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16. Abstract

Male beagle dogs were subjected to various hot air temperature/humidity combinations in an attempt to develop a safe temperature/humidity index for dogs being transported by aircraft. Only those environments in which all exposed dogs could maintain a rectal temperature less than 108 °F during 6 hours of continuous exposure were considered safe.

Results from the experiments provided data to formulate an equation used in defining the tolerance index. Increasing the environment's humidity serves as a catalyst in decreasing a dog's tolerance to heat. In order to offset the effects of an increase in air temperature (starting at 85 °F with a 90 percent relative humidity), relative humidity would need to be decreased by 4 percent for every 1 °F rise in temperature. Changes in rectal temperature and behavior (barking and excessive movement) in relation to the exposure environment are presented and discussed.

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A TEMPERATURE/HUMIDITY TOLERANCE INDEX FOR TRANSPORTING BEAGLE DOGS IN HOT WEATHER

Introduction

Pet owners, humane organizations, shippers, and others have long been justifiably concerned about the health and safety of dogs when transported by commercial aircraft during hot weather. Because animal deaths have occurred in air transportation during hot weather seasons, the United States Department of Agriculture (USDA) incorporated air temperature limits in the Animal Welfare Act, which applies to dogs shipped by commercial conveyances.

Present transportation regulations stipulate that dogs shall not be transported when the ambient air temperature surrounding a live dog exceeds 85 °F or if the animal will be subjected to an air temperature in excess of 75 °F for more than 4 hours at any time (2). While this regulation affords some assurance for safe and humane treatment during transport, it also presents the problem for the shipper and the airline that since temperatures above 85 °F are not uncommon in the summer, the consignee of a dog cannot be certain whether their animal will be accepted for shipment by the airlines because of different interpretations of the regulations.

Dogs can often withstand extremely warm air temperatures, if airflow is adequate and not restricted; water is available for drinking; and the humidity of the environment remains low. A dog's primary and most efficient mechanism for dissipating excess body heat is by evaporative heat loss through open-mouth panting. High humidity restricts evaporative heat loss and inhibits effective cooling in the dog. Present standards do not address humidity in determining warm air temperature limits.

The purpose of this study was to determine which warm air temperature/humidity combinations would be safely tolerated by short-haired dogs confined in a shipping crate of 14 percent ventilation and to use this data to develop a temperature/humidity tolerance index for dogs subjected to shipping containers (14 percent ventilation) during air travel in hot weather months.

Methods

Dogs selected for the study had to be of the same sex and uniform in age, size, weight, body conformation, breed, and evenness of temperament. Breeding background had to be verifiable, and the dogs had to be readily available. The dog type that fit these criteria was the colony-bred beagle. Dogs used in experiments were healthy males between 6 and 7 months of age and weighed from 18 to 23 pounds. They were maintained on a diet of Purina Puppy Chow® and/or Hill's PD® canned food, depending on their arrival weight. None of the animals received any medication for at least 7 days prior to testing. Their order for testing was determined by body weight, with the heavier dogs tested first. Prior to testing, all dogs were semiconditioned to a wire face muzzle (used during testing to prevent chewing of the test equipment) and a test shipping crate.

On the days of testing, the dogs were fed 4 ounces of Hill's® PD canned food. Thirty minutes later they were weighed and prepared for testing. A flexible thermistor probe was inserted about 6 inches past the anal sphincter to monitor rectal temperature (RT). Both RT and behavior (barking and excessive movement) were monitored continuously for all dogs. At 9:00 a.m. daily the dogs were transported in a test crate to a room outside the test chamber, where baseline data were obtained for 45 minutes; ambient air temperature was 74-75 °F. All dogs were tested individually only once in a crate with 14 percent openness to satisfy required ventilation (3) (Figure 1). At 10:00 a.m. the dogs (one test per day) were handcarried into the exposure chamber and placed in a preheated test crate. Nine temperature/humidity conditions were studied using 10 dogs in each condition. The test environments were provided in the Civil Aeromedical Institute (CAMI) animal environmental chamber (10'H by 10'L by 8'W). Airflow supplying the heat and humidity to the chamber was located in the ceiling and not directed at the open areas of the crate. Environmental conditions desired were obtained 12 hours in advance of testing and maintained throughout heat exposure. Excessive movement was observed through a window in the chamber. Barking could be heard through an intercom system. Chamber and crate temperature/humidity were recorded every 5 minutes.

