Electrical Tech Note — 384

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Animal Heat and Moisture Production Rates

Animals and humans produce heat and moisture and when located in a confined space this heat and moisture production often must be taken into consideration if a desirable environment is to be maintained. When there is a low density of individuals in the space the effect of this heat and moisture production is minimal. By placing a high density of individuals in a confined space the combined heat and moisture production must be controlled if a suitable environment is to be maintained. Over the years research has been conducted to quantify the heat and moisture production rates of humans and particularly domesticated animals. Since this heat and moisture is released into the air, an understanding of the psychrometrics of the air is essential. *Tech Note 386* discusses psychrometrics of air. A heat balance study and a moisture balance study are conducted to determine if there is an excess or a deficit of heat and moisture in the space. These heat and moisture balance studies must be conducted at different typical outside temperatures and they will determine when supplemental heating or cooling is needed, and the minimum air flow rates needed to prevent a build-up of moisture in the space. In some cases a gas balance study is needed to maintain a sufficient level of oxygen for a healthy environment and to prevent the build-up of toxic gases.

Humans and animals are homeothermic creatures that must maintain a constant body core temperature for survival. A slight change in body core temperature requires an increase in metabolism for regulation. This is illustrated in *Figure 384.1.* There is a narrow range of temperature called the ***comfort zone*** over which the body can regulate a constant core temperature without any increase in metabolism. This comfort zone is different for different animals.

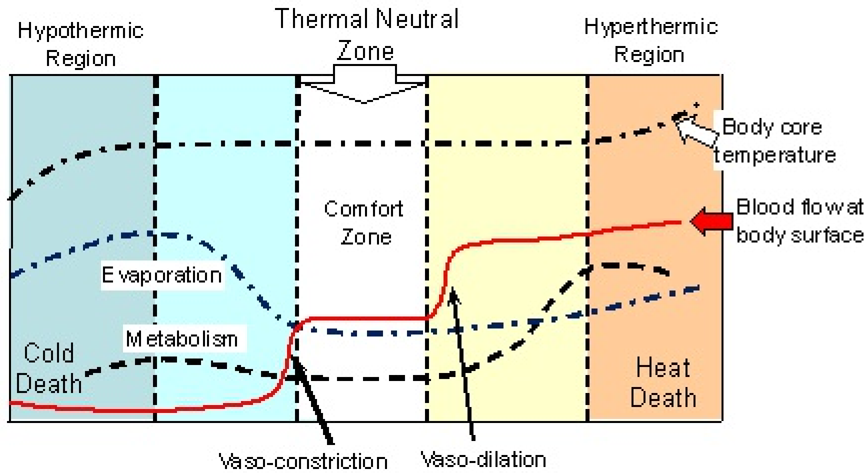

***Figure 384.1** Generalized graph of body core temperature of homeothermic animals with several important temperature regulation methods depicted such as metabolism, surface blood capillary constriction and dilation, and surface, lung, and tongue water evaporation.*

The body has a complex control system that maintains constant core temperature. Shivering when the temperature is cold is actually an involuntary physical activity that produces surface body heat. Goose bumps on the surface of the skin is an involuntary physical action that stands up the hair on the surface in order to increase the thickness of an insulating still air layer near the skin. In hot weather, capillaries on the surface dilate in order to move blood to the outer surfaces of the body to get rid of heat. In cold weather the capillaries constrict in order to prevent excessive heat loss from the surface. This capillary constriction usually occurs first in the ears, fingers, and toes since the body can still maintain life without them. Animals control body core temperature by different methods and it is important to have some knowledge of these methods. Evaporation of moisture from the external body surfaces and from lung internal surfaces as well as the surface of the tongue are important means of body cooling.

Heat and Moisture Balance: Since environmental conditions change constantly, it is not an easy task to maintain a suitable environment for livestock. In the wild, animals can move to suitable locations where the natural body functions can maintain life supporting conditions. Once animals are confined, humans must provide a suitable environment. This requires an understanding of how animals maintain body temperature. It can be a delicate balance between providing a minimal suitable environment and excessive energy loss. It is important to understand that an environment considered comfortable for a human is not necessarily comfortable for livestock.

