Hot Weather Shelter For Lactating Dairy Cattle

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Contents

PART I

PART II

PART III

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The depressing effects of high environmental temperatures on milk production, feed consumption and body weight of dairy cows are well known. The reactions of dairy cattle subjected to high temperatures under controlled atmospheric conditions have been reported and reviewed (1, 3, 11, 15, 18, 25, 27).* High temperature effects under natural or field conditions have also been reported (4, 6, 8, 11, 13, 20, 21, 26, 28, 29, 30).

Means of reducing stress from high temperatures through practical measures include provisions of shade (4, 8, 9, 14, 20, 21), sprinkling with water (19, 31, 32), evaporative coolers (4, 9, 20, 21), and air conditioning (11, 12).

Ragsdale *et al.* (24) report depressing effects on milk production began to be noticed when temperatures exceeded 85° F. Other findings by Ragsdale *et al.* (23) indicate that the critical temperature may be conditioned by breed or size of cattle. Brody (2) reported that 70° to 100° F. diurnal temperature rhythm had roughly the same depressing effect on lactating dairy cattle as an 85° F. constant environmental temperature. Also, it was noted that dairy cattle seemed to become acclimated to the temperature after the first week of exposure to the 70° to 100° F. diurnal rhythm; whereas a constant temperature of 85° F. caused deterioration.

States in the southwestern and south central United States have an appreciable number of hours of temperature above 85° F. (Figure 1). Records of the United States Weather Bureau indicate that large portions of Oklahoma and Texas have 1000 hours or more each year when

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*Numerals in parentheses refer to "Literature Cited," pages 45-46.

Research reported herein was done under Oklahoma Station Project 677.

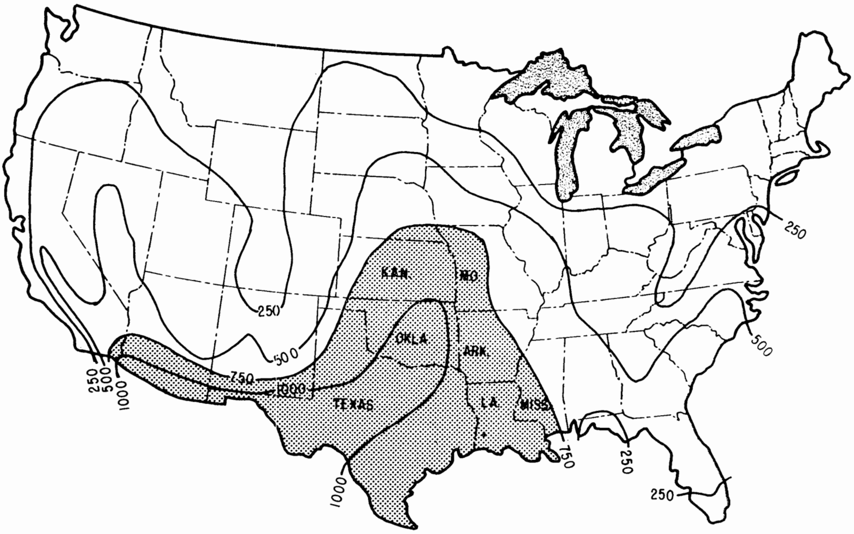


Fig. 1.—Average annual number of hours of temperatures above 85° F. occurring in the U. S., based on 5-year records, U. S. Weather Bureau.

dry bulb temperatures are above 85° F. This amounts to 11 percent of the total time each year.

The states of Texas, Oklahoma, Kansas, Missouri, Arkansas, Louisiana, and Mississippi all lie within or partially within a zone having more than 750 hours of temperature above 85° F. each year. According to the 1950 census (34) this area has 19 percent of the dairy cow population in the U. S., but in 1949 produced only 8.6 percent of the whole milk and 14.9 percent of the cream sold in the United States. Conditions other than weather doubtless contribute to this situation. However, experiments in controlled temperature chambers have shown that hot weather is a depressing factor.

The Oklahoma Agricultural Experiment Station began experiments in the late summer of 1950 to obtain data on the performance and use of a temperature-controlled, hot weather shelter for dairy cattle as compared to a more or less conventional open-front shelter; and to obtain data on the performance of lactating dairy cattle that used the shelters. The experiments were continued through 1953. During 1952 and 1953, the performance of lactating dairy cattle with no summertime shelter whatever was compared with that of cattle with shelter. The engineering and cow performance aspects of the work are reported here in Parts I and II, respectively.

PART I

Engineering Aspects of Environmental Control in Hot Weather Shelters

METHODS AND MATERIALS

Two special structures were erected for providing temperature-controlled and non-temperature-controlled shelter, respectively.

The temperature-controlled shelter was 26 by 50 feet with an entrance vestibule and instrument room on the east end. Lightweight concrete blocks, manufactured with an expanded shale aggregate and with core spaces filled with the same kind of aggregate to reduce heat gain, were used for the wall construction. Certain sections of the south and east walls were built with other types of concrete block and core filling for experiments on heat gain. The south and north walls and windows were shaded by an extended roof overhang to reduce heat gain from solar irradiation.

The shelter was ceiled with cement asbestos sheathing and insulated over the ceiling with a nominal 2-inch thick, paper-backed insulation blanket. The attic space floor was unlined. The attic space was ventilated through a screened and louvered opening in the east gable end with a net free opening of 11½ square feet and and access door in the west gable end with an opening area of approximately 7½ square feet. The roof was covered with heavyweight, 2½-inch corrugated aluminum roofing donated by Kaiser Aluminum and Chemical Sales, Inc.

Cooling and ventilating equipment for the cooled shelter included an 8000 cfm evaporative cooler which discharged into the west end of the shelter, and two 30-inch attic fans. Cooler operation was controlled by a standard, bi-metallic switch which responded to a five-degree temperature variation. The low initial cost and energy cost of evaporative cooling as compared to cooling with refrigerative equipment was the chief consideration in the choice of evaporative cooling.

Operation of the evaporative cooler in the cooled shelter was controlled by a temperature-sensitive switch, which was normally adjusted to turn the cooler on at 80° F. Continuous traces of temperature and relative humidity were maintained in the cool shelter with a recording instrument mounted 3 feet above the floor in the central area of the shelter. A recording instrument to provide continuous traces of outdoor temperature and humidity was maintained in a standard outdoor instrument shelter in the pasture area in which the experimental shelters were located.

It should be recognized that complete temperature control is not possible with evaporative cooling, since outdoor wet bulb temperature limits the dry bulb temperature depression which can be obtained. However, if dairy cattle shelter cooling were to be applied in dairy farm management, managers would doubtless adopt the cooling system which would be lowest in cost, but adequate insofar as temperature control is concerned. Since evaporative coolers of adequate air delivery rate can generally maintain temperatures below 85° F. in the cooled space, it appeared that evaporative cooling would be a reasonable choice.

The non-temperature controlled shelter was a conventional, open-front, south-facing loafing barn 26 feet 6 inches wide by 48 feet 8 inches long. Trussed rafters on a pole supporting framework comprised the structural frame. The walls were sheathed with 1-inch vertical boards. The roof was covered with heavyweight, 2½-inch corrugated aluminum roofing donated by Kaiser Aluminum and Chemical Sales, Inc. The north wall was equipped with 4 by 4 foot plywood panels which could be individually removed to provide various patterns of rear-wall ventilation opening.

RESULTS

The site for the two experimental shelters was on the south slope of a pasture, well exposed to prevailing southerly winds. The pasture was divided by fences, so that each shelter was in a pasture area of approximately 15 acres. The pasture included some shade trees which were fenced off during the second year of the experiment to deny the cows access to shade from trees.

Cool Shelter Temperature

Analysis of temperature in the cool shelter for the first season, 1950, showed that the maximum indoor dry bulb temperature was 84° F.; and that the average indoor temperature during the hottest hours of seven hottest days averaged 80° F. Outdoor-indoor temperature difference averaged 11 F. degrees during the hottest part of the day, with an average maximum difference of 12 F. degrees. During the 1951 experimental period, the maximum daytime temperatures in the shelter averaged 84° F., with an average maximum outdoor temperature of 92.5° F.

Linear regression analyses of the outdoor and indoor dry bulb temperatures at 4:00 p.m., normally the hour of peak temperatures, were made for the data collected during the 1952 and 1953 summers. These analyses yielded the regression equations $t_i=0.298t_o+56.5$ for the 1952 data; and $t_i=0.227\ t+61.6$ for the 1953 data. In these experiments t_i is the indoor dry bulb temperature and t_o is the outdoor dry bulb temperature, both in degrees Fahrenheit, at 4:00 p.m. These relationships are graphed in Figure 2. During both the 1952 and 1953 summers, the shelter was continuously occupied by four lactating dairy cows from shortly after the morning milking until they were taken out for the afternoon milking at approximately 4:00 p.m. While the barn was occupied by cattle during daytime, all doors were closed, but windows were open for exhaust for the cooler. Between the evening and morning milkings, the cattle were free to leave the shelter and graze in adjoining pasture.

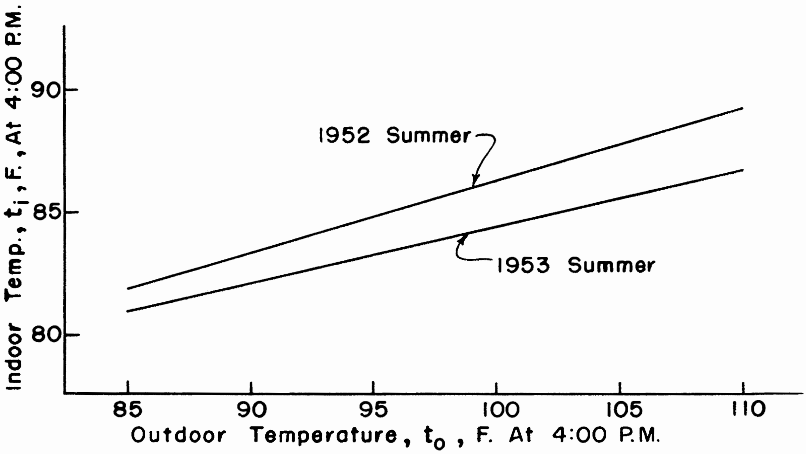


Fig. 2.—Average variation of indoor, cooled-shelter temperature with outdoor temperature.

Cool Shelter Humidity

A characteristic of evaporative cooling is that the moisture ratio, and hence the relative humidity and partial pressure of the water vapor in the air, are increased, thus making heat dissipation through evaporation of moisture from surfaces of dairy cattle more difficult. Relative humidity in the cool shelter during the 1952 and 1953 summers generally fluctuated between 70 and 80 percent during the afternoon hours when temperatures were highest, and seldom exceeded 80 percent. Mean relative humidity at 4:00 p.m. averaged 72 percent during the 1952 summer. These humidity conditions were typical for the summers of 1951 and 1953 as well. During the 1950 season, the experiments were begun during the latter part of the summer during cooler weather. Relative humidities during that season averaged approximately 80 percent in the shelter with maximums of as much as 90 percent.

Cool Shelter Fly Control and Cleanliness

The increased relative humidity due to evaporative cooling was accompanied by fly and odor problems. The combination of high humidities and cool temperatures seemed to be attractive to flies. Measures to control flies included screening of windows which were kept open for cooler exhaust, spraying, and a network of cordage soaked with a toxic liquid and suspended from the ceiling. However, in spite of control measures, the fly population was generally at an objectional level.

The increased humidity seemed to accentuate the normal cow odor, and to require more bedding and more frequent cleaning than would be needed for an ordinary, open-type loafing barn during the summer season.

Open Shelter Temperature

In a dry climate such as is characteristic of central Oklahoma during summertime, the dry bulb temperature and air movement rate are important indices of comfort for cattle in an open shelter with a high roof. An analysis was made of maximum temperatures in the shelter for a 48-day period during the 1952 summer. These temperatures were significantly higher than the maximum outdoor temperatures by ½ to 1½ Fahrenheit degrees. The temperatures were all measured with all of the rear wall openings closed. It is believed that differences would have been even smaller had the rear wall panels been removed to allow free ventilation through the shelter.

