Warm-up Rate

A comparison of the observed values of heat transmission, solar heat gain, and warm-up rate is given in table V. These results are shown separately in figures 12, 13, and 14. In table V, trailer A, which had the lowest heat transmission and the least solar heat gain is assigned a value of 1.00 and all others are shown in relative order. In figures 12, 13, and 14 and tables II, III, IV, V, VII, and VIII, trailers are cross-identified by capital letter designations. In other figures and tables they are not so identified.

Pull-down Rate

The time required for the trailers to be reduced in temperature by their respective refrigerating units from about 91F to 32F and then to -1F is shown in figure 15. The time required to lower the temperature to -1F ranged from less than three hours to more than fifteen. The air temperatures in the trailers at the start of the pull-down test ranged from 88F to 94F. These temperatures were observed before the refrigerating units were started and after the doors had been closed for 30 minutes, during which time the 16" fan in each trailer was in operation. Neglecting sun load, the approximate mean wall temperature of the trailers ranged from 84F to 87F at the start of the test, and was approximately 38F for all trailers at the end of the test. The electrical input to the 16" fan in each truck ranged from 190 Btu per hour to 392 Btu per hour during the pull-down.

The time required for reduction of trailer temperature from initial temperature to -1F, from initial temperature to 32F, from 60F to 40F, and from 30F to 10F is shown in table VI. Trailers are similarly identified by number in figure 15 and table VI.

Five of the seven trailer units were defrosted, automatically or manually, once during the temperature pull-down to -1F. No defrosts occurred during the other temperature