It had been demonstrated previously that healthy dogs could tolerate a hot environment without residual effects as long as their rectal temperatures remained below 108 °F (4). If a dog's rectal temperature reached 108 °F during the testing, he was removed from the test. If a rectal temperature of 108 °F was not reached, the dogs were monitored during a maximum of 6 hours of exposure. Following testing, dogs were returned to their living quarters and observed for a minimum of 7 days for any signs of postexposure sequelae.

Results

Table 1 shows the percentage of dogs which safely tolerated 6 hours of continuous exposure to each environmental condition while confined in a crate with 14 percent of its wall surface area open for ventilation. In this study, the use of the phrase "safely tolerate" refers to the natural ability of the dogs to maintain a rectal temperature less than 108 °F at all times during exposure to a hot/humid environment and not demonstrate

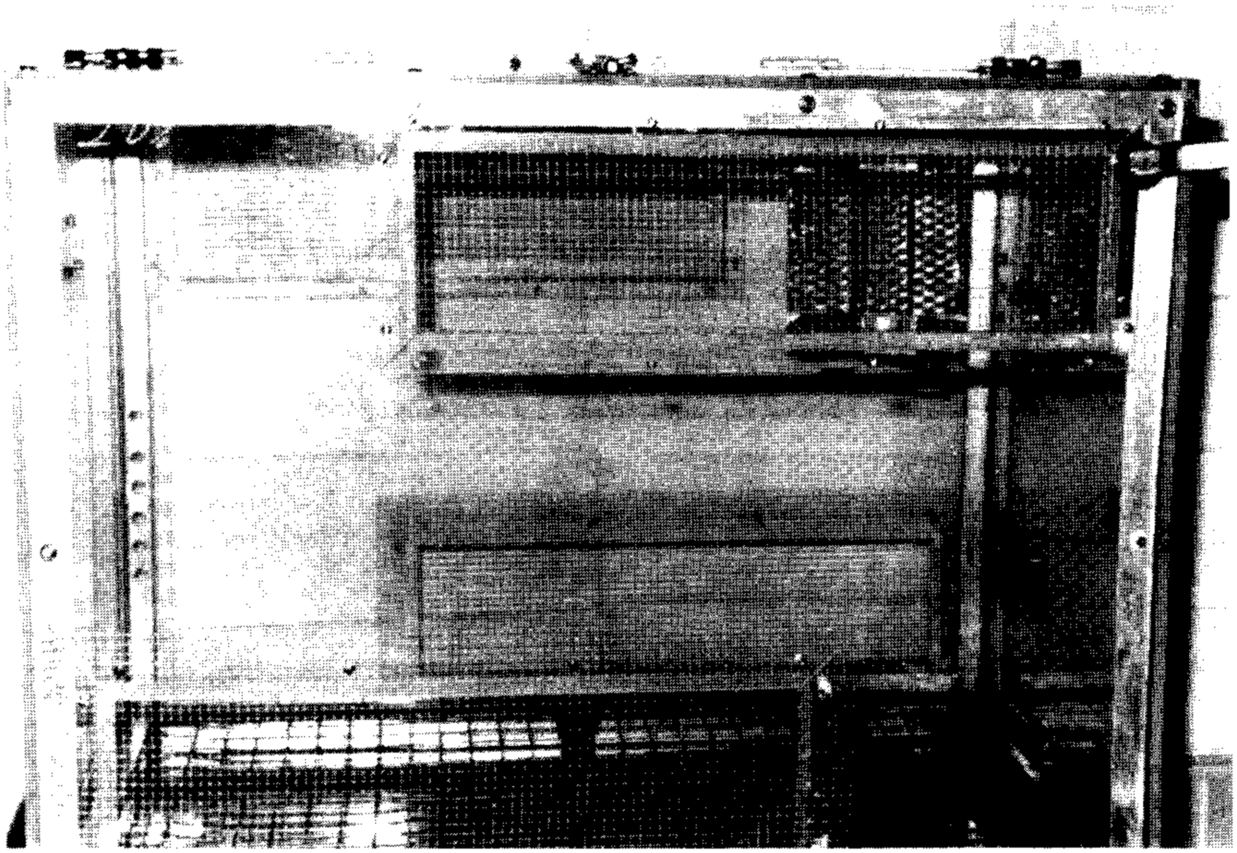

Figure 1. Simulated shipping crate (30"L by 22"H by 18"W) used for exposing beagle dogs to heated environments. Each of the two parallel long sides provides 16 percent ventilation. The two parallel short ends are not open for ventilation. Total openness of the crate (considering all four sides) for ventilation purposes equals 14 percent.

Table 1. Percentage of Dogs Safely Tolerating 6 Hours of Continuous Exposure to Hot Air Temperature/Humidity Conditions While Confined in a Crate Having 14 Percent of Its Wall Surface Open for Ventilation.

Temperature/Humidity Environment °F/%RH	Tolerance* %
85/90	100
90/70	100
95/50	100
95/70	70
95/90	20
100/30	100
100/50	80
100/70	0
105/50	10

*Ten dogs per environmental condition

ill effects from the exposure. None of the exposed dogs were allowed to succumb to any of the nine hot/humid environments studied.

Table 2 shows the average time in minutes at which dogs exposed to each environment started open-mouth panting and at what rectal temperature the open-mouth panting began. Data indicate that, when the air temperature remained constant, the dogs exposed to the higher humidity start the panting process earlier than those at lower humidities. If humidity remained constant, the dogs exposed to the higher air temperatures also started panting earlier than those at lower temperatures. However, there was little difference in each group's rectal temperature when open-mouth panting started.