Open Shelter Natural Ventilation

Experiments were conducted during 1950 and 1952 to evaluate the effect of rear wall openings on air motion through the open-front shelter. The rear wall consisted of 4 ft. by 4 ft. panels which could be individually removed. The method of conducting the experiment consisted in removing panels to provide the desired amount of opening area expressed as a percentage of the gross rear wall area. Anemometer traverses were then made at heights of 2½ ft. and 5 ft., respectively, with a rotating vane anemometer. One such series of traverses were made along a line 6 ft. from the open front of the shelter, and one along a line 6 ft. ahead of the rear wall. Simultaneous anemometer readings were made in the shelter and 25 ft. beyond the end. All observations were made during southerly winds, with anemometers oriented to face south.

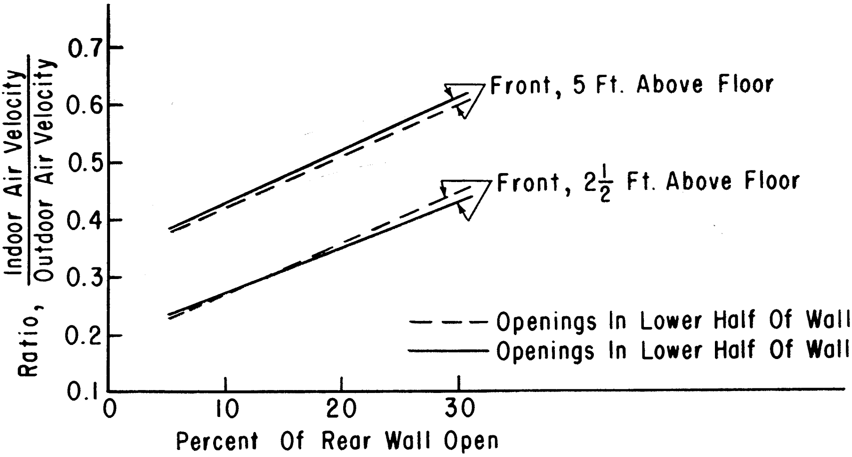
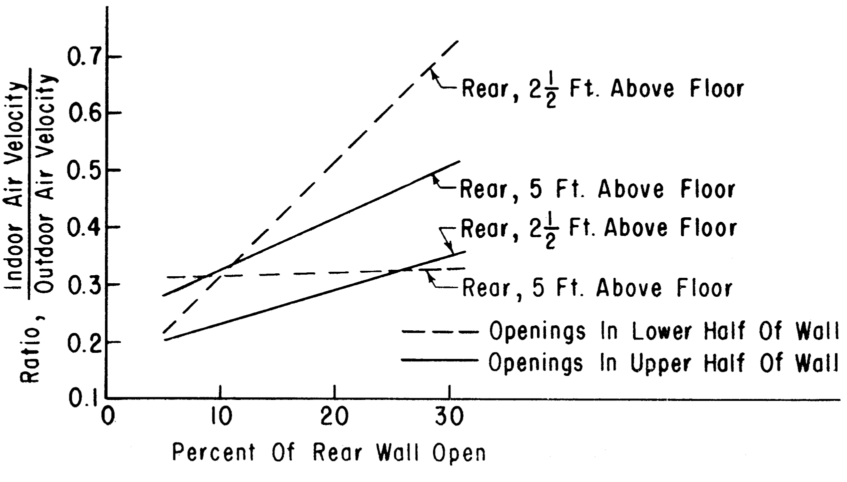


Fig. 3.—Effect of openings in rear wall of an open shelter on air motion at front of shelter.

The results of these experiments are graphed in Figure 3 for air motion at the front of the shelter, and Figure 4 for air motion at the rear of the shelter. These graphs were fitted by linear regression analysis to averages of velocity readings at 4 ft. intervals through the two 12-ft. center bay of the shelter. The end walls produced end effects which reduced the wind velocities near the end wall as is apparent in Figure 5. Hence, the data of Figures 3 and 4 are applicable to only the central portions of an open shelter to within approximately 12 ft. from each end wall.

Fig. 4.—Effect of openings in rear wall of an open shelter on air motion at rear of shelter.



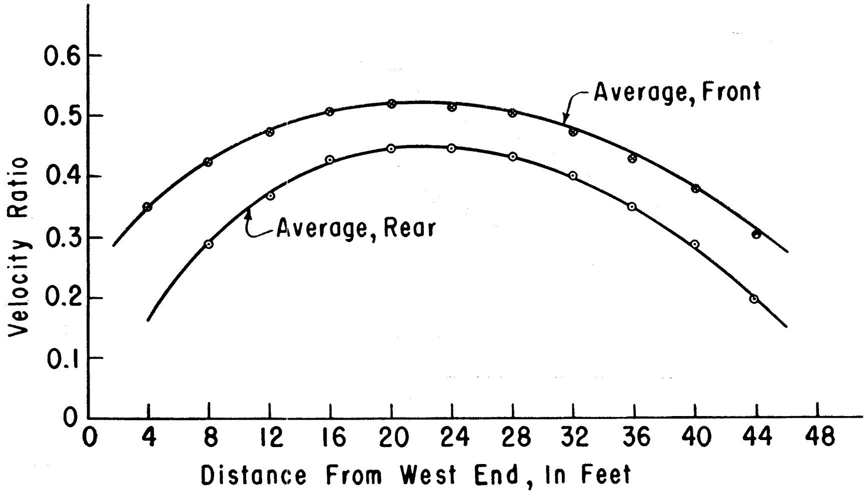


Fig. 5.—End wall effects on air motion through an open shelter.

It is clear that air motion can be markedly increased by openings in the rear wall of an open front shelter which faces prevailing winds. Effects at the front half of the shelter seem to be independent of whether the rear openings are low or high in the wall. However, a "funneling" effect occurs in the rear half of the shelter such that wind speeds are much higher near the floor than at the 5 ft. level if the openings are in the lower half of the wall.

No effect was noted due to horizontal discontinuity of the rear wall openings. In some cases, only every third or every other panel was removed. However, no appreciable differences were noted in wind speeds ahead of the closed panels as compared to the open panels.

Air motion is known to have an important effect on surface temperatures and the temperature gradient at the surface of dairy cattle. Therefore, it seems desirable that open-front cattle shelters which are intended to provide maximum hot weather comfort be equipped with generous openings in the lower portions of the rear wall. Provision of openings amounting to 1/3 of the gross area of the rear wall should produce air speeds in the central area of the shelter approximately 1/2 or more of the outdoor wind speed, if the shelter faces the wind.

Open Shelter Cleanliness

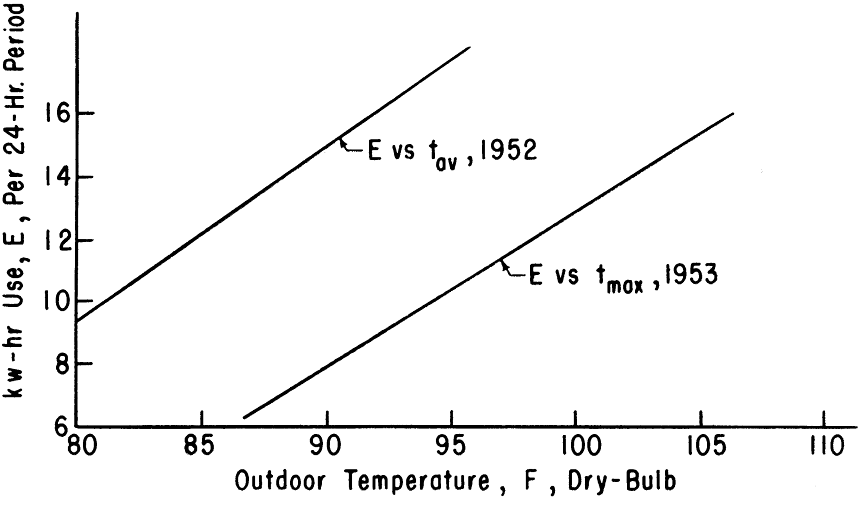
As contrasted with the evaporatively-cooled shelter, no cleaning or bedding were required for the open-front shelter, since the free ventilation of the shelters maintained dry, relatively clean conditions throughout the summer. The fly population did not seem as high or troublesome to the cattle in the open shelter as in the cool shelter, although no fly counts or studies of fly population were conducted.

Energy Use by Evaporative Cooler

Energy use by the evaporative cooler in the cool shelter was metered throughout the experiments. The mean energy use per 24 hr. period during July and August, 1951, 1952, and 1953 was 8.77 kw.-hr., or 0.783 kw.-hr. per 24 hr. period per 1000 cu. ft. of volume in the cooled shelter. In 1950, the experiment did not commence until August. 1. The mean power consumption for the month of August, 1950, was 9.57 kw.-hr. per 24 hr. period. For the entire summer experimental period, which for the years 1951 through 1953 averaged 98 days in June, July, August, and September the mean power use was 8.02 kw.-hr. per 24 hr. period, or 0.716 kw.-hr. per 24 period per 1000 cu. ft. of cooled space. The cooler had a nominal rating of 8000 cfm., or a nominal capacity of 0.714 air changes per minute for the shelter space.

A study was made of the data on energy use by the evaporative cooler as a function of the outdoor average dry bulb temperature during the 1952 summer, and the maximum dry bulb temperature during the 1953 summer. The average temperature was taken as the mean of the daily maximum and minimum. The results of fitting a straight line by least squares to the data are shown in Figure 6. It is noted that power use for evaporative cooling more than doubles when the maximum outdoor temperature is 100° F. as compared to 85° F.

Fig. 6.—Energy use for evaporative cooling of experimental dairy cattle shelter.



Effect of Attic Fan Operation

An experiment was conducted during the summer of 1952 to study the effect on evaporative cooling requirements of operation of attic fans to accomplish nighttime cooling. Such cooling effect could conceivably reduce the need for daytime evaporative cooling. The experiment covered a 50-day period, during which 5 five-day periods were scheduled with and without attic fan operation, respectively. When the attic fans were used, the ceiling hatches to the fan chambers were opened at between 4:30 and 5:00 p.m. Time-controlled switches for the fans were set to run the attic fans from 4:00 to 6:00 a.m. the following morning, since the lowest nighttime temperatures usually occur during that time.

Mean energy consumption by the evaporative cooler during the experiment was 10.2 kw.-hr. per 24 hr. when no attic fan ventilation was used, and 9.7 kw.-hr. when evaporative cooling was supplemented by use of attic fans. Analysis of variance of the energy use data as affected by attic fan ventilation yielded an "f" value non-significant at the five percent level.

Sol-Air Temperature Studies

Solar irradiation is one of the important factors which determine heat gain to building and animal surface during hot summer weather. In these experiments on hot weather shelter for dairy cattle, it was found necessary to evaluate heat gain due to solar irradiation in order to compare the performance of several building material surfaces; and to compare dairy cow surfaces of differing characteristics and under varying wind speeds. It was found that the sol-air temperature concept was useful for this purpose. Results of these experiments have been reported (21,22).

In these experiments, the sol-air temperature concept was found to be useful as a basis for evaluating the heat gain characteristics of different kinds of concrete block masonry wall construction in the cooled dairy cattle shelter, for comparing surface temperatures of metal roof coverings, and for evaluating the temperature response of dairy cattle surfaces outdoors in hot weather.

Cattle Surfaces Under Metal Roofs

The sol-air thermometer was used to measure the temperature rise of four cattle surface specimens when exposed to irradiation from the galvanized steel roof covering on the open-front shelter used in these

Table I.—Surface Temperature Rise of Cattle Surface Specimens, August 11, 1953.

Effect	Mean Temperature Rise, t_e - t_0	
	Deg. F	Percent
Breed and Color		
Hereford, red	3.70	100
Aberdeen-Angus, black	2.74	74
Jersey, fawn	2.34	63
Hereford, white	2.30	62
Time of Observation		
1204 p.m.	2.30	55
1217	1.92	46
1225	0.77	18
1231	0.85	23
1239	3.70	88
1252	3.33	79
1302	2.15	51
1317	3.53	84
1332	3.37	80
1347	3.36	80
1402	4.19	100
1417	2.40	57

experiments. The sol-air thermometer was mounted 4 ft. above the earth floor and 10 ft. from the east end of the shelter and approximately 8 ft. from the south-facing open-front. A total of 12 sets of observations were made at 15 minute intervals (approximately) during the afternoon of August 11, 1953. Bright sunshine on the metal roofs prevailed during the observations. Air temperatures varied from 91.5° F. to 99.0° F. Each set of observations on each specimen included readings at each of three thermocouple junctions on each skin specimen. Wind speed through the shelter varied from 0 to 260 ft/min.