When animals are confined, a heat and moisture balance study is usually necessary. Even cold air contains heat and in a heat balance study the difference in heat content between the inlet and outlet air is considered as well as the heat produced by equipment in the space such as motors and lighting, the heat produced by the humans or livestock, and any heat loss or gain by conduction through the building surfaces. In the case of a moisture balance study, the difference in moisture content of the inlet and outlet air is considered, as well as the moisture produced by the humans or livestock in the confined space. Some normal processes in the space may produce moisture that must be removed from the space such as periodic washing of surfaces or equipment. Usually a moisture balance study is conducted first at low outside temperatures to determine the minimum necessary air flow rate, then a heat balance study determines if that rate needs to be increased to get rid of excess heat, or if supplemental heat is required.

Improperly designed ventilation of a confined livestock space on a farm can result in an unhealthy environment, and it can result in an excessive waste of energy. Maintaining a balance between these two extremes is not an easy task. The purpose of this Tech Note is to provide some basic heat and moisture production information concerning mainly livestock. Detailed information on these and other animals and humans can be obtained from Handbooks published by the American Society of Biological and Agricultural Engineers, and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

Terminology: The common unit of heat used for animal confinement is the *British Thermal Unit* or *Btu*. A ***Btu*** is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit at standard conditions. Heating unit size is specified in rate of heat produced such as Btu per hour. The metric unit of heat is the Joule. The Joule is a very small unit of heat so generally for heating purposes equipment is rated in mega-Joules (MJ). One watt-second is equal to one Joule so another unit that can be used to quantify heat is the kilowatt (kW) and the kilowatt-hour (kWh). Here are some useful conversions. There are more conversions at the end of this Tech Note.

1 kWh = 3,413 Btu = 3,600,000 Joules (3.6 MJ)
1 kJ = 0.948 Btu

A term called ***basal heat*** production is the heat produced by an animal at rest and fasting when the ambient temperature is in the comfort zone. This is the minimum heat production needed to sustain life. ***Stable heat*** production is typical heat production of an animal in a normal situation such as a cow in a free stall barn. This is the value that is useful when designing an animal building ventilation system. Heat loss from a human or an animal consists of two components; sensible heat and latent heat. ***Sensible heat*** is removed from the body by transfer to the surrounding air by convection, contact with a cooler surface, or radiation to a cooler surface. The body will radiate heat direct to outer space on a clear night, or a human will radiate heat direct to a cold window surface. A person will feel warmer in a room with the same temperature when there are drapes or curtains over the windows in cold weather rather than direct exposure to the bare window glass. The opposite is true for cooling in the summer. ***Latent heat*** loss is by evaporation of water from body surfaces. For every pound of water evaporated from a body surface about 1000 Btu of heat is removed. ***Total heat*** is the sum of both sensible heat and latent heat.

When a heat and moisture balance evaluation is conducted for an animal confinement area, it is necessary to know both the sensible heat production of the animals as well as the latent heat produced by the animals. Sensible heat production is used in the heat balance evaluation, and latent heat is used in the moisture balance evaluation. Actually the most useful information about animal moisture needed for a moisture balance evaluation is the amount of water produced by the animal over a unit of time. If latent heat production is in units of Btu per unit time per animal that value can be converted to pounds of water per unit time per animal by dividing by 1000 to get a rough estimate. By dividing the latent heat production by the latent heat of vaporization of water the pounds of water produced by the animal can be determined. Values of latent heat of vaporization of water at different temperatures are given in *Table 384.6.* Just knowing the heat loss from an animal by evaporation from animal surfaces is not enough when designing ventilation for an animal confinement area. Another source of moisture is by animal excrement. It is important to know if the animal moisture production rate provided also includes animal excrement moisture since that is moisture often added to the ventilation requirement. *Table 384.1* provides heat production rates for Holstein dairy cows in production. Since the values in the Table are for a 1000 pound cow, a linear adjustment can be made for cow weight that is different. Multiply Table value by 1.4 for a 1400 pound cow.