TIME REQUIRED to REDUCE TRAILER TEMPERATURE from Approx. 91 °F to −1 °F

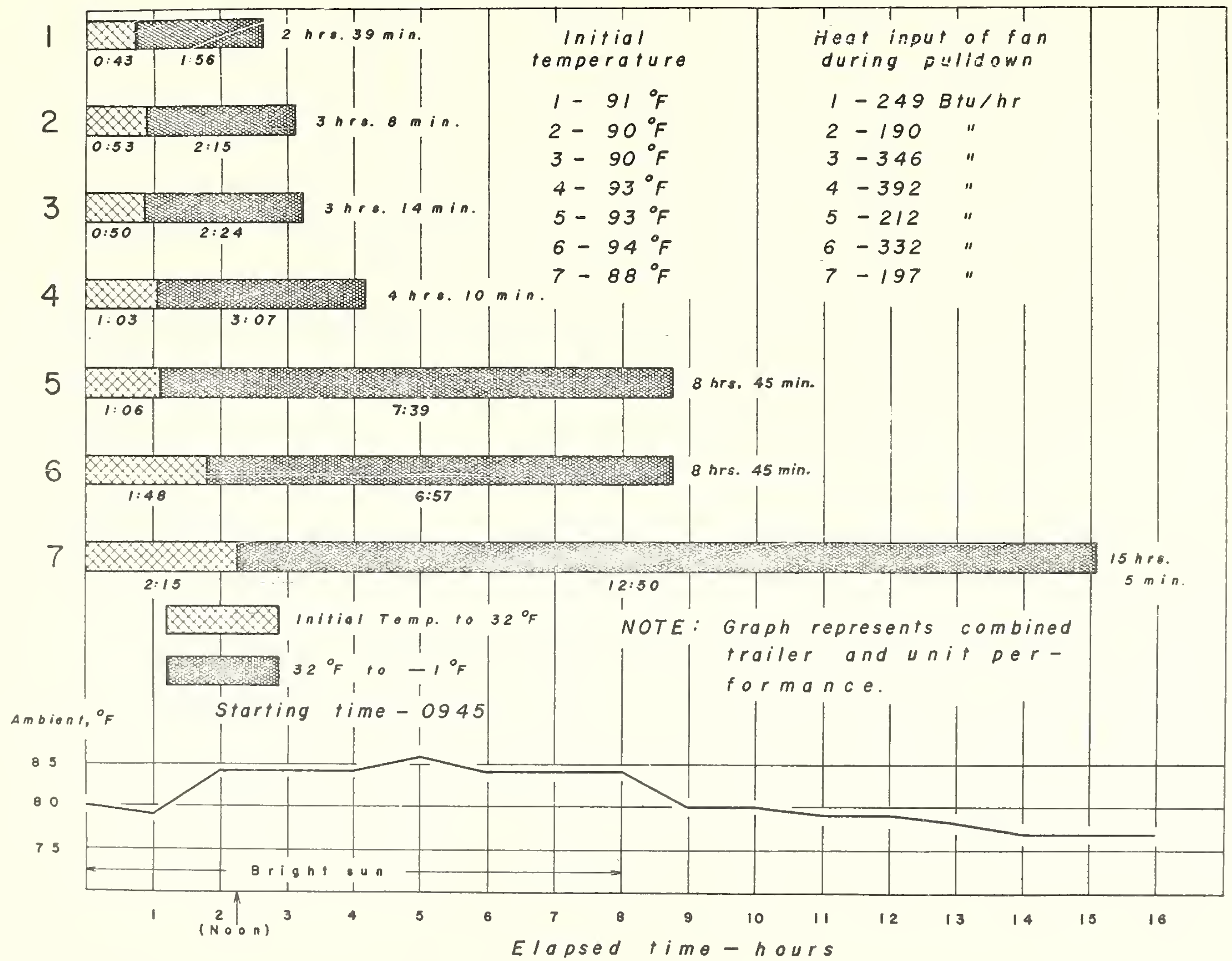


Fig. 15

Table V

Relative Heat Transfer
Characteristics of Seven Trailers

Trailer	Heat Transmission (1.00=75.1 Btu/hr(°F)) See fig. 12	Solar Heat Gain (1.00=233 Btu/hr) See fig. 13
A	1.00	1.00
B	1.01	3.76
C	1.17	3.19
D	1.19	2.03
E	1.22	2.99
F	1.23	3.01
G	1.42	4.36

Warm-up Rates

Trailer	0-70F (1.00=4.8°F/hr)	0-40F (1.00=5.8°F/hr) See fig. 14	40-70F (1.00=3.8°F/hr)
A	1.00	1.00	1.00
B	1.44	1.64	1.30
C	1.31	1.47-	1.20
D	1.40	1.77-	1.18
E	1.27	1.33	1.22
F	1.53	1.77+	1.37
G	1.40	1.47+	1.35

Table VI

Time Required for Temperature Pull-down

Trailer	Initial Temperature °F	Initial Temperature to -1F Hrs:Min.	Initial Temperature to 32F Hrs:Min.	60F to 40F Hrs:Min.	30F to 10F Hrs:Min.
1	91	2:39	0:43	0:19	0:43
2	90	3:08	0:53	0:22	0:56
3	90	3:14	0:50	0:22	0:50
4	93	4:10	1:03	0:25	1:05
5	93	8:45	1:06	0:31	2:33
6	94	8:45	1:48	0:35	2:35
7	88	15:05	2:15	0:44	5:05

ranges listed in table VI. Possible malfunctioning of one or more units during the pull-down test was reported by industry personnel in attendance, and control failure of one unit was remedied promptly at the start of the test. The question was raised whether interior temperatures experienced during the heat loss test might have damaged components of the refrigerating unit. This is not considered likely since the maximum single air temperature observed in the trailers, as shown in table II, ranged from 132.6F to 151.6F. All panels, doors, etc., attached to the refrigerating unit enclosures during the test were closed or adjusted as they would be in normal service.

No determination was made as a part of this test whether the units furnished were similarly rated, or whether accessory equipment, such as protective guards, controllers, etc., was typical to that normally furnished by respective suppliers for commercial application. All units operated on inherent engine power throughout the entire test.

Refrigerating Unit Capacity

The comparative net refrigerating capacity of the units varied from 6,400 to 15,900 Btu per hour, as shown in figure 16, and was observed during the final four hours of operation in the pull-down test, when each trailer was at about 0F interior temperature. The ambient temperature averaged 77.9F for six of the trailers and 75.7F for one of the trailers, and average interior temperatures ranged from -1.4F to 0.6F. Some units were cycling on thermostat during this period; others ran continuously and internal heat loading was different for all trailers.

The net refrigerating capacities reported were computed as follows:

$$Q = \frac{K(HTC)(T_2 - T_1) + H_I}{T_R}$$

where Q = net refrigerating capacity, Btu/hr

HTC = heat transmission coefficient, Btu/hr(°F) (see fig. 12).

T_2 = average ambient temperature, °F

T_1 = average trailer temperature, °F

H_I = internal electric heat load, Btu/hr

T_R = running time of refrigerating unit, percent

K = 1-0.002 (°F change)
= factor for approximate change in HTC with change in mean wall temperature between heat transmission test (in which HTC was determined) and refrigerating unit test.