The ability of the dogs to safely tolerate hot environments was dependent on the air humidity (Table 3), as well as air temperature. Data suggests that, for dogs to maintain approximately the same effective rate of evaporative cooling, relative humidity needed to be lowered by 20 percent (e.g., 90 to 70 percent RH) for every 5 $^{\circ}$F increase in air temperature above 85 $^{\circ}$F.

Only four temperature/humidity conditions were safely tolerated by all exposed dogs for 6 hours. Data from these four conditions is presented in greater detail in Tables 4, 5, 6, and 7. Each group's average rectal temperatures increased as the environment's air temperature increased. However, all dogs were able to maintain a rectal temperature less than 108 $^{\circ}$F throughout exposure because relative humidity was sufficiently lowered as air temperature increased (Table 4). Figure 2 shows the pattern of average rectal temperature for each test condition during 6 hours of exposure. The average rectal temperature at the end of 6 hours for dogs exposed at 85 $^{\circ}$F/90 percent RH was lower than the starting value.

Dogs tested in each environment displayed discontent from the test conditions by barking and exhibiting excessive movement (movement other than the expected repositioning of the body during a 6-hour period). However, not all dogs, at each test condition, displayed barking or excessive movement. Those that did bark all started during the first hour of exposure, whereas only some of the dogs that displayed excessive movement initiated this activity during the first hour of testing. Table 5 shows that the average time spent barking increased as the air temperature of the test environment increased. However, there was no clear relationship between excessive movement and the test environment temperature (Table 6). More than 50 percent of all barking and excessive movement took place during the first hour of testing (Table 7).

Table 2. Relationship of Temperature or Humidity Change to Time When Open-Mouth Panting Begins

Temperature/Humidity (°F/%RH)	Average Time When Panting Began (Minutes)	Average Rectal Temperature When Panting Began (°F)
100/30	9.6	102.5
100/50	8.8	102.2
100/70	8.3	102.6
95/50	13.1	102.7
95/70	10.5	102.4
95/90	7.7	102.4
95/50	13.1	102.7
100/50	8.8	102.2
105/50	6.4	102.4
90/70	10.5	102.4
95/70	9.6	102.5
100/70	8.3	102.6

Table 3. Effects of Relative Humidity on Animal Tolerance When Air Temperature and Ventilation Remain Constant

Environmental Condition			
Crate Openness %	Air Temperature °F	RH %	Animal Tolerance* %
14	95	50	100
14	95	70	70
14	95	90	20
14	100	30	100
14	100	50	80
14	100	70	0

*Ten dogs were exposed to each environment. Tolerance meant a dog could remain in the environment for 6 hours and maintain a rectal temperature less than 108 °F at all times.