Table 384.1 *Heat and moisture production rates for Holstein dairy cows on the basis of a 1000 lb cow. Multiply these values by a factor to adjust for the average weight per cow.*

Cows	**Ambient**	**Latent moisture**	**Latent heat**	**Sensible heat**	**Total heat**
(1000 lb)	**Temp. °F**	**lbs. H_2O per hr.**	**Btu per hr.**	**Btu per hr.**	**Btu per hr.**
1000	30	0.77	800	2950	3750
1000	40	0.91	950	2650	3600
1000	50	1.05	1100	2300	3400
1000	60	1.28	1340	1900	3240
1000	70	1.34	1400	1700	3100
1000	80	1.82	1900	1000	2900

Figure 384.2 shows the total heat production of a typical Holstein dairy cow subdivided into sensible heat and latent heat. The values used to produce this graph are the same as in *Table 384.1.* Even though cows appear to lay around a lot, their heart is working very hard. If a dairy cow is physically active, energy and blood flow is being diverted from milk production. In order for diary cows to have high milk production, they must have plenty of clean water, nutrition, and time to rest. Because their heart is working hard pumping blood to make milk, the cow has lots of body heat to dissipate to the environment. High producing Holstein dairy cows in production need a cool environment. Dairy cows cool their body by transferring heat to the surrounding air directly from body surfaces by conduction. Perspiration from body surfaces is not a major means of cooling. However evaporation from respiratory surfaces is extremely important for dairy cows. When the surrounding air is very warm, dairy cows resort to panting to increase evaporation and heat loss. Notice in *Figure 384.2* that when surrounding air temperature increases, diary cow total heat loss to the environment decreases. Notice also that for Holsteins, latent heat loss from the body increases dramatically when the surrounding temperature exceeds 70ºF.

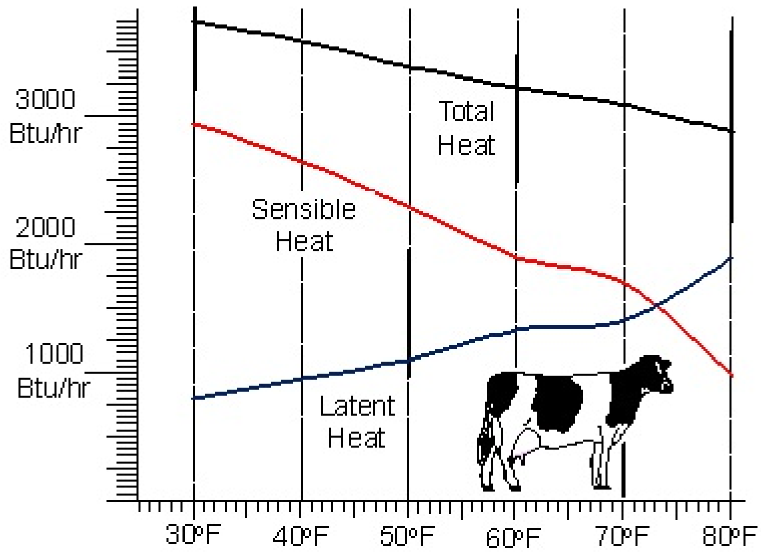

Figure 384.2 *Heat production rate for 1000 pound Holstein dairy cow in production. Adjust values linearly for weight different than 1000 pounds.*

Figure 384.3 was adapted from data taken from the Handbook of the American Society of Biological and Agricultural Engineers and represents milk production of Holstein dairy cows at various environmental temperatures. The graph demonstrates that Holstein cows are cold weather animals. When the temperature of the housing space exceeds 65ºF, a decrease in milk production starts to become significant. Above 85ºF drop in milk production becomes dramatic. The *Figure 384.2* heat production graph shows that the dairy cow's principle form of cooling the body is by evaporating water generally from respiratory surfaces. Body energy is diverted from milk production to body cooling. At 80ºF, Holstein dairy cow milk production is estimated to be only 82% of what it was at 50ºF. It is important to do whatever is cost and energy efficient to create a comfortable environment for farm production animals.