For all trailers the final four hours of the pull-down test began well after sundown and solar effects were neglected in the above computation.

REFRIGERATING UNIT CAPACITY
(Final 4 hours of pulldown test)

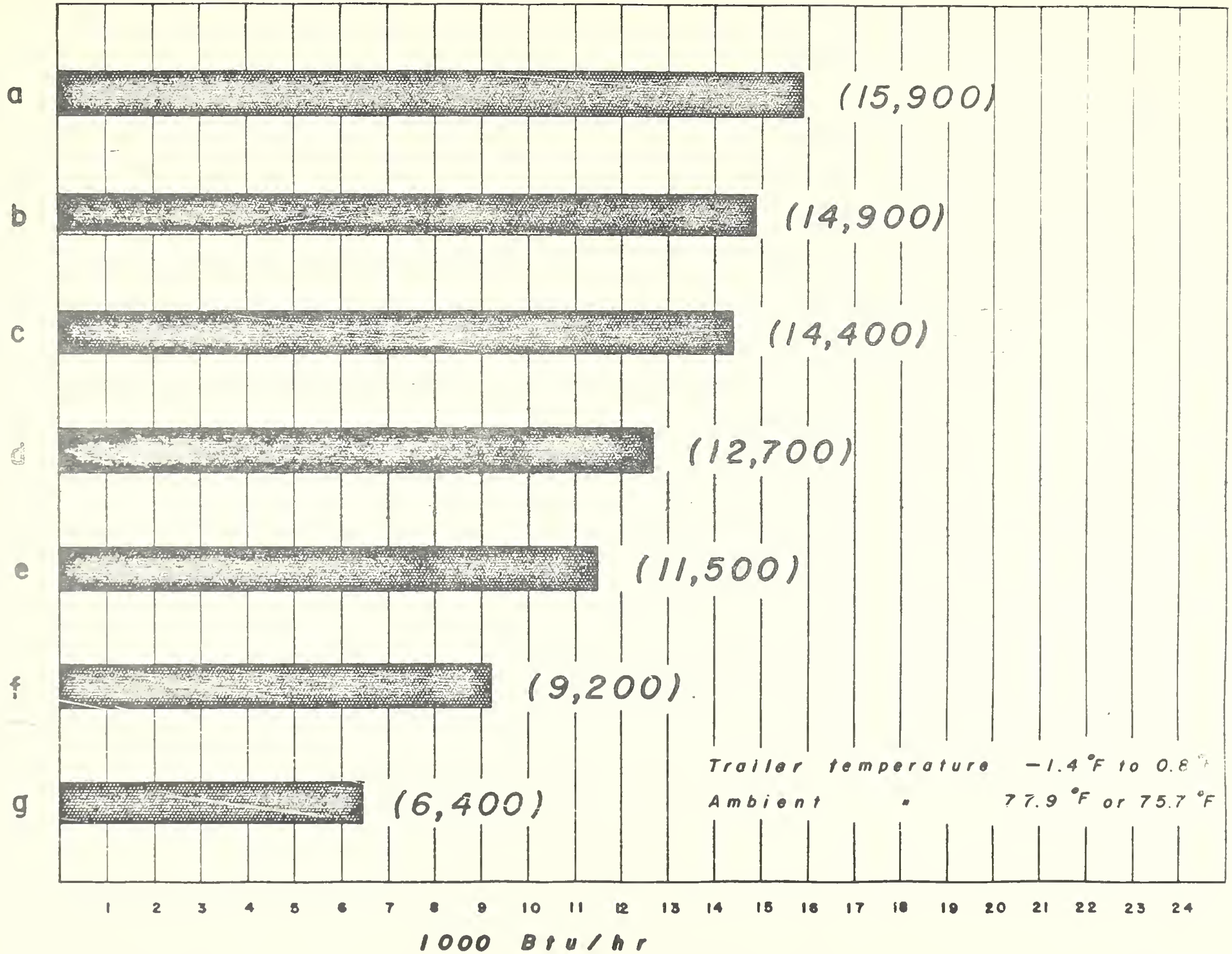


Fig. 16

Sweating of Trailer Exteriors

During the evening hours when all trailers were being held at interior temperatures of about 0F, some "sweating" was observed on all of the test vehicles. It was generally predominant around doors and door frames. Some condensation was observed on roofs and sidewalls and appeared to be forming at regularly-spaced intervals, indicating frame member locations. Since no observation was made of relative humidity during this period, test results are qualitative only.