Table 4. Average Start, Final, and Peak Rectal Temperatures of Dogs Safely Tolerating 6 Hours of Heat/Humidity Exposure

ENVIRONMENT	RECTAL TEMPERATURE (°F)					
	Start		Final*		Peak **	
°F/%RH	Average	Range	Average	Range	Average	Range
85/90	101.4s=0.325	101.0-102.0	100.7s=0.493	99.9-101.5	102.9s=1.136	101.4-105.2
90/70	101.5s=0.678	100.7-101.3	101.6s=0.530	100.7-102.3	103.8s=1.340	102.3-106.6
95/50	101.3s=0.417	101.0-102.2	101.8s=1.275	100.0-104.3	104.4s=0.845	102.5-105.4
100/30	101.6s=0.340	101.1-102.0	102.5s=1.027	101.3-104.9	104.6s=1.346	102.6-107.3

Ten dogs were tested at each environment.

*Final rectal temperature was the last recorded at the end of 6 hours exposure.

**Peak rectal temperature was the highest temperature reached during the 6 hours exposure.

s = standard deviation

Table 5. Average Number of Periods and Minutes in Which Barking Occurred During 6 Hours of Heat Exposure

Environment Temperature/Humidity	Dogs Barking During Exposure	Periods During Which Barking Occurred*	Time of Actual Barking
(°F/%RH)	(Number)	(Number)	(Minutes)
85/90	8	6.5	9.7
90/70	10	10.4	11.6
95/50	9	16.7	12.7
100/30	7	18.2	29.1

Ten dogs were tested at each environment, but average values are expressed per actual number of active dogs in each category.

*Each hour consists of 12 equal 5-minute periods.

Table 6. Average Number of Periods and Minutes in Which Excessive Movement Occurred During 6 Hours of Heat Exposure

Environment Temperature/Humidity	Dogs Displaying Excessive Movement	Periods During Which Excessive Movement Occurred*	Time of Actual Excessive Movement
(°F/%RH)	(Number)	(Number)	(Minutes)
85/90	8	7.3	12.3
90/70	7	6.5	7.8
95/50	9	11.0	12.5
100/30	6	7.2	10.2

Ten dogs were tested at each environment, but average values are expressed per actual number of active dogs in each category.

*Each hour consists of 12 equal 5-minute periods.