The temperature rise of the specimen's surfaces due to irradiation from the roof and other parts of the shelter was computed for each observation by subtracting the air temperature from the specimen's surface temperature. The means of the temperature rises are listed in Table I on the basis of differences in color and breed of cattle from which the specimens were obtained; and time of observation. Statistical analysis of variance in temperature rise due to differences in specimens and hour of observation indicated that these effects were statistically significant above the one percent confidence level. These temperature rises may be regarded as the additional temperature increment by which the air in the shelter should be warmed to produce the same heat gain to upward-facing cattle surfaces as is produced by irradiation from the metal roof and other parts of the shelter. It is evident that the lighter colored hair coats have a definite advantage compared to a black Aberdeen-Angus hair coat. It is of interest that the radiation effect, principally from the metal roof covering on the south slope of the shelter, was sufficient to give a significant and measurable response in the sol-air thermometer.

Shelter Heat Gain Studies

One of the objectives of the shelter studies was to obtain data on the amount of heat gain through roof and wall components of shelters. Such data can be of help in selection of materials which will minimize heat gain to the interior of a shelter and as a result reduce the heating load on cooling equipment and animals. Extensive data on the thermal properties of many different construction materials are currently summarized in the*ASHRAE Guide,* but data are not available for materials including 8-inch concrete block masonry and metal roof coverings—both of which are important construction materials for livestock shelters. Therefore, experiments were conducted to (1) compare the heat gain characteristics of different kinds of 8-inch concrete block masonry construction, (2) evaluate radiant heat gain from metal roof coverings, and (3) study the effect of attic space ventilation on temperatures in attic spaces over cooled shelters.

Heat Gain; Concrete Block Masonry

The west wall of the temperature-controlled livestock shelter included twelve special sections which were incorporated in the wall during construction. These sections were arranged as in Figure 7. Sections 3, 6, 7, and 10 were constructed with pumice aggregate block; sections 2, 5, 8, and 11 with sand and crushed rock aggregate block; and sections 1, 4, 9, and 12 with expanded shale aggregate block. The cores of the block in lower sections 4 and 12 were filled with expanded shale aggregate. The cores in the other lower sections were filled with pumice aggregate. The upper sections were not filled. Painting treatment of the exterior surfaces consisted of two coats of portland cement base white paint on sections 7 through 12, while sections 1 through 6 were unpainted. The appearance of panels 7 through 12 before painting is illustrated in Figure 8. The indoor surfaces of the walls and ceiling of the shelter were painted white.

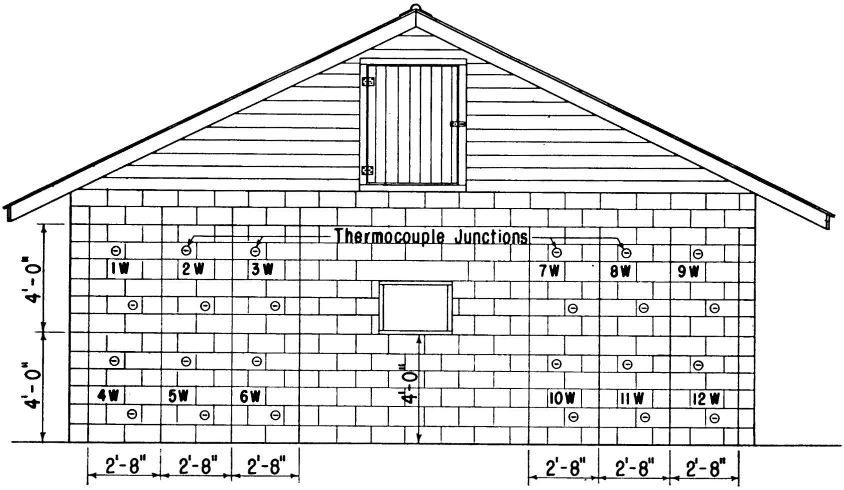
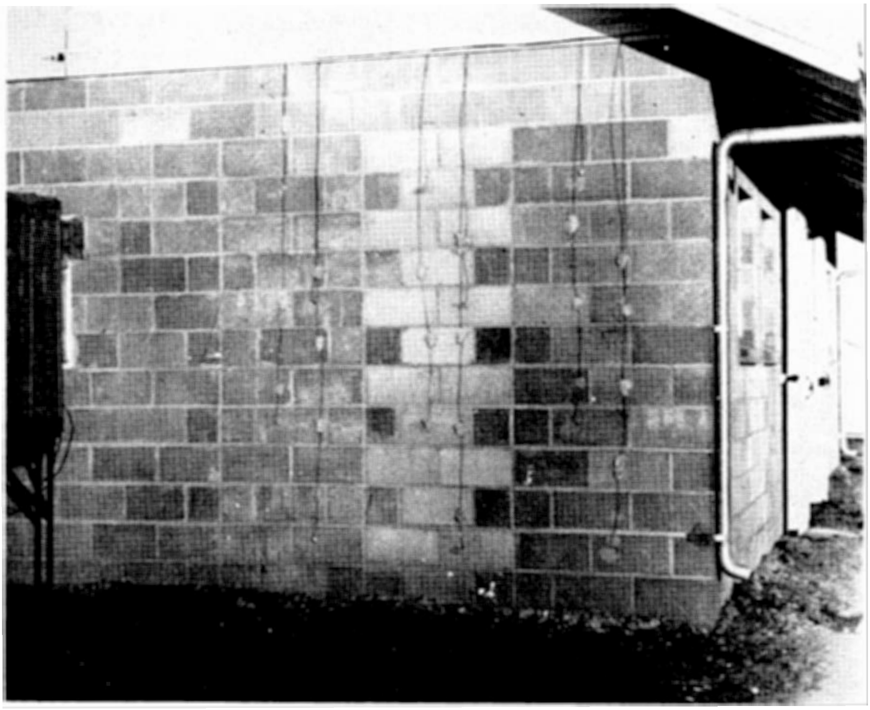


Fig. 7.—Experimental panels of concrete block masonry in west-facing wall of cattle shelter.

Fig. 8.—Appearance of experimental panels before painting.



The west wall was chosen for studies of heat gain through concrete block masonry because high outdoor temperatures and maximum solar irradiation intensity generally coincide for west-facing surfaces. Hence, differences in heat gain resulting from different block treatments or characteristics are accentuated and more readily observed.

Data on heat gain through the special concrete block masonry sections were collected with a heat flow meter. This device consists of a thin bakelite wafer fastened or held in intimate contact with the surface from which heat transfer is to be measured. Thermopiles embedded in each face of the meter generate an e.m.f. due to the temperature gradient which exists across the wafer. In these experiments a recording potentiometer was used to obtain a continuous trace of meter output. The meter is calibrated in terms of btu per hr.-sq. ft. per millivolt output. Figure 9 depicts the heat flow meter in place on the inside wall face of one of the special wall sections. Drafting tape was used to seal the edges of the meter to prevent air circulation between the wall surface and contact face of the meter.

Data on heat gain for at least one 24-hr. period were collected through each of the west wall sections on days when solar irradiation was relatively undiminished by clouds or haze.

Fig. 9.—Heat flow meter installed on inside face of west wall, experimental shelter.

Since heat gain data could not be collected simultaneously for all twelve of the special sections but instead was obtained for only one section at a time per 24-hr. period, the data reflected the effects of day-to-day differences in outdoor weather conditions as well as differences in characteristics of the concrete block masonry. Therefore, it was necessary to reduce the data to a uniform basis which would not be unduly confounded by differences in solar irradiation, outdoor temperature, and indoor temperature. This was done by selecting the three consecutive maximum values of heat gain for each type and treatment of block as measured by the heat gain meter and dividing each of the maximum results by the corresponding one of three consecutive maximum values of "sol-air minus indoor air temperature" to obtain a coefficient, designated $U_{e,max}$, which has the dimensions of btu/hr.-sq. ft.-deg. temperature difference. Therefore, $U_{e,max}$ is defined by the expression:

$$U_{e,max} = (q/A)_{max} / (t_e - t_i)_{max} \qquad \text{(Equation 1)}$$

In this study the sol-air temperature t_e was computed for half-hour intervals on the basis of measured values of solar irradiation intensity and previously determined values of b/f_{cro} for the concrete block masonry surfaces obtained from sol-air thermometer studies. The indoor temperature t_i was taken as the mean of temperatures read at half-hour intervals during the hours 1300 to 2030 from a continuous trace of indoor temperatures. Therefore, it is assumed that the indoor air temperature was constant at this mean value—an assumption which was not far from reality since the indoor temperature seldom fluctuated more than 3 or 4 degrees during these hours.

The mean time lag between the hour of maximum temperature difference $(t_e - t_i)$ and maximum heat gain was taken as the interval between the mean time of occurrence of the maximum temperature difference and maximum heat gain.

Results of the analysis of heat gain are presented in Table II. The values of $U_{e,max}$ were subjected to statistical analysis of variance with the results as given in Table III. All of the variance ratios were found to be significant above the 99 percent confidence level.

It is clear that by appropriate selection and treatment of 8-inch concrete block for wall construction of cooled shelters, maximum heat gain rate can be reduced to less than one-half of the highest values that can occur. Concrete block made with pumice aggregate exhibited a $U_{e,max}$ of about 0.25 when the cores are filled with pumice aggregate and the weather side is painted white as compared to a value of 0.56 for block manufactured with sand and crushed rock aggregate, unpainted and with cores empty.

Although the average reduction in the mean value of $U_{e,max}$ due to white paint as compared to an unpainted surface was approximately 13 percent, the effect was not consistent as is apparent from the $U_{e,max}$ values for expanded shale aggregate block, for example. It appears that these inconsistent variations gave rise to the relatively large variance ratio due to "Interactions" in Table III. It is to be noted that the expanded shale aggregate concrete block sections show little effect due to either painting or core filling. It is believed that such effects may have been obscured because all of the expanded shale block sections were at

Table II.—Analysis of Heat Gain, Concrete Block Masonry Walls, West-Facing Exposure

	Kind of Aggregate Used in Manufacture of Block											
	Expanded Shale				Sand and Crushed Rock				Pumice			
	Painted		Unpainted		Painted		Unpainted		Painted		Unpainted	
	Filled	Empty	Filled	Empty	Filled	Empty	Filled	Empty	Filled	Empty	Filled	Empty
$U_{e,max}$	0.274	0.286	0.300	0.283	0.403	0.533	0.479	0.554	0.312	0.432	0.355	0.480
	0.312	0.292	0.311	0.270	0.401	0.570	0.491	0.574	0.219	0.425	0.369	0.544
	0.281	0.280	0.310	0.290	0.410	0.627	0.515	0.554	0.207	0.404	0.412	0.558
Mean $U_{e,max}$	0.289	0.286	0.307	0.280	0.405	0.577	0.495	0.561	0.246	0.420	0.379	0.527
Mean time lag, Hrs.	4	4-½	4	4	3	1-½	3-½	2-½	3-½	3	5	2-½
Hour of max. heat gain (CST)	1900	2030	2000	2000	1930	1730	1930	1830	1900	1930	2130	1900
Date of observations	29 Aug.	30 Aug.	26 Aug.	25 Aug.	28 Aug.	12 Sep.	23 Sep.	24 Sep.	15 Sep.	20 Aug.	5 Sept.	2 Sept.

the extremities of the end wall so that end effects became large. The results of the experiments are summarized in Table IV.