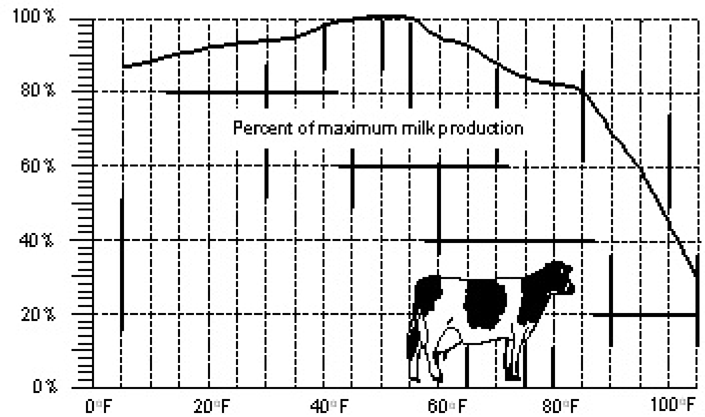

Figure 384.3 *Optimum temperature for dairy cows is about 50°F with a significant decrease in milk production when the temperature exceeds 80°F.*

Figure 384.4 is for Holstein dairy calves contained in a confined space and it is clear that at elevated environmental temperatures cooling by evaporating water becomes the significant means of body cooling. Loss of heat as indicated by the increase in latent heat indicates that evaporative cooling is the means of heat removal from the calf's body when the temperature exceeds about 75°F. Heat production data for diary calves is limited, so this graph can only be used as an approximation when determining ventilation rates for confined dairy calf housing.

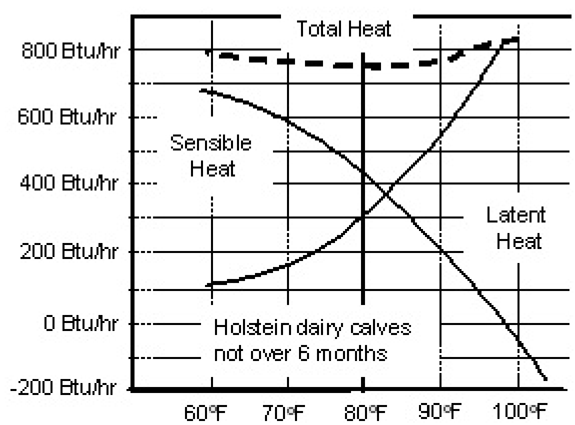

Figure 384.4 *Heat production rates for dairy calves up to 6 months of age.*

Figure 384.5 is heat production for beef cattle and it can be a little difficult to interpret. Note the dashed line that represents total heat loss from the cattle. At about 75°F total heat is less than latent heat loss. Notice the bottom solid line that represents sensible heat. At above about 75°F the values become negative. This means the animal is gaining sensible heat from the air which is being expelled from the body as latent cooling. So total heat represents only the heat produced from body functions.

There is limited data on heat production for beef cattle, so this effect may not apply in all cases. Please be aware there can be a big difference in heat production rates for different breeds of animal and the ideal environmental temperature for one breed may be much different for another breed. For example a Jersey dairy cow is more effected by a cold environment than a Holstein cow, but the Jersey cow does much better in a warm environment.