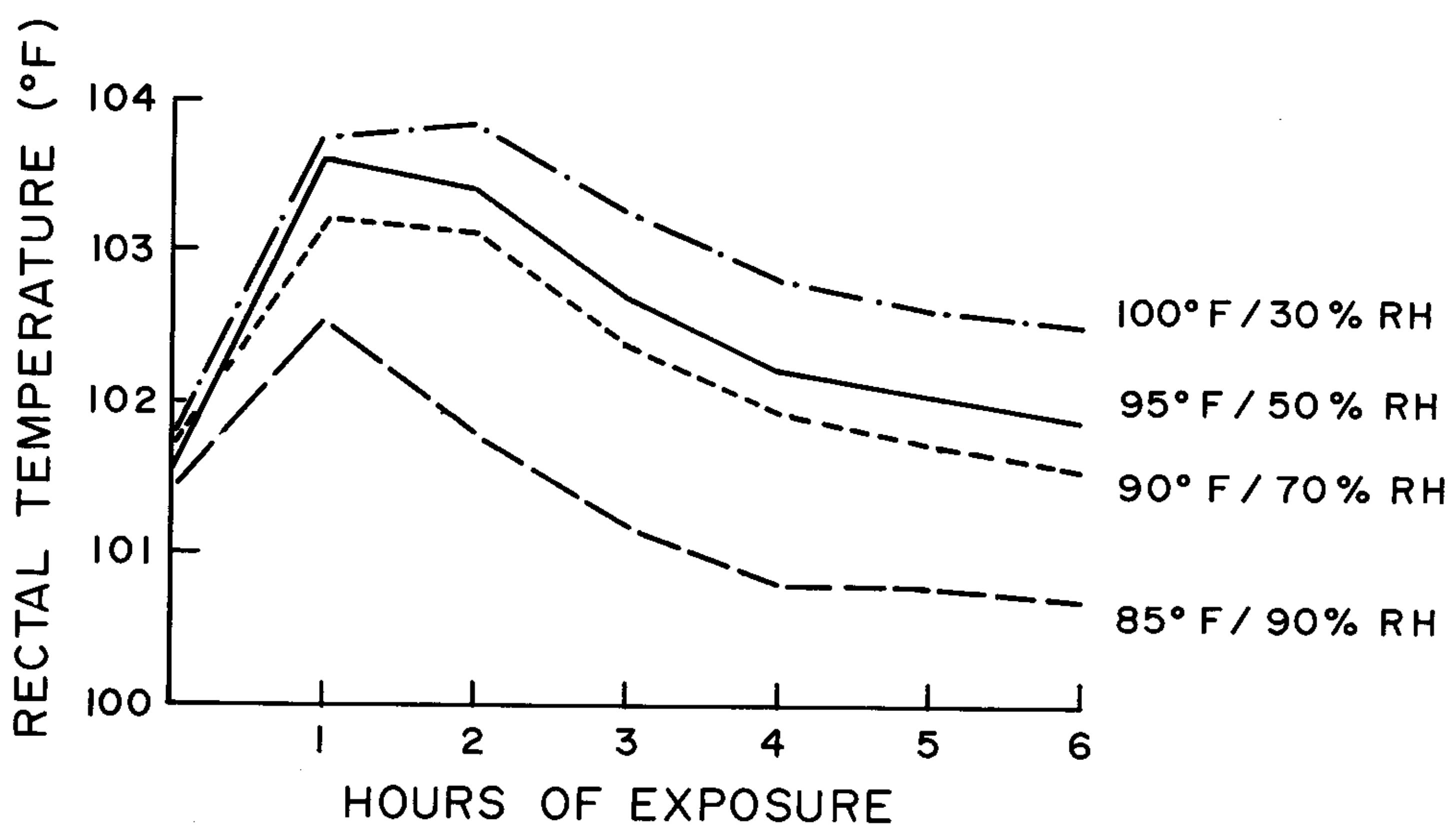

Figure 2. The average rectal temperature (hourly values are an average of 12 readings 5 minutes apart) for each test group of dogs is plotted against hours of heat/humidity exposure.

Table 7. Percent of Total Barking and Excessive Movement That Occurred During the First Hour of the Total 6 Hours of Heat Exposure*

First Hour Occurrences

Environment Temperature/Humidity (°F/%RH)	Barking		Excessive Movement	
	Percent of Total Periods	Percent of Total Minutes	Percent of Total Periods	Percent of Total Minutes
85/90	63	67	52	63
90/70	55	60	49	54
95/50	43	72	42	53
100/30	46	53	64	76

*Refer to Tables 5 and 6 for total periods and minutes of barking and excessive movement.

Results from all nine environments studied provided the data necessary to formulate equations that would show which hot weather temperature/humidity combinations could or could not be safely tolerated by 100 percent of the dogs exposed.

Fitting of Tolerance Data

Assiduous inspection of the data indicated that a linear equation (of the form 4T + H + constant) described the line of separation between 100 percent tolerance and less than 100 percent tolerance. T = the air temperature (F) of the exposure environment, H = the relative humidity (%RH) of the environment, and the constant = 430. A parallel line also appeared in the area of zero tolerance. A difference of 60 existed in the 4T + H between 100 percent tolerance and zero tolerance. If we let X = 4T + H - 430, then when X = 0, we have 100 percent tolerance, and at X = 60, we have zero tolerance. The trivial mathematical solution shows that there is 100 percent tolerance for X less than zero, and zero tolerance for X greater than 60. Assuming an "S shaped" response over the interval between X = 0 and X = 60, a cubic equation, which has been used frequently to fit biological response, was used to fit the range.