5. CONCLUSIONS AND DISCUSSION

1. The principal conclusion indicated by this work is that commercial insulated, refrigerated semi-trailers, as typified by the seven units tested, differ to such extent in heat transfer characteristics that prediction of performance is difficult or impossible. Findings which support this conclusion and indicate differences between trailers are discussed later.

2. Adequate procurement specifications are needed which include refrigeration or heat transfer requirements.

3. Adequate test methods and apparatus are needed to permit determination by both operator and manufacturer of heat transfer performance of not only new trailers (and their refrigerating units) but of these same trailers and units after they have been in service.

4. The "warm-up" test suggested as a simple test to determine heat transmission characteristics of refrigerated trailers is completely unreliable for this purpose. This is discussed later under "warm-up test."

It should be noted that the series of tests covered by this report dealt with new, presumably dry trailers and did not encompass heat transfer problems arising from motion, wind, rain, vibration, loading, and other variables which should be considered in a comprehensive study of these vehicles.

The findings which illustrate the differences in performance of different trailers were:

a. Heat Transmission: The heat transmission of the vehicles varied sharply, ranging from 75.1 to 106.8 Btu/hr for each °F of temperature difference between inside and outside.

At hypothetical conditions of 110F ambient temperature and 0F trailer temperature, the heat load due to transmission (correcting for change in mean wall temperature) would be 7100 Btu/hr for the trailer with the lower rate and 10,100 Btu/hr for the one with the higher rate of 106.8 Btu/hr(°F). The difference between trailers of 3000 Btu/hr at hypothetical conditions of 110F and 0F is nearly half the total capacity observed for one of the refrigerating units tested in this study at the more favorable conditions of 80F and 0F. If the unit with the lowest capacity shown in figure 16 had been used to refrigerate the trailer with the highest heat transmission shown in figure 12, it would not have been able to reduce the trailer temperature to 0F in the pull-down test.

b. Solar heat load: The heating effect of the sun differed sharply, nearly 5 to 1, between the several trailers. Bearing in mind that the temperature rise in the trailers due to sun load was determined during the heat loss test when trailer temperatures were already above ambient, it can be safely assumed that the heat gains due to the sun would be still greater when the trailer temperature is lower than ambient. Even so, as shown in table III, heat gain due to sun load ranged from 230 Btu/hr to more than 1000 Btu/hr for the several trailers. As a further indication of the difference between trailers it is interesting to note, from figures 12 and 13 that trailer A, which had the lowest transmission rate, also had the least solar heating effect, while trailer G, which had the highest transmission rate, also had the highest solar heating effect. This would be expected. However, trailer B, which had a transmission rate almost as low as trailer A, had a solar heating effect of 876 Btu/hr, approaching that of the highest, trailer G, 1015 Btu/hr. In table VII the lack of relationship is more clearly demonstrated.

Table VII

Relative Magnitude of Heat Transmission and Solar Heat Effect

Trailer	Transmission Coefficient Btu/hr(°F)	Order		Solar Heat Effect Btu/hr
A	75.1	1	1	233
B	76.2	2	6	876
C	87.5	3	5	744
D	89.0	4	2	472
E	91.6	5	3	696
F	92.4	6	4	702
G	106.8	7	7	1015

Even though the trailers were at different interior temperatures during this test and therefore some comparative value of the preceding is lost, it is significant to note that trailers A and B with the greatest variation in relative order between transmission rate and solar heat effect had similar interior temperatures during the 3:00 A.M. to 6:00 A.M. periods used to determine basic heat transmission rate.

c. Warm-up Test: If this test was suitable for determining heat transmission of a refrigerated trailer, the warm-up rate would be a function of the heat transmission rate. In table VIII, the data shows the extreme lack of relationship between heat transmission rate and warm-up rate from OF-40F. (The OF-40F range is used for example because all trailers passed through this range before sunrise and solar heating is, therefore, not a factor).