Table III.—Analysis of Variance of $U_{e,max}$ as Affected by Characteristics of Concrete Block Masonry

Source of variance	Degrees of freedom	Mean square	"f" or variance ratio
Type of aggregate used in manufacturing the block	2	0.14368	182.0
White paint Vs. no paint on outdoor surface	1	0.02654	33.6
Cores filled Vs. cores empty	1	0.07048	89.3
Interactions	7	0.01157	14.7
Error	24	0.0007896	

Table IV.—Summary of Maximum Heat Gain Rate as Affected by Characteristics of Concrete Block Masonry Walls.

Characteristic	Mean $U_{e,max}$		Mean Time Lag	
	BTU/Hr.-Sq. Ft.-Deg/	Percent	Hrs.	Percent
White paint on outdoor surface				
Painted	0.371	87.2	3.25	90.7
Unpainted	0.425	100.0	3.58	100 0
Core filling				
Not filled	0.442	100.0	3.83	100.0
Filled with light-weight aggregate	0.353	80.0	3.00	78.3
Aggregate used in manufacturing block				
Expanded shale	0.291	57.1	4.13	100.0
Sand and crushed rock	0.509	100.0	2.63	63.6
Pumice	0.393	77.2	3.50	84.8

Further evidence of the effect of the characteristics of concrete block masonry on heat gain under two cooled shelters was obtained by an analysis of temperature differences existing across the indoor wall surface "film" for the special masonry sections in the west wall of the cooled shelter. Assuming that the indoor wall surfaces of the masonry wall surfaces have similar heat transmission characteristics, and that indoor air circulation over the surfaces is similar from one section to another, the temperature difference across the "film" will be an index of heat gain from the wall surface to indoor air at the moment during which temperature observations were made.

Indoor wall surface temperatures were measured with 20-gauge iron-constantan thermocouple junctions mortared into the surface. Two junctions were installed in the indoor surface of each of the 12 wall sections. Indoor air temperatures were taken from the trace of a recording hygrothermograph near the center of the shelter.

Data obtained on August 1, 2, and 3, 1951, were used to compute differences between the indoor surface and indoor air temperature at hourly intervals from 1600 to 2030 with the results tabulated in Table V. These data were subjected to statistical analysis of variance of temperature difference as affected by the factors listed in Table V. All of the indicated factors including the kind of aggregrate used in manufacturing the block, the use of white masonry paint on the outdoor surface, the use of light-weight aggregate for filling the core spaces, maximum outdoor temperature, and hour were found to be significant above the 1 percent confidence level. The mean temperature difference for the lightweight aggregrate concrete block, with cores filled with lightweight aggregate and 2 coats of white masonry paint on the outdoor surface was found to be only 22 percent of the mean temperature difference for the block manufactured with sand and crushed rock aggregate, cores empty, and the outdoor surface unpainted.

Heat Gain; Effect of Attic Ventilation

For shelters with an attic space separated from the cooled space below by an insulated ceiling, heat gain from the attic space will be proportional to the difference in temperature between the attic space and the cooled space. It is common experience that solar irradiation on the roof of the poorly ventilated attics can raise the attic space temperature many degrees above outdoor temperature and cause an appreciable increase in heat gain to the cooled space below. If adequate natural ventilation of the attic space could keep temperatures therein close to outdoor temperatures, heat gain would be reduced.

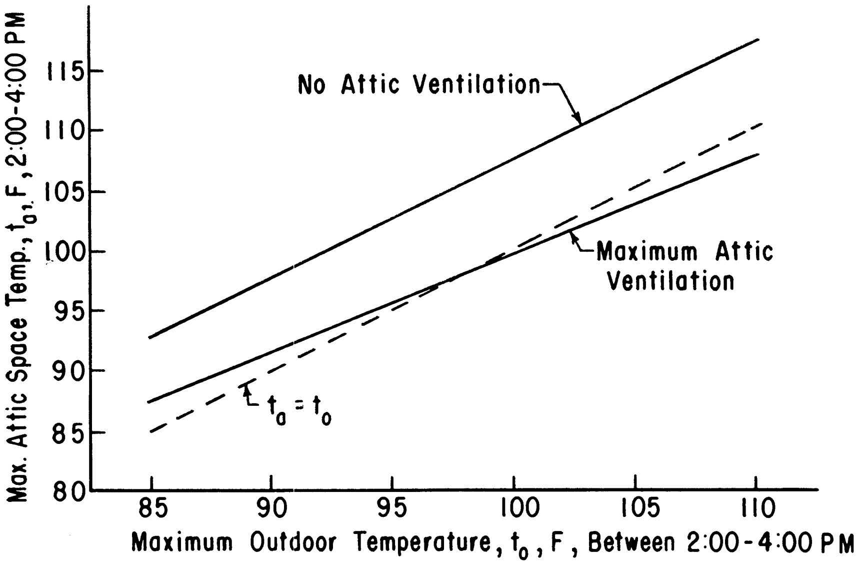
Table V.—Analysis of Wall Surface-to-air Temperature Differences.

Factor	Mean Temp. Diff.*		Factor	Mean Temp. Diff.*	
	Degrees F.	Percent		Degrees F.	Percent
Aggregate used in mfg. block			*Hour*		
Sand and crushed rock	7.61	100.0	1600	1.29	18.1
Pumice	4.36	57.4	1630	3.02	42.3
Expanded shale	3.60	47.3	1700	3.56	49.9
Paint on outdoor surface					
Unpainted	6.73	100.0	1730	4.78	66.9
Painted; 2 coats white masonry paint	3.65	54.3	1800	5.61	78.5
Core Filling					
Cores empty	6.13	100.0	1830	6.26	87.7
Cores filled with lightweight aggregate	4.25	69.2	1900	6.88	96.3
Date					
3 Aug. (Max.=101° F.)	7.03	100.0	1930	6.53	91.6
2 Aug. (Max.= 96° F.)	5.76	81.9	2000	7.14	100.0
1 Aug. (Max.= 92° F.)	2.77	39.4	2030	6.81	95.4

*t_{is}—t_i

An experiment was conducted during the summer of 1952 in the attic space of the cooled shelter to study the effect of attic ventilation through gable end openings on attic temperatures. A special set of shutters was provided for the louvered opening in the east end gable wall. Four attic ventilation treatments were assigned at random to one day of each week during the summer for a total of 10 weeks. These treatments consisted of 4 different amounts of attic space ventilation varying from complete closure to full opening of gable openings. Statistical analysis of the data on attic space temperature at 4:00 p.m. indicated that differences among the mean temperatures for each of the treatments adjusted for outdoor temperature were significant above the 1 percent confidence level. Differences among the linear regression coefficients for attic space temperature on outdoor temperature at 4:00 p.m. were not significant. A graph of maximum attic space temperature during the period 2:00 to 4:00 p.m. versus maximum outdoor temperatures is shown in Figure 10 for the two extremes of ventilation; namely, all openings closed and fully opened. With all openings, the total ventilation openings amounted to 19 sq. ft. of free opening, or approximately 1.4 percent of the attic floor area. It is evident that generous ventilation of the attic space results in worthwhile reduction in temperatures. According to Figure 10, a reduction of one-third in heat gain to the cooled space from the attic is achieved by full ventilation of the attic

Fig. 10.—Attic space temperatures in temperature-controlled shelter.



space as compared to no ventilation at an outdoor temperature of 100° F. It will be noted that when outdoor temperatures are above 98° F., attic temperatures with maximum ventilation are below outdoor temperatures due to the cooling effect of the shelter space below.

Radiant Heating from Metal Roof Coverings

Cattle in an open, unceiled shelter were exposed to radiant heat emission from metal roof surfaces heated by solar irradiation. The net radiant heat exchange between the surface of an animal and a heated metal roof covering will depend on the temperatures and emissivities of the surfaces, and the geometry of location and orientation of the surfaces with respect to each other. However, one of the factors related to the design of the shelter and which can be controlled to reduce radiant heat emission from the roof covering to the surface of livestock in the shelter, is the height of the roof. If a small surface of the animal is considered placed parallel to the heated roof surface and in some "typical" position within the shelter, it is possible to compute a "view factor", F_{CR}, which appears in the expression for the net radiant heat exchange, q_{CR}, between the cow and roof surfaces, as recommended by Hottel (7), page 72, for net heat due to direct interchange,

$$q_{CR} = e_C \, e_R \, A_C \, F_{CR} \, \sigma (T_R^4 - T_C^4) \qquad \text{(Equation 2)}$$

where the subscripts "C" and "R" denote "cow" and "roof," and

q_{CR} = net exchange, BTU/hr
e = surface emissivity, dimensionless
A_C = Area of cow surface under consideration, sq. ft.
F_{CR} = View factor, cow surface to roof surface, dimensionless
σ = Stefan-Boltzmann Constant, btu / (sq. ft.) (hr.) (deg.R)^4 = 0.1713×10^{-8}
T = Absolute temperature of the surface, deg. R

It is apparent that only F_{CR} will vary with the geometry of the surfaces. Values of F_{CR} can be computed from data by Hottel (7) for two parallel surfaces. This was done for roof heights varying from 6 to 12 ft. above ground at the eaves for a shelter similar to the open shelter used in these experiments with the results graphed in Figure 11. One sq. ft. of cow surface parallel to the roof and located in the center of the shelter at a height of 4 ft. above the ground was taken as the basis for the computation of F_{CR}.

Only a limited portion of a cow's surface will be parallel or nearly parallel to the roof surface at any time, but the net heat exchange be-

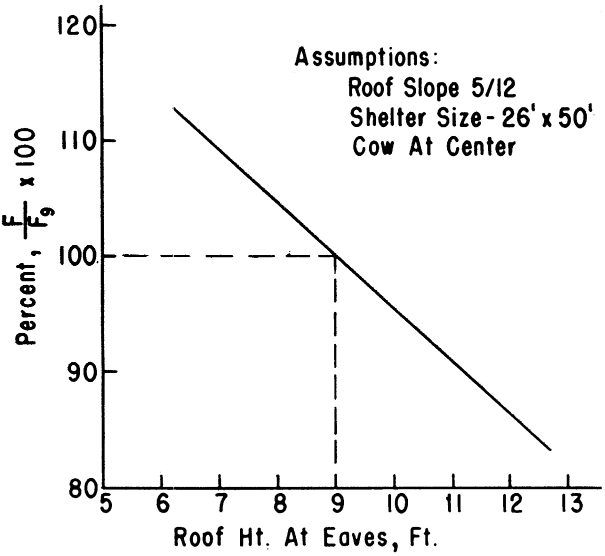


Fig. 11.—Effect of roof height on view factor in radiant heat emission from roof surface to cattle at center of shelter.

tween two parallel surfaces will be the maximum compared to other relative orientations. Hence, Figure 11 may be regarded as the relative effect of roof height on maximum net radiant heat exchange. It is seen from Figure 11 that decreasing the height to 6 ft. at the eaves will increase maximum radiant heat exchange by approximately 13 percent as compared to a "standard" height of 9 ft., while increasing the roof height to 12 ft. will effect a decrease of approximately 13 percent.

Another factor in radiant heat exchange which can be controlled by selection and treatment of the roof covering is the absorptivity for solar irradiation and the emissivity for long wave length or low temperature radiation of metal roof coverings used for livestock shelters. The absorptivity for solar radiation of the solar-irradiated side and its film coefficient will govern the temperature rise of the roof surface, while the emissivity of the other side will govern the radiant heat emission to the shelter space and occupants of the shelter.

In these experiments, data were collected on the under-surface temperatures of aluminum and galvanized steel roof sheets incorporated in the roof on the south slope of the open-front shelter. These data were obtained with iron-constantan thermocouple junctions soldered to the metal sheets. Two recording potentiometers were used with the thermocouples to obtain continuous traces of temperatures of the metal cover-

Table VI.—Data on Roof Surface Temperatures, in Degrees Fahrenheit, for Two Selected Days.