A general form of the cubic equation is:

$$ax^3 + bx^2 + cx + d = 1 \quad \text{[Eq.1]}$$

If we let x=0, then d=1. We want the cubic to be zero at x=60.

$$\text{i.e.:} \quad a60^3 + b60^2 + c60 + 1 = 0 \quad \text{[Eq. 2]}$$

Additional properties needed are for derivatives to be equal to zero when x=0 and when x=60. The derivative of equation (1) is:

$$3ax^2 + 2bx + c = 0$$

when $x = 0$, then $c = 0$

when $x = 60$, $3a60^2 + 2b60 = 0$

which leads to $b = -90a$.

Substituting into equation (2), we solve for a = 1/108,000. Substituting into the general cubic equation we have:

$$1/108{,}000 \; x^3 - \frac{90}{108{,}000} * x^2 + 1 = \text{tolerance}$$

$$\text{and} \quad \left(1 - \frac{x^2 \, (90-x)}{108{,}000}\right) * 100 = \text{percent tolerance} \quad \text{[Eq.3]}$$

Equation [3] is used to determine a tolerance less than 100 percent (when x falls between 0 and 60). A tolerance of less than 100 percent means that it is expected that some percentage less than 100 of the dogs exposed to that particular temperature/humidity combination would not be able to safely tolerate the exposure as previously described.

By using the above equations, a tolerance index (Table 8) was developed to show the percentage of healthy adult dogs that would be expected to safely tolerate the given high temperature and humidity conditions during transport.

Discussion

It is easily understood how an increase in atmospheric temperature can cause an increase in body temperature, especially when the air temperature rises to near body temperature and above. Humidity alone does not directly cause the body temperature to rise. However, when the air temperature is near 80 F and higher, high humidity can promote an increase in body temperature by decreasing evaporative heat loss through open-mouth panting (1). The net quantity of heat lost by evaporation is an inverse function of the environmental temperature and humidity (5).

Besides the usual problems induced by high temperature and humidity, it must be recognized that what a dog experiences when living in a typical hot/humid environment (e.g., at home, in the shade, relaxed, with water available, and munching on morsels of food) is not the same as the stressful confinement of a shipping crate with restricted ventilation. We have observed that, under nonstress conditions, a dog's rectal temperature can rise several degrees Fahrenheit when it is first placed in a crate (even though it has had previous experience being in the crate). If the dog is allowed to relax with few outside disturbances, its rectal temperature will return to normal levels. Some of the observed dogs appeared to accept the confinement of the crate more easily than others. While recording baseline data outside the test chamber, we noted that some animals' acceptance seemed to be related to their ability to maintain visual contact with or awareness of the investigator who was seated several feet away.

When the dogs were placed in the hot/humid environment of the test chamber, many became disturbed and exhibited behavioral responses. The two categories of recorded responses were barking and excessive movement. Barking was transmitted by means of an intercom between the chamber and outside. Excessive movement (observed visually) was any movement other than normal postural changes, such as pawing at the crate wall or floor, continuous circling, slithering around the crate floor, and twisting/turning. For most dogs, this type of activity occurred more

Table 8. High Temperature/Humidity Index for Shipping Healthy Adult Beagle Dogs

RELATIVE HUMIDITY (%)

TEMPERATURE (°F)