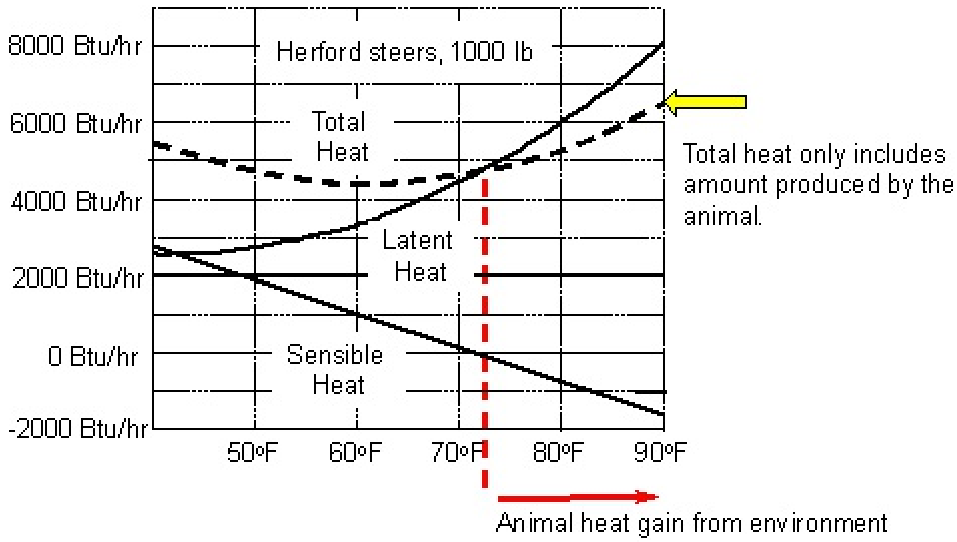

Figure 384.5 *Heat production rates for Herford beef cattle.*

Sensible heat loss is a greater factor for hogs than for other livestock with a thick hair coat. *Table 384.2* provide heat production information for hogs of different weights as well as a sow and litter. *Figure 384.6* shows the change in sensible and latent heat production for 200 pound growing hogs. The Figure is based upon the same data that is shown in *Table 384.2.* Notice that total heat loss from swine reaches a minimum at temperatures from about 70°F up to about 85°F. This trend tends to indicate the comfort zone for hogs.

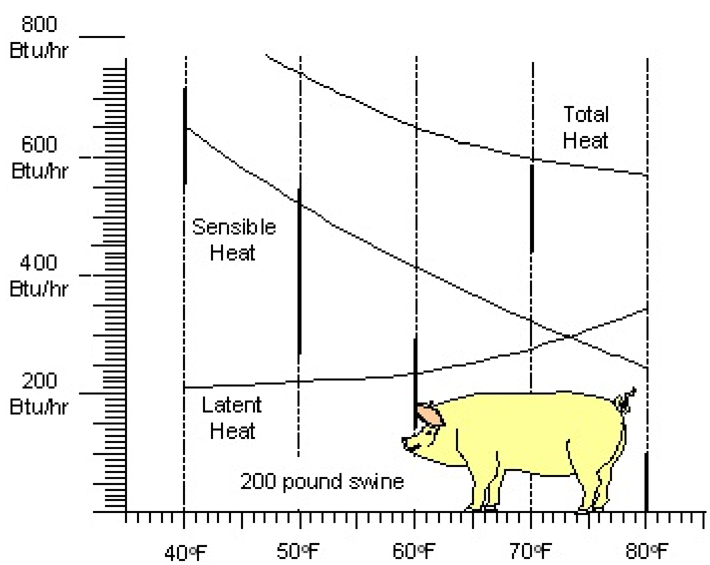

Figure 384.6 *Heat production for 200 pound growing hog subdivided into latent and sensible heat production.*

Table 384.2 *Heat and moisture production rates for swine including sows with litters of different ages. Total heat production is the sum of latent heat and sensible heat.*

Hogs	Ambient	Latent moisture	Latent heat	Sensible heat
	Temp. °F	lbs. H_2O per hr.	Btu per hr.	Btu per hr.
100 lb hog	40	0.14	147	443
	50	0.15	158	352
	60	0.18	189	281
	70	0.22	231	199
	80	0.27	284	136
200 lb hog	40	0.20	210	650
	50	0.21	220	520
	60	0.23	236	414
	70	0.27	278	322
	80	0.33	346	224
sow & litter (0 wk)	80	0.70	733	785
sow & litter (2 wk)	80	0.96	1000	1050
sow & litter (4 wk)	80	1.07	1113	1079
sow & litter (6 wk)	80	1.19	1243	1161
sow & litter (8 wk)	80	1.30	1359	1627