Time (CST)	June 27—Wind, SSW10-15 mph			June 28—Wind, S5-10 mph		
	Aluminum	Galv. Steel	Outdoor Air	Aluminum	Galv. Steel	Outdoor Air
1:00 PM	110	125	92.0	112	128	92.5
1:20	111	127	92.0	112	127	93.0
1:40	111	126	93.0	110	125	93.5
2:00	111	124	93.0	110	124	94.0
2:20	111	123	93.0	111	124	94.0
2:40	109	120	93.5	109	121	94.5
3:00	107	118	94.0	107	118	95.0
3:20	106	116	94.0	106	117	95.0
3:40	106	116	94.0	106	115	95.5
4:00	104	112	94.0	105	113	95.0
4:20	103	110	94.0	102	110	94.5
4:40	100	106	94.0	100	107	94.5
5:00	99	104	93.5	98	104	94.0
5:20	97	101	93.0	96	102	94.0
5:40	95	98	92.5	94	98	94.0
6:00	93	96	92.0	93	96	94.0
6:20	91	93	91.5	90	92	93.0
6:40	89	90	91.0	87	89	92.5
7:00	87	87	90.0	86	87	92.0

ings. Data for two selected days are presented in Table VI. Sol-air temperatures of the roof coverings were also computed for the solar irradiation intensities, outdoor air temperatures, and wind conditions which prevailed at the time the roofing surface temperatures were measured. It was found that the temperatures of the metal roofing could be plotted as a function of the sol-air temperature to give a linear relationship as in Figure 12. It should be noted that under a given combination of outdoor temperature, solar and sky irradiation intensity, and wind, the aluminum roof covering will have a lower sol-air temperature than galvanized steel since the value of b/f_{cro} is higher for the galvanized steel.

From the relationships graphed in Figure 12, roof surface temperatures can be estimated for any sol-air temperature within the range shown. The total radiant heat emission from the roof covering to the shelter space will vary directly with the fourth power of the absolute temperature of the roof covering and the emissivity of the covering for low-temperature radiation. The effects of emissivity on total radiant heat emission based on the temperature data of Figure 12 are shown in Figure 13. The low-temperature emissivity of 0.28 used for galvanized steel is for "galvanized sheet iron, gray oxidized" at a temperature of 75° F., listed in McAdams (16), page 476. The emissivity value of 0.22

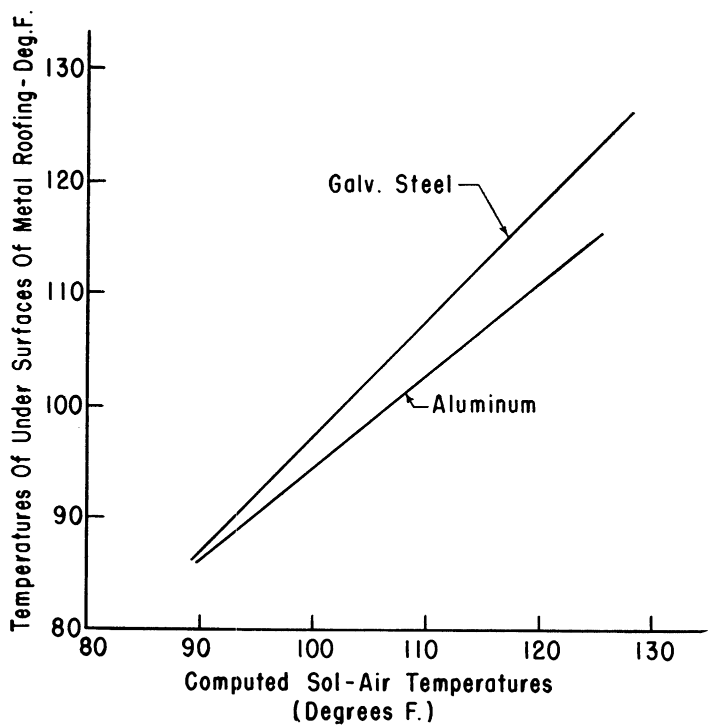


Fig. 12.—Temperatures of metal roofing as a function of sol-air temperature.

for aluminum roof covering is based on a value of 0.216 listed by McAdams (16), page 427, for "Aluminum-surfaced roofing" at a temperature of 100° F.

As illustrated in Figure 13, the total radiant heat emission from a 5/12 slope, south-facing roof slope for aluminum roofing with an emissivity of 0.22 will be from approximately 70 percent at high intensity solar irradiation to 77 percent at low intensity solar irradiation of the values for galvanized steel roofing with emissivity of 0.28. It should be recognized that emissivities for a given kind of metal roof covering can vary depending on surface oxidation, rusting, and discoloration.

Wind speed over the roof is another partially controllable factor in radiant heat emission from metal roof coverings to a shelter space. Wind-induced air motion over a heated roof surface results in a greater convective cooling rate as compared to still air conditions. An "everyday" illustration of this effect can be observed on a hot, bright summer day by standing inside a metal-covered building. If the outdoor air is generally still, but a light breeze arises, distinct "popping" or "creeping"

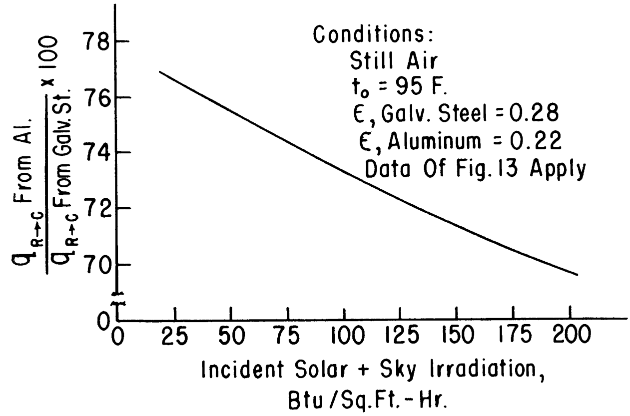
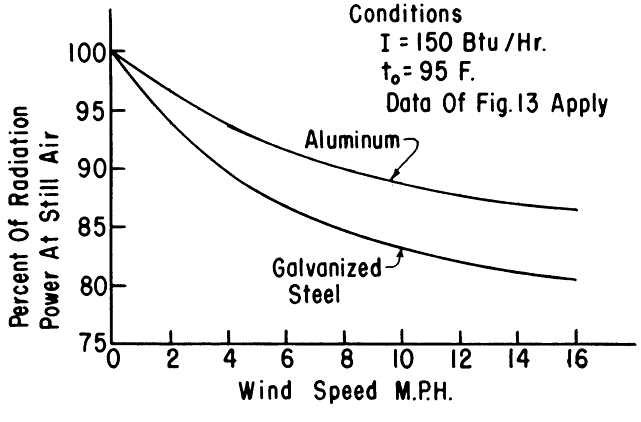


Fig. 13.—Comparison of radiant heat emission from under surface of galvanized steel and aluminum roof coverings.

sounds can be heard as the metal covering quickly cools and contracts due to the breeze. The roof slope is also of some importance since flat roof slopes in the order of 3/12 or less will not be swept by winds as readily as steeper roof slopes of 5/12 to 6/12 or greater.

The effect of wind speed on radiant heat emission from the roof on the open livestock shelter used in these experiments is shown in Figure 14 as a function of wind speed over the roof surfaces. The data for these graphs were computed from the relationships between roof surface temperatures and sol-air temperatures shown in Figure 12. It is seen from Figure 14 that for galvanized steel roofing even a comparative-

Fig. 14.—Effect of wind speed on radiant heat emission from under-surface of metal roof coverings.



ly light breeze of 8 mph over the roof covering can cause a reduction of 15 percent in radiant heat emission to the shelter space as compared to still air conditions.

Cow-surface Temperature Studies

Cow-surface temperature is one index that might be used to evaluate the effect of environment on animal comfort. Other conditions being constant, a rise in surface temperature will result in an increase in heat gain to the animal's body. In these experiments data were collected on the effects of ambient temperature, air motion, and solar irradiation on cow surface temperatures. Temperature observations were made with a 20-gauge iron-constantan thermocouple junction on a two-pronged holder. The data were collected on a Guernsey, Jersey, Ayrshire, and Holstein cow in the cool shelter and a similar group in the open shelter. All measurements were made during the 1953 summer during six days separated by 10-day intervals.

Surface Temperatures; Effect of Ambient Temperatures

A linear regression analysis of skin-surface temperatures as a function of ambient air temperatures was made for data taken under relatively calm air conditions with a mean air speed of 85 fpm (0.97 mph), a minimum of 0 fpm and a maximum of 383 fpm (4.35 mph). The regression expression obtained was $(t_s - t_a) = 91.35 - 0.95\ t_a$, where t_s is skin-surface temperature, deg. F.; and t_a is ambient air temperature. It is evident that the skin-to-air temperature gradient becomes zero at close to 96° F., and no convective heat transfer occurs between the cow's surface and the air.

Surface Temperatures; Effect of Air Motion

It is well known that air motion over a surface increases the coefficient of convective heat transfer as compared to still air conditions. Dairy cattle in the cooled shelter were apparently able to sense the increased cooling effect of the blast from the evaporative cooler and learned to select favorable positions in front of it.

Analysis of five sets of temperature observations on five different days on each of the four cows in the cooled shelter while standing in the blast from the evaporative cooler gave a mean skin-to-air temperature gradient of 13.4° F. at a mean air velocity of 775 fpm and a mean ambient air temperature of 79.3° F.

Another analysis has been made by Nelson, *et al* (21) that evaluates the effect of air speeds of from 0 to 1000 fpm on the ratio of forced to free convective cooling from cattle surfaces. From these results it was apparent that a wind speed of about 10 mph (880 fpm) can more than double the convective cooling rate from surfaces exposed to this air speed as compared to still air conditions.

Cow-surface Temperatures; Effect of Solar Irradiation

In order to study the response of dairy cattle surface temperatures to solar irradiation combined with summertime outdoor temperatures, data were collected on surface temperatures of dairy cattle exposed to sunshine during hot summer weather. Observations were made on 4 cows including a Guernsey, Jersey, Holstein, and Ayrshire on six selected days in the period July 3 to August 20, 1953. Surface temperatures were measured on the loin at three points reasonably close together for the Ayrshire (white), Jersey (fawn), and Guernsey (fawn). Temperatures were measured at three points on the loin (black) and at three points on the rump (white) of the Holstein. In each instance, one set of 3 readings each was taken on the hair surface and skin surface, respectively, with a 20-gauge, iron-constantan thermocouple junction on a two-prong holder.

Air temperatures and wind speeds were observed during each group of surface temperature readings. Pyrheliometer traces were obtained for data on solar irradiation intensity at the time of the observations. An analysis described by Nelson, *et al* (22) was made to correlate hair surface temperature with ambient temperature, wind speed and solar irradiation intensity. This analysis yielded expressions for hair surface temperatures for 4 breeds and colors as follows:

$$t_{sh} = a + (b - cV)\ I + d \times (t_0) \qquad \text{(Equation 3)}$$

where

t_{sh} = hair surface temperature on loin or rump, deg. F.
V = wind speed, ft./min.
I = solar irradiation intensity, btu/(sq. ft.) (hr.), on a horizontal surface.
t_0 = ambient air temperature, deg. F.

and the constants a, b, c, and d have the values in Table VII. Results of computations of hair surface temperatures according to eq. (3) are diagrammed in Figure 15 for a set of conditions which are fairly typical of hot summer weather in Oklahoma. It is apparent that wind has an important effect in reducing temperatures of cattle surfaces exposed to strong solar irradiation.

Table VII.—Values for Constants in Eq. (6), Surface Temperature of Cattle.