°F	10	14	18	22	26	30	34	38	42	46	50	54	58	62	66	70	74	78	82	86	90	94	98
80	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
81	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
82	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
83	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
84	100	[illegible]	100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100	100	100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100	100	100	100	100	100	99
85	100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100	100	100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100	100	100	100	100	99	95
86	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	95	90
87	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	95	90	83
88	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	95	90	83	74
89	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	95	90	83	74	65
90	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	95	90	83	74	65	55
91	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	95	90	83	74	65	55	45
92	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	95	90	83	74	65	55	45	35
93	100	100	100	100	100	100	100	100	100	100	100	100	100	99	95	90	83	74	65	55	45	35	26
94	100	100	100	100	100	100	100	100	100	100	100	100	99	95	90	83	74	65	55	45	35	26	18
95	100	100	100	100	100	100	100	100	100	100	100	99	95	90	83	74	65	55	45	35	26	18	10
96	100	100	100	100	100	100	100	100	100	100	99	95	90	83	74	65	55	45	35	26	18	10	5
97	100	100	100	100	100	100	100	100	100	99	95	90	83	74	65	55	45	35	26	18	10	5	1
98	100	100	100	100	100	100	100	100	99	95	90	83	74	65	55	45	35	26	18	10	5	1	0
99	100	100	100	100	100	100	100	99	95	90	83	74	65	55	45	35	26	18	10	5	1	0	0
100	100	100	100	100	100	100	99	95	90	83	74	65	55	45	35	26	18	10	5	1	0	0	0
101	100	100	100	100	100	99	95	90	83	74	65	55	45	35	26	18	10	5	1	0	0	0	0
102	100	100	100	100	99	95	90	83	74	65	55	45	35	26	18	10	5	1	0	0	0	0	0
103	100	100	100	99	95	90	[illegible]	[illegible]	65	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10	5	1	0	0	[illegible]	[illegible]	[illegible]	0
104	100	100	99	95	[illegible]	83	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
105	100	99	95	90	83	74	65	55	45	35	26	18	10	5	1	0	0	0	0	0	0	0	0

SAFETY ZONE

DANGER ZONE

The calculated safety zone shows the temperature/humidity combinations healthy adult dogs could safely tolerate for 6 hours of continuous exposure when confined in a shipping crate with no less than 14 percent of its total wall surface open for ventilation. Temperature/humidity combinations beyond 100 °F/30% RH and 85 °F/90% RH were not tested on dogs. The calculated danger zone indicates the chances of a dog safely tolerating those temperature/humidity combinations when tolerance is less than 100 percent.

intensely within the first hour in the test environment. Initial isolation in this strange environment may have contributed slightly to early barking. Usually within an hour, the dogs would then generally calm down and appear to accept the situation with only sporadic episodes of activity. Rectal temperature would generally rise when barking or excessive movement occurred. However, when the dogs became quiet, rectal temperature would decline unless activity had been quite intense.

Open-mouth panting with the tongue extended was normal during heat exposure. However, two dogs at 85 °F/90%RH and one dog at 90 °F/70%RH never exhibited open-mouth panting during 6 hours of heat exposure. The peak rectal temperatures for these three dogs were 101.4, 101.6, and 102.3 °F respectively. The time when panting began appeared to be influenced by an increase in either air temperature or humidity, all other conditions remaining constant. Rectal temperatures when panting started were very similar among the groups, regardless of the environment.

General observations of the test animals seemed to indicate that the first 30 to 60 minutes of exposure to hot environments are critical for a dog in establishing the ability to successfully tolerate the heat. Early open-mouth panting with little or no excitement appears to enable the dogs to maintain a lower rectal temperature for a longer period.

Conclusions

Based on separate studies at CAMI, a hot/humid environment which causes a dog's rectal temperature to rise above 108 °F exposes that animal to possible heat stroke and even death. Such environments should not be considered safe for shipping dogs.

Healthy adult dogs transported in USDA-approved shipping kennels having no less than 14 percent overall ventilation capacity should be expected to safely tolerate air temperatures of 100 °F or less during 6 hours of transport, provided proper consideration is given to the humidity of the shipping environment.

Our studies also indicated that any given dog's behavior cannot be reliably predicted when that dog is confined to a shipping kennel and exposed to a stressful hot/humid environment. When a fractious dog is anticipated, assistance in helping that dog maintain a relative state of quiescence is advantageous. This can usually be accomplished by administering a low level tranquilizer.

The temperature/humidity index discussed in this report should serve as a useful guide for shippers and airlines when transporting dogs during the summer months.

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