Table VIII

Relative Magnitude of
Heat Transmission and Warm-up Rate

Trailer	Heat Transmission Coefficient Btu/hr(°F)	Order		Warm-up Rate OF-40F, °F/hr
A	75.1	1	1	5.8
B	76.2	2	5	9.5
C	87.5	3	3	8.5
D	89.0	4	6	10.3
E	91.6	5	2	7.7
F	92.4	6	7	10.3+
G	106.8	7	4	8.5+

Note that trailer A with the lowest heat transmission rate had the lowest warm-up rate, as might be expected. However, trailer B, with a transmission rate nearly as low as trailer A, had a warm-up rate almost twice as great. Note also trailers C and G, with almost identical warm-up rates, while trailer C had a transmission rate of 87.5 Btu/hr(°F) compared to 106.8 Btu/hr(°F) for trailer G.

d. Pull-down test: The time required to precool a trailer from ambient temperature to below 0F is of major significance to the owner or operator. A strict interpretation of test results (figure 15 and table VI) shows excessive differences in pull-down time (from approximately 92F to -1F) ranging from less than three hours to over 15 hours. Since the excessive time required by trailer 7 can be attributed to probably malfunctioning during at least a part of the pull-down, it may be disregarded for comparative purposes.

Comparing, instead, the average pull-down time for trailers 1 and 2, 2 hr, 54 min., and trailers 5 and 6, 8 hrs, 45 min., shows that variations of more than 3 to 1 can be expected unless purchase specifications and tests to determine this important performance requirement are included in the procurement of trailers. It must, of course, be clearly recognized that pull-down time is not a function solely of trailer mass or construction, or solely of refrigerating unit performance, but is, instead, a function of all of these variables.

e. Refrigerating unit capacity test: The net refrigerating effect of the units in the several trailers differed greatly. Observed under conditions of 0F trailer temperature and 80F ambient temperature, the average of the two highest, 15,370 Btu/hr, is nearly twice the average of the two lowest, 7,780 Btu/hr. Assuming these units were competitively rated, this points out the need for adequate specifications and performance tests to assure proper matching of the trailer and its refrigerating unit.

It follows then that the logical first step in matching a refrigerating unit to a refrigerated trailer is the determination of all pertinent thermal characteristics of the trailer. Then and then only can an applicable set of requirements for refrigerating unit performance be set out. To establish the necessary thermal characteristics for refrigerated trailers, detailed laboratory and over-the-road studies are needed to establish requirements in keeping with the best commercial practice, and standard test methods and apparatus must be devised for evaluating performance of trailers both at the time of procurement and at intervals throughout their service life.

6. GENERAL DISCUSSION

The manufacturers who voluntarily submitted trailers and units for these observations have rendered a significant service, not only to their part of the industry but also to the operators who buy and use their products. The tests, perhaps for the first time, have demonstrated certain ranges of performance which exist among reputable products competitively and normally furnished for similar service. Naturally, every reasonable precaution has been taken to prevent the presenting of test results so as to aid or otherwise affect any one manufacturer-participant in comparison with others. Since the work was conducted without restricting observers from the area, some conclusions will probably be expressed which may or may not correctly indicate relative performance. The essential temperature data for all phases of the test was coded at the time of observation in such a manner that specific performance values necessary for accurate reporting of any test for a particular trailer are not known to others than the authors.

The necessity for this manner of reporting is obvious; the purpose of the project was to determine ranges of performance of typical <u>new</u> refrigerated, 35-foot semi-trailers, not to show which trailer was the best or poorest in any category.

In order to assist the engineering departments of the various participating manufacturers information pertaining to the general (not specific) relative position of their respective trailer has been made available to each participant who has agreed to refrain from using the information in advertising or sales promotion in any manner.

Although these tests yielded reliable relative data, they are only preliminary in nature to the important comparative work yet to be done. Only new, supposedly dry, trailers were used; no interpretation was made of air infiltration; no comparison was made between still tests and over-the-road conditions; and steady-state conditions could not be achieved because trailers were exposed to changing wind, sun, and ambient temperatures. A major unknown variable in connection with the heat load of refrigerated trailers--the effect of moisture gain in the insulated panels--was not considered.

Prompt coordinated industry and government action in conducting further study of these problems can result in better equipment, rated under standard conditions, permitting optimum economic utilization of these products by the trucking industry.

It is not contemplated that comparative performance data on competing products shall ever be published, but the authors recommend that standard rating conditions, test methods and apparatus be adapted or developed by cooperation of all parties to the rapidly-expanding industry of transportation of perishables by motor truck. By means of such standards, manufacturers can give assurance to purchasers about the performance of equipment; spoilage in transit can be minimized and foods can be delivered to consumers in good condition with greater ease.

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