Breed and Color	a	b	c $\times 10^{-5}$	d
Fawn Jersey	72.3	0.0381	1.77	0.2461
Fawn Guernsey	74.9	0.0381	1.77	0.2461
Black Holstein	72.0	0.0581	1.77	0.2461
White Holstein	70.6	0.0497	1.77	0.2461
White Ayrshire	68.2	0.0497	1.77	0.2461

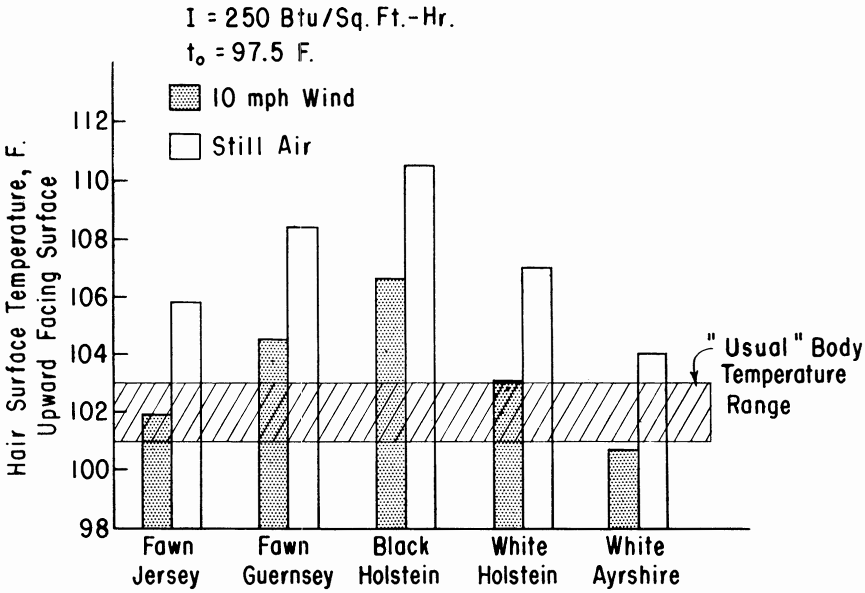


Fig. 15.—Hair surface temperatures of dairy cattle under "typical" hot weather conditions.

PART II

Effect of Shelter on Milk Production

Milk production data were collected and compared for cows kept in air-cooled and open-shelter barns in 1950 and 1951. The procedure was changed in 1952 and 1953 to include a third group of cows maintained in open pasture without access to shelter. Physiological data and observation of cows at grazing time were recorded for the three groups in 1953.

1950 AND 1951 EXPERIMENTS

Methods

Twenty cows of four major breeds—Ayrshire, Guernsey, Holstein and Jersey—were used in 1950, and 18 were used in 1951. The cows were paired according to breed, age, size, and stage of lactation and assigned at random to two 15-acre pastures. One group of cows had free access to open shelter and the other group had air-cooled shelter except during the milking periods.

At the start of the experiment each year, the cows were allowed 10 days to become accustomed to their new environment. In 1950, the experiment started on July 28. The switch-back design was used and the cows in the two groups were alternated each 10 days between pastures containing the air-cooled and open shelter. Six 10-day periods were completed during the 1950 season. In 1951, a double-reversal design was employed using 21-day periods. The first period started on June 20.

The cows in both groups were removed twice daily to the University dairy barn some 200 yards away for milking. Milking times were 4:00 a.m. and 4:00 p.m. The cows were fed grain at milking time according to production at the beginning of the experimental period, and the same level of feeding was maintained throughout the experiment. The concentrate mixture consisted of 4 parts ground milo, 3 parts wheat bran, 2 parts ground oats and 1 part cottonseed meal plus 1 percent each of salt, ground limestone, and steamed bone meal. Salt was also available *ad lib.* Holsteins were fed 1 pound of grain for each 4 pounds of milk produced daily. Other breeds were fed at the following ratios: Ayrshires 1:3½; Guernseys 1:3; and Jersey 1:2½.

Under the method of feeding used, the cows were overfed as the summer and lactation progressed and as production declined. It was felt, however, that this method of feeding would prevent any decline in production due to lack of feed and if a decline occurred it would be due to treatment.

After milking, the cows were returned to pasture. The only roughage the cows received in 1950 was from permanent pasture in which the shelters were located. In 1951 the cows were fed silage and alfalfa hay free choice, in addition to pasture. The hay racks were refilled each morning and fresh silage was fed each evening.

Results

Milk production was not significantly affected by the air-cooled shelter (Figures 16 and 17), although the average production for the cows in the open barn was slightly greater in these experiments. In 1950 the cows averaged 25.6 pounds of milk daily while in the pasture containing the air-cooled barn, and 26.0 pounds daily while in the pasture containing the open-front shelter. In 1951 milk production averaged 29.5 pounds daily from the cows having access to the air-cooled barn, and 30.9 pounds daily from cows having access to the open-front shelter. A statistical analysis of the 1951 milk production data showed no significant difference due to shelter or environment.

The summers of 1950 and 1951 were cooler than normal and the cows preferred to remain outside the shelters. In 1950 the cows entered the shelters only to drink water and remained there less than one-half hour per day between 9:00 a.m. and 6:00 p.m. The maximum outdoor temperature was 97° F. during the experimental period. It was observed that the cows preferred the shade of trees in the pasture to either the air-cooled barn or the shade within the open-front shelter. The trees were fenced off after the 1950 experiment. In 1951 the highest temperature was 100° F., which was recorded on August 3.

1952 AND 1953 EXPERIMENTS

Methods

Since no difference in milk production was observed the first two years, the experiment was changed to include a group of cows which were maintained without access to shelter of any kind. The third group of cows was added by equally dividing the 30-acre pasture into three smaller pastures of approximately 10 acres each.

Four cows, one each of the four breeds, Ayrshire, Guernsey, Holstein and Jersey, were included in each of the three pastures. An attempt was made to select cows that were in heavy production so that maximum stress would be exerted.

The cows in Pasture I were enclosed in the air-cooled barn after the morning milking and remained there until after the evening milk-

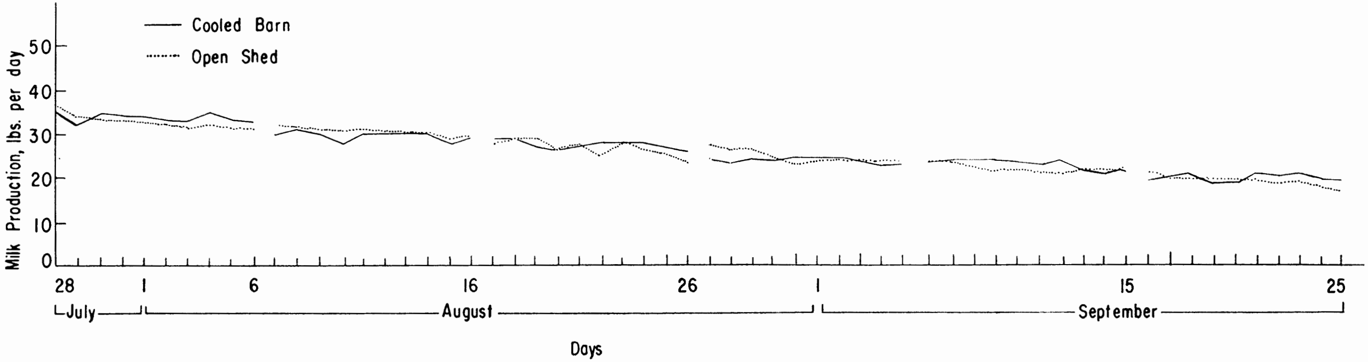


Fig. 16.—Average milk production (lbs./day/cow) was essentially the same for both groups during the summer of 1950. Breaks in lines indicate change-over periods in the switch-back treatments.

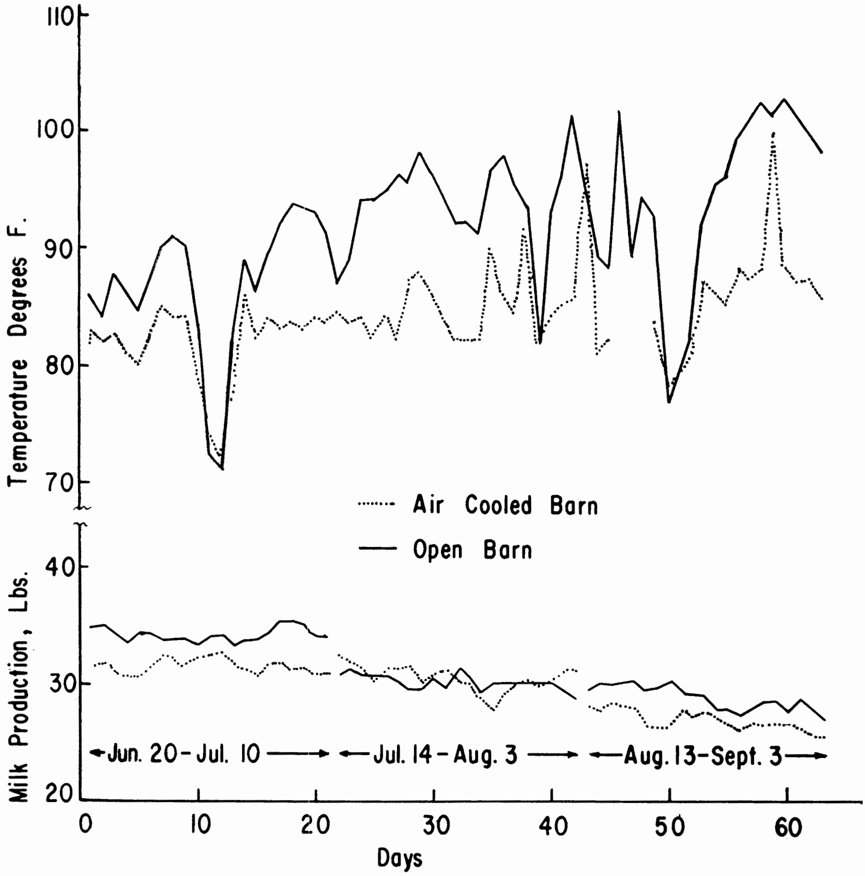


Fig. 17.—Average milk production (lbs./day/cow) and temperature record during the 1951 test period. As in 1950, milk production between groups was not significantly different. Breaks in lines of production records indicate change-over periods in the double-reversal treatments. Mechanical difficulties were responsible for the break in the temperature line shown for the air-cooled barn.

ing. At night the cows had free access to the air-cooled barn and the pasture. The cows in Pasture II had free access to the open shed and pasture at all times. The cows in Pasture III were placed in an open pasture without shelter day or night, except for milking time.

The cows were not rotated among pastures as in the previous experiments. Alfalfa hay and silage were fed *ad lib.* Concentrates were fed according to milk production levels at the beginning of the experiment. Feeding rates were the same as in the previous years.

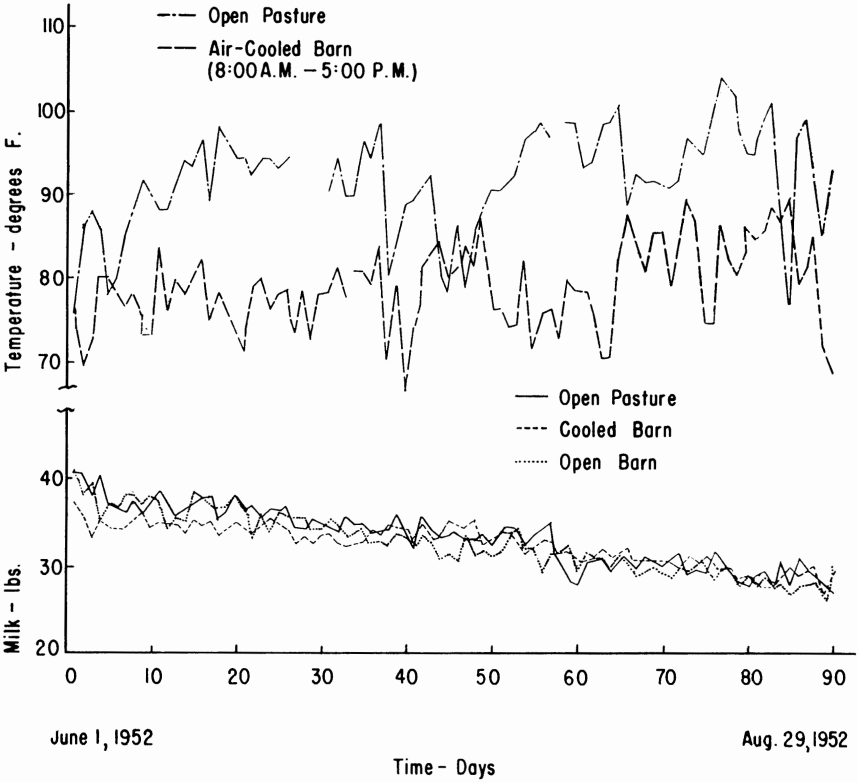
The trials started on June 1 in 1952 and June 7 in 1953. Both trials lasted continuously for 90 days.