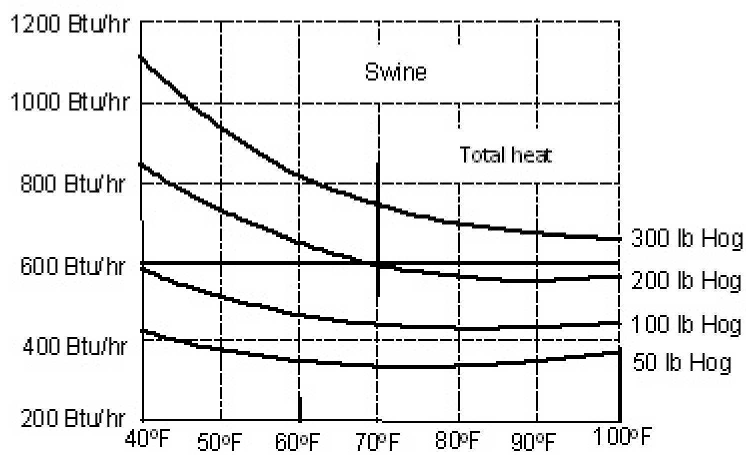

Figure 384.7 *Total heat production of hogs at weights ranging from 50 pounds to 300 pounds. Approximate ratios of latent and sensible heat given in Table 384.2 can be used to estimate total and sensible heat production at 300 and 50 pound weights.*

Because of the breed of swine as well as feed ration it is difficult to use the diagram of *Figure 384.8* for purposes other than for a general indication of effect of ambient temperature on hogs. The diagram shows an increase of feed required when the swine are in an environment outside their comfort zone. What can be determined from this graph is that for swine, the comfort zone ranges from about 65°F to about 85°F.

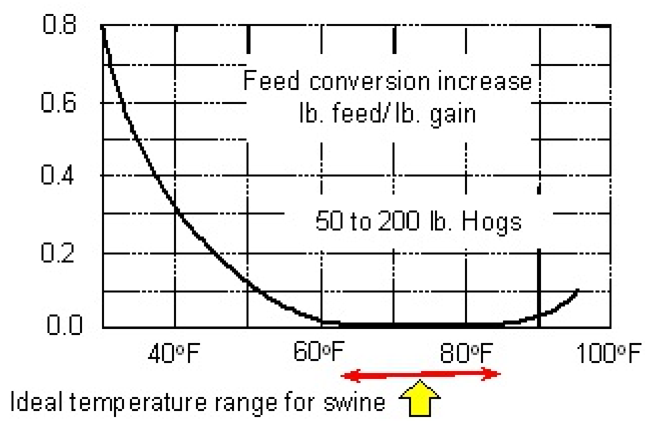

Figure 384.8 *Feed intake for hogs increases below 60°F to maintain body heat. At high temperature feed consumption increases because of increased metabolism* for *cooling.*

Values of heat production for white Leghorn laying hens and for turkeys housed in confined areas are given in *Table 384.3.* This data is intended as a general guide for these species. It is recommended that before designing a confinement system other references for the particular breed be evaluated. One source of information on heat and moisture production is the Handbook of the American Society of Agricultural and Biological Engineers (ASABE) and the Handbook of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). Total heat production is the addition of latent heat and sensible heat.