Results

Milk Production.—In 1952, the average daily milk production during the 90-day period was 27.4, 28.2, and 29.0 pounds for the cows in Pastures I, II, and III, respectively. Results of milk production are summarized in Figure 18. The slightly lower performance of the cows in Pasture I was due chiefly to one cow whose lack of persistency in milk production affected the group average. This was attributed to the inherent make-up of the cow since she performed similarly in prior and subsequent lactations.

In 1953, the average milk production for the 90-day period was 34.3, 31.7, and 33.8 for the cows in Pastures I, II, and III, respectively. Results are summarized in Figure 19.

Fig. 18.—Production and temperature records for 1952. Average milk production per cow was essentially the same for the three groups. Maximum open-barn temperature was almost identical to open pasture. Broken line indicates mechanical failure of recorder.



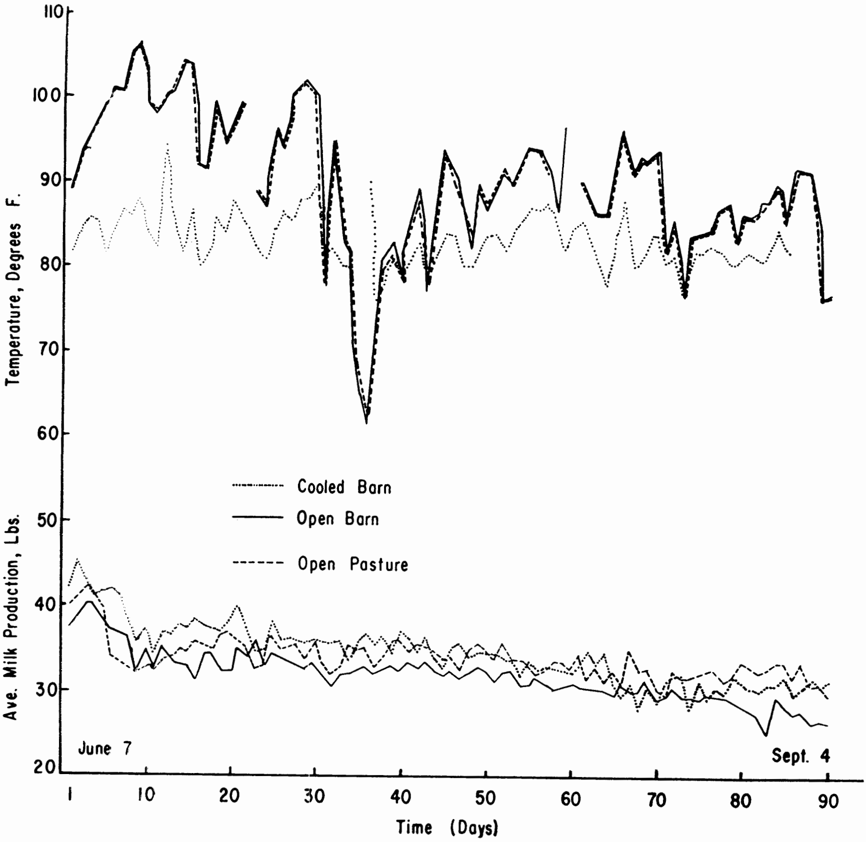


Fig. 19.—Production and temperature records of 1953. As in previous years, milk production was not significantly different between groups. Temperatures averaged somewhat higher in 1953 than in previous years. Broken lines indicate mechanical failure of recorder.

Statistical treatment of this data employing the analysis of variance (33) showed no significant difference, at the 5 percent level of probability, between groups due to treatment or between breeds.

Weather Conditions.—Weather conditions during the summer of 1953 more nearly approached the usual warm weather in Oklahoma, although it was not an extremely hot summer as is quite often experienced in this state.

There were 13 days during the 90-day experimental period in which the maximum temperature exceeded 100° F. There were also some "cool" days.

The distribution of variations in maximum daily temperatures reached during the experimental period was as follows:

Range Maximum Temperature	**Number of Days**
100.0° F. — 107.0° F.	13
95.0 — 99.5	13
90.0 — 94.5	23
85.0 — 89.5	21
80.0 — 84.5	11
75.0 — 79.5	4
70.0 — 74.5	3
Below 70.0	1
	89

The temperature on September 4, 1953, the last day of the experimental period was not recorded. The mean of the maximum temperatures during the 89 days recorded was 83.6° F. in the air-cooled barn, 90.6° F. in the open shed, and 90.8° F. in the pasture. The mean of the minimum temperatures was 73.9° F., 70.8° F. and 70.5° F., respectively. From the above averages it is seen that the advantage of the air-cooling in lowering the maximum temperature was only about 7° F. This difference between averages was narrowed by the days of lower maximum temperatures. Had there been more days of high maximum temperatures, the average differences would have been wider. For example, on the day it was 107° F. in the open pasture, the maximum reached in the air-cooled barn was 86.0° F. The differences between the mean temperature would actually be greater during the warm daylight hours, however, since the maximum temperature in the air-cooled barn was often attained in the early morning hours. The mean hourly temperature and humidity readings for the 1953 summer experimental period is found in Figure 20. This graph includes the temperatures in the air-cooled barn, open shed, and the open pasture. The graph also includes the relative humidities under the same three conditions.

From this graph it is readily seen from the open-pasture measurements that Oklahoma maximum summer temperatures are accompanied with a low relative humidity. It is also seen that the night-time temperatures are "cool" as compared to day-time readings, particularly from 11:00 a.m. to 6:00 p.m.

It is also important to note that although lower maximum temperatures were maintained in the air-cooled barn than in the open shed or pasture during the warm day-time hours, the relative humidity was considerably higher due to the moisture from the evaporative cooler. During the coolest night-time hours however, the reverse is true since the enclosed barn did not cool down as low as the open-front barn or

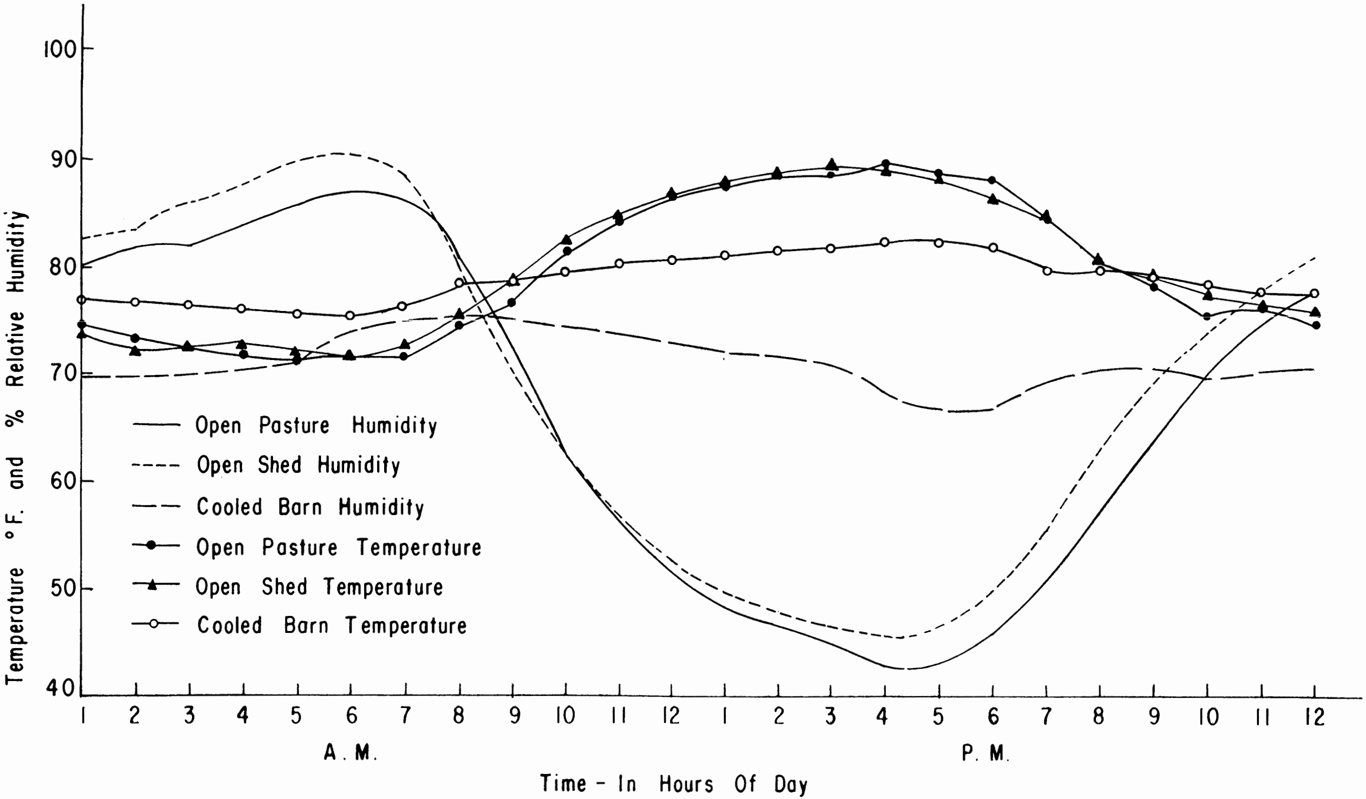


Fig. 20.—This graph illustrates the mean hourly temperature and humidity records for the three experimental conditions in 1953. Note that the hours of high temperature are accompanied by low humidity.

the open pasture and the humidity did not rise as high. Under open-air conditions in Oklahoma the relative humidity reaches 80-90 percent on the average during the cool early morning hours and drops to 40-45 percent during the hot afternoon.

Feed Consumption.

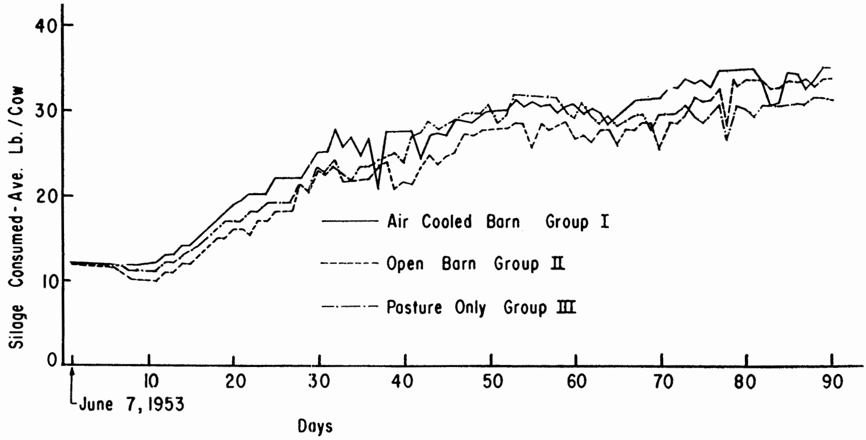
Grain—Grain was fed according to milk production at the beginning of the experiment and the same amount was offered each cow throughout the entire experimental period. Although this meant that the cows were overfed during the latter stages of the experiment, it eliminated the possibility of lowered milk production due to lack of nutrients. Weigh backs were recorded each day and the percent of the grain offered that was refused by the cows amounted to 0.0, 2.0, and 5.2 percent for Groups I, II, and III, respectively. The cows in Group III consumed slightly less concentrate percentagewise. This can probably be attributed to treatment, but feed consumption was still adequate to meet the nutrient needs of the cows and maintain production equal to the other groups.

Pasture—The cows in Group I were allowed to graze at will after the evening milking until they were removed from the pasture for the morning milking. The cows in Groups II and III had access to their pastures at all times except during the milking periods. Since the pasture consisted of native grasses only, it would not be considered to have a very great effect on differences in milk production between the groups of cows.

Hay—Alfalfa hay was fed *ad lib.* to the cows in each group. It was placed in the mangers each morning. Enough was fed so that there were some weigh backs each day. The amounts consumed by the cows in each group are shown in Figure 21.

Silage—Grain sorghum silage was placed in outside feed bunks each evening while the cows were being milked. A constant amount was fed the first 10 days of the experiment after which the amounts were gradually increased until some refusal was recorded each day. This was achieved on the 30th day of the experiment. The average silage consumption of the cows by groups is also found in Figure 21.

It is readily seen here that as the silage consumption increased, the consumption of hay decreased. The increase in daily silage consumption no doubt was also affected by the maturing of the pasture grasses as the summer progressed.



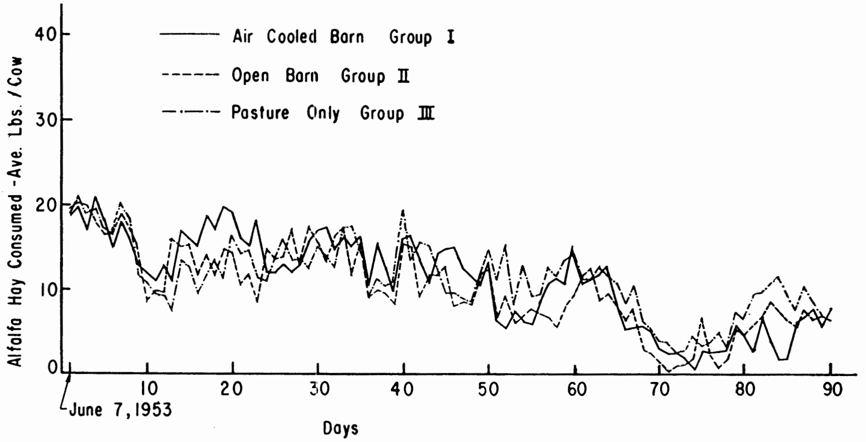


Fig. 21.—Average silage and alfalfa hay consumption per cow for each of the three groups in 1953. After the tenth day, silage was fed *ad lib.* and as silage consumption increased, hay consumption was reduced.

The lower amount offered during the early stages of the experiment may have contributed to the decrease in daily milk production at that time.

Water Consumption.—Water consumption by the different groups was recorded each day in gallons, and was determined by attaching water meters to the lines feeding water to the tanks. The average daily water consumed per cow in each group through the 90-day experimental period was 14.7, 13.8, and 18.2 gallons for the cows in the Groups I (air-cooled barn); II (open-shed) and III (no shelter), respectively.

The daily water consumption per group was correlated with the daily maximum temperatures for the three groups and the correlation coefficient was 0.45, 0.56, and 0.59 for Groups I, II, and III, respectively. The differences in water consumption by the three groups were statistically significant at the 5 percent level of probability.

During a nine-day 24-hour watch the cows in Groups II and III drank 4.4 and 4.3 times per day, on the average.

Physiological Data.—Body temperatures, pulse rates, and respiratory rates of all cows were recorded daily during the fourth year experiment. All values were determined by the same worker throughout an 80-day period beginning June 17, 1953. The data were collected in the same sequence each day as follows: Respiration rates for the cows in Groups III, II, and I, respectively, starting at 1:30 p.m. Three, 30-second counts were made, doubled and recorded as number of respirations per minute. The three values were later averaged. The pulse rates were determined from the caudal artery in the tail and the rectal temperature was determined with a 5-inch veterinary clinical thermometer. The sequence employed for the latter two values was Group I, II ,and III, respectively. Collection of these data was completed by approximately 3:00 p.m. The average values obtained in this study are summarized as follows:

	Group I	**Group II**	**Group III**	**Statistical Significance***
Respiration Rates/Minute	68.6	64.8	74.1	Non-significant
Body Temperature	101.6°F.	101.5°F.	102.4°F.	Significant
Pulse Rates/Minute	74.0	70.9	74.8	Non-significant

*Analysis of variance at 5 percent level of probability

During a five-day period from August 25 to 29 the same data were collected by the above methods, starting at 3:00 a.m. The results are summarized below:

	Group I	**Group II**	**Group III**	**Statistical Significance***
Respiration Rates/Minute	37.6	42.9	47.6	Non-significant
Body Temperature	101.0°F.	100.7°F.	101.3°F.	Significant
Pulse Rates/Minute	75.3	68.2	72.4	Non-significant

*Analysis of variance at 5 percent level of probability

These data are within the range of results obtained by other workers and have been reviewed by Findlay (5) and McDowell (17). It is shown that the day-time respiration rates and body temperatures are increased when compared to the night-time values and that pulse rates are relatively unaffected by day-time temperatures. A statistically significant difference between groups was found in the body temperatures of the cows, whereas the difference between groups for pulse rates and respiration rates were statistically non-significant. Since the body temperatures of the cows in different groups were significantly different at both daytime and nighttime measurements this would indicate that these were individual cow differences. On the other hand the higher body temperatures and respiration rates of the cows in Group III at nighttime may have possibly been a carryover of the distress of daytime treatment.

Study of Cows' Time.—The cows were observed for nine days to study how they spent their time. The nine days studied were selected at random according to a prearranged schedule. Groups II and III were watched both day and night, while the cows in Group I were observed during the period after the evening milking and before the morning milking, only.

The results of this study are summarized in the following table:

Observation	**Group I Cooled Barn**	**Group II Open Shed**	**Group III No Shelter**	**Remarks**
	(Average time/cow/per day in hours)			
Total time grazing		5.15	4.57	
Evening and night-time grazing	3.01	2.95	1.83	After 5:30—6:00 p.m. to 4:00 a.m.
Time at hay manger		1.38	1.48	Practically all hay eating was during period after a.m. milking and before p.m. milking
Time at silage bunk		1.30	1.67	Most silage eating was during evening and night
Time spent standing at rest		5.02	5.13	
Time spent lying down		7.70	7.65	
Time spent in shed		4.35		88 minutes standing at rest; 90 minutes lying down; and 83 minutes at hay manger
Time spent in shed during daylight hours		4.28		Represents approximate period between 5:30 a.m. and 4:00 p.m.
Total time in shade		5.88		257 minutes inside shed; and 96 minutes in shade of shed*
Total time cows were observed		20.55	20.50	Remaining time cows were at milk barn

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*Based on 6 days observation

The cows in Group III which had no shelter made every possible attempt to seek shade. During the hottest days they were frequently observed placing their noses and faces in the shade of fence posts. They would also seek shade at the hay manger or silage bunk. The latter were of low construction and placed with their long axes to the east and west so that little or no shade would be available to the cows.

Some cows in both Group II and Group III were observed to stand often for long periods of time with their heads and necks extended above the water in their water tanks. They would not be drinking but would stand in this manner and evidently gained some beneficial effect from evaporation of the water in the tanks.

The cows in Group II spent more total time grazing than did those in Group III. The cows in Group III spent more time grazing in daylight hours, however.

PART III

Economic Analysis

The foregoing results indicate that cooling of dairy cattle shelters by evaporative cooling is not promising as a means of profitably increasing milk production under Oklahoma conditions. It further appears that if milk production is to be increased by improved hot weather shelter, refrigerative-type cooling equipment would be required to maintain more or less constant temperatures in the shelter at a lower temperature than can be produced with evaporative cooling equipment. It should be noted that the cooling effect obtainable by evaporative cooling depends primarily on outdoor weather conditions, whereas any desired temperature level can be maintained with refrigerative-type equipment if adequate capacity is available.

An economic analysis was made to estimate the increases in milk production that would be required to make cooling of a dairy cattle shelter with refrigerative equipment worthwhile.

On the basis of this analysis, the prospects of increased returns from cooling dairy cattle shelters under present circumstances in Oklahoma are not particularly attractive. The added milk production needed per year just to offset the extra costs of providing cool shelter are diagramed in Figure 22. Milk prices of $4, $5, and $6/cwt are considered.

Even with milk at $6/cwt., and a cooling requirement of only 1000 hours per year, approximately 700 lbs. of milk per year would be required to justify the cool shelter. For a cow which produces an average of 800 lbs. of whole milk per month, and a 4-month cooling period (June, July, August, and September) an average increase in production of $(700\times100) / (4\times800) = 21.88$ percent would be required during these four months.

The question about this increase would be: Would the 75° F. cool shelter result in an increase in production of at least 20 percent by high-producing dairy cows over an environment comparable to an 85° F. constant temperature? This increase would need to be obtained without additional feed, or expenses other than the cost of maintaining the cool shelter at 75° F. during the hot months; and the milk would need to bring an average price of $6 per cwt. Under 1956 conditions (cf. Jacob, (10) pp. 99-101), a whole milk price of $4 per cwt. is representative, with a national average annual production per cow of approximately 6,000 lbs. per year.

SUMMARY

Two dairy cattle loafing shelters were erected and used for experiments on summer temperature control as a means of improving comfort for lactating dairy cattle during hot summer weather. One of the shelters was a completely enclosed and insulated masonry shelter equipped with an evaporative cooler and ventilating fans. The other was a typical open-front shelter.

Experiments were conducted during four summers. Data were collected on temperature, humidity, and air motion in the shelters. Heat gain to shelter interiors through six kinds of concrete block masonry wall construction and two kinds of metal roof covering was evaluated. Power use for evaporative cooling as influenced by outdoor temperature and by use of supplementary cooling equipment was studied.

Data on sol-air temperatures for concrete block masonry surfaces and metal roof coverings were obtained with a sol-air thermometer. These data were correlated with surface temperatures and heat gain through concrete block masonry and radiant heat emission from metal roof coverings. The effects of ambient temperature air movement, and solar irradiation on surface temperatures of dairy cattle were studied.

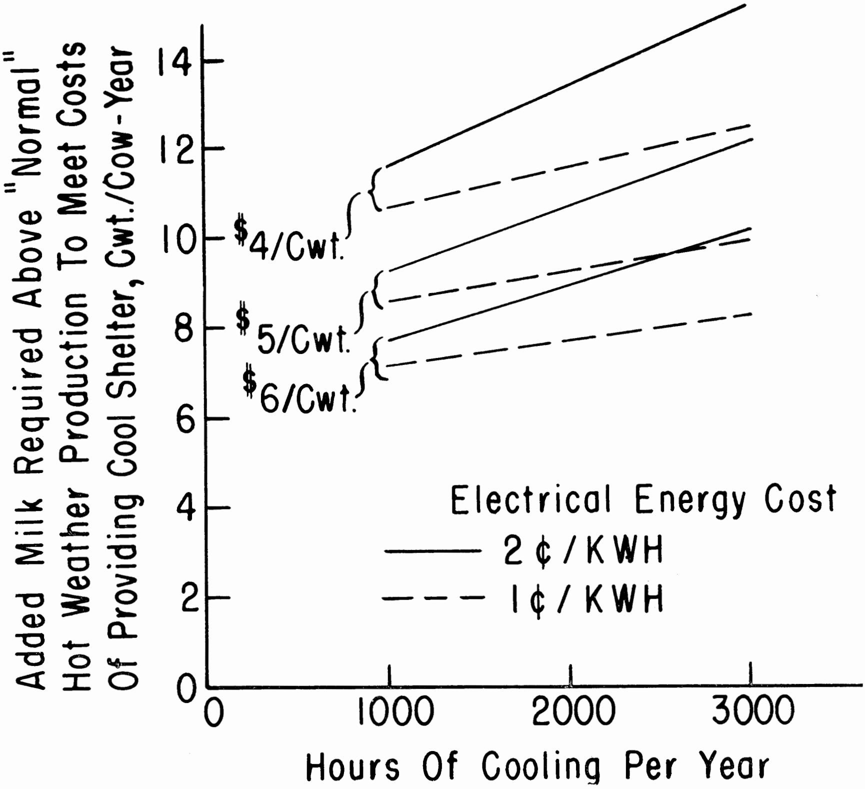

Fig. 22.—Additional milk production needed to pay excess costs of providing summer-time shelter cooled to 75° F.

The loafing shelters were tested for four consecutive summers to determine their effect on actual milk production using small groups of well-fed, high-producing cows. High levels of production were maintained in all groups, including one group without shelter. No large differences among groups were observed which could be attributed to the type of shelter or environment provided. An analysis of milk production data showed the observed differences among groups to be of no statistical difference at the 5 percent level of probability.

The cows in the air-cooled barn and the open shelter appeared to be much more comfortable than the cows without shelter. Observations indicated that cows preferred shade outside rather than inside the shelters.

An economic analysis was made to determine milk production and price levels at which summer-time cooling of shelters could become economically feasible.

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