Table 384.3 *Heat and moisture production rates for laying hens, and turkeys.*

White Leghorn	**Ambient**	**Latent moisture**	**Latent heat**	**Sensible heat**	**Total heat**
Weight 4 lbs.	**Temp. °F**	**lbs. H_2O per hr.**	**Btu per hr.**	**Btu/hr.**	**Btu/lb/ hr.**
laying hen	50	0.0126	13.2	26.4	39.6
laying hen	60	0.0134	14.0	26.4	40.4
laying hen	70	0.0138	14.2	26.0	40.2
laying hen	80	0.0164	17.1	23.6	40.7
laying hen	90	0.0201	21.0	14.0	35.0
Turkeys (Btu/hr lb)*	75	0.006*	6.2*	10.8*	17.0*

This heat and moisture production data for sheep is published on the basis of surface area of the animal at different ambient temperatures and with minimum fleece length and 10 cm fleece length. To make this data easier to use *Table 384.4* provides approximate sheep surface area based upon animal weight. *Figure 384.5* provides heat production of sheep with short and long fleece and was adapted from an ASABE published source.

Table 384.4 *Surface area of sheep based upon weight.*

Sheep weight (lbs)	40	60	80	100	120	140	160
Sheep surface area (ft^2)	6.8	8.9	10.8	12.5	14.1	15.7	17.1

Table 384.5 *Heat and moisture production of sheep on the basis of Btu/hr ft^2.*

Ambient Temperature	Moisture Production lbs of H_2O	Latent heat Btu/ft^2	Sensible heat Btu/ft^2	Total heat Btu/ft^2
0.1cm fleece length				
50°F	0.0048	5.0	33.0	38.0
60°F	0.0048	5.0	26.0	31.0
70°F	0.0048	5.0	20.0	25.0
80°F	0.0071	7.5	14.5	22.0
10 cm fleece length				
50°F	0.0057	6.0	14.0	20.0
60°F	0.0076	8.0	12.0	20.0
70°F	0.0100	10.5	10.0	20.5
80°F	0.0143	15.0	6.0	21.0

A single total heat production value given in *Figure 384.9* is provided here for a pleasure horse not involved in physical exercise. This value is intended to be used in a confined area where pleasure horses are housed in stalls with no other source of heat or moisture production other than that necessary for horse housing.

Figure 384.9 *Total heat production for a 1000 pound pleasure horse.*

Human heat production data is often provided as values in watts of sensible heat, latent heat and total heat. *Figure 384.10* and *Figure 384.11* are provided as a general guide for an average adult at various activity levels. This data is intended to be used to point out the general significance of human body heat and moisture production when designing confined spaces such as offices, classrooms, and other work spaces. Before actually designing such a space it is important to select data based upon the individuals that will occupy that space as well as their activity level. A good starting point for finding such information is the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).

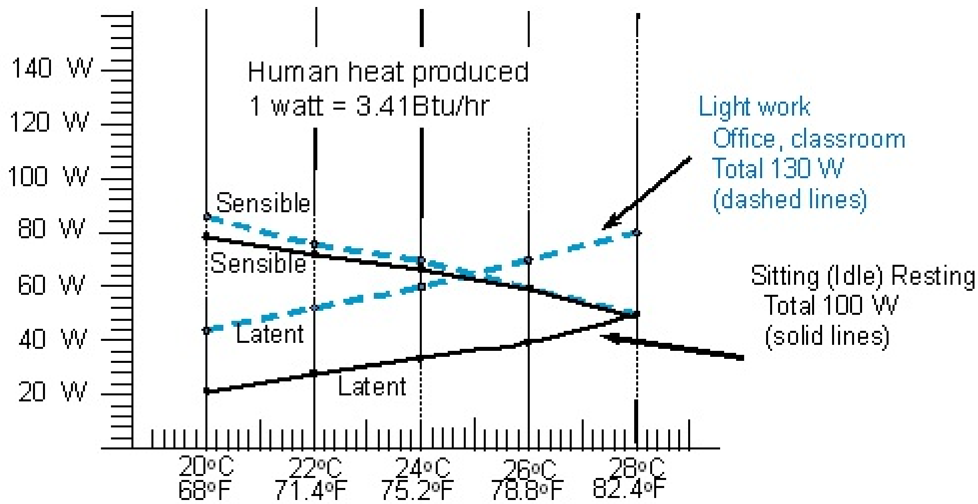

Figure 384.10 *Sensible heat and latent heat production of adult humans sitting quietly or performing light work. Total heat is the sum of latent and sensible heat.*

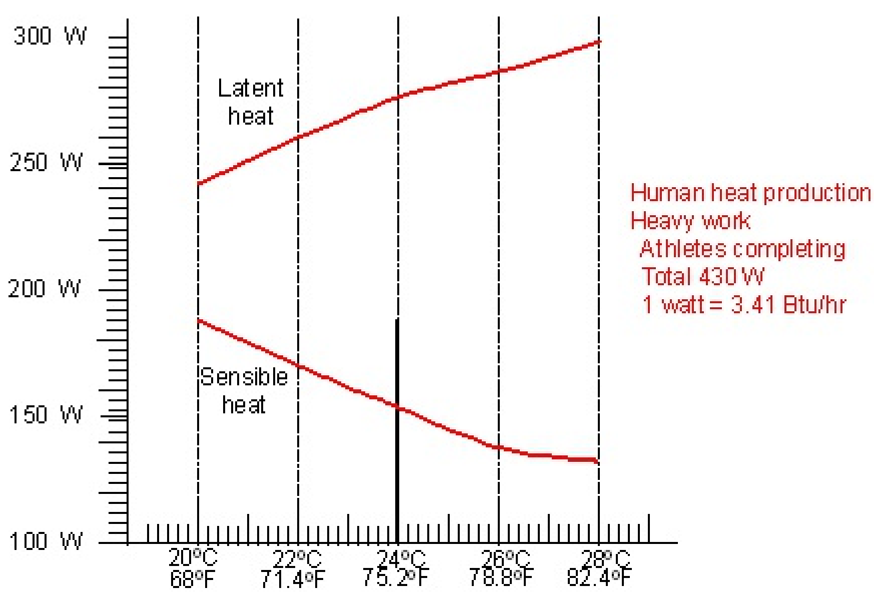

Figure 384.11 *Sensible heat and latent heat production for adult human involved in heavy physical work or an athlete involved in vigorous activity. Total heat is the sum of latent and sensible heat.*

Conversions:

When conducting a heat and moisture balance evaluation for an animal confinement space it is often necessary to make a conversion between pounds of water per hour and latent heat in Btu/hr. This conversion requires using the latent heat of vaporization of water at the temperature at which the vaporization occurs. *Table 384.6* gives those values for a variety of temperatures that may be typical in animal housing. Latent heat of vaporization of water changes as temperature at which evaporation occurs.

Table 384.6 *Values of latent heat of vaporization of water at several temperatures.*

Temperature	Latent heat of water
50°F 10°C	1060 Btu/lb
60°F 16°C	1056 Btu/lb
70°F 21°C	1050 Btu/lb
80°F 27°C	1044 Btu/lb
100°F 38°C	1033 Btu/lb
212°F 100°C	970 Btu/lb

To make conversions between kiloJoules per kilogram, kiloCalories per kilogram, and Btu per pound, use the following methods.

kcal/kg x 1.8 = Btu/lb   Btu/lb x 0.556 = kcal/kg

kJ/kg x 0.43 = Btu/lb   Btu/lb x 2326 = kJ/kg

It may be necessary to convert between Btu/hr, watts, kcal/hr, and kJ/hr. For that purpose use the following methods.

Watts x 3.41 = Btu/hr   Btu/hr x 0.293 = Watts

kcal/hr x 3.97 = Btu/hr   Btu/hr x 0.252 = kcal

kJ/hr x 0947 = Btu/hr   Btu/hr x 1.056 = kJ/hr

References:

American Society of Agricultural and Biological Engineers Handbook
American Society of Heating, Refrigerating, and Air-Conditioning Engineers Handbook
Structures and Environment Handbook, Midwest Plan Service

Note: This Tech Note is intended for educational purposes only. Before proceeding with an actual design of an environmental system, verify heat and moisture production data from a reliable source such as those indicated in the references.