Portable protective dog enclosure and its thermal effects on the animal

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INTRODUCTION

Working dogs and their handlers may need protection from toxic environments during transportation, temporary housing and field work. Portable chem-bio protective (CBP) kennel covers and tents are being designed and becoming available for use. While affording protection from toxic air, the CBP may cause overheating of the dog due to the added insulation of the CBP enclosure. The overheating potential was assessed through systematic measurements of the heat transfer properties of the enclosure and the prediction of their effect on the dog's thermo-physiological responses by computer modeling.

METHODS

Chemical-biological protective (CBP) enclosure The enclosure (Figure 1) was tested in a climatic chamber to quantify its heat and vapor transfer properties. The tent shelter was on a table in the chamber with a dog cage (Vari Kennel) inside to support the cover. A sweating thermal human manikin head (MTNW) was the heat and moisture source to represent the dog. Air flow in the chamber was horizontal and temperature and humidity were controlled precisely.

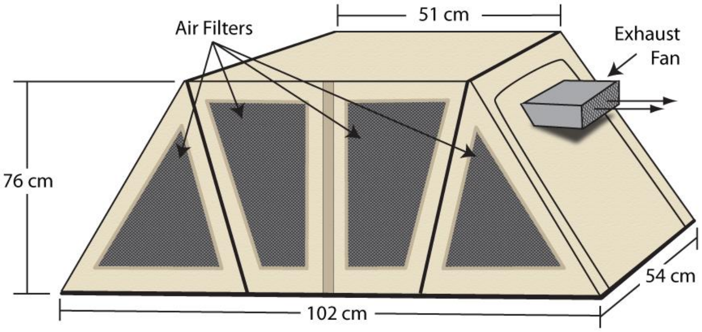

Figure 1. Schematic of protective cover.

The flow of dry heat (Qk_dry) from within the kennel (k) to the surrounding ambient (a) environment can be expressed as:

Qk_dry = (Tk-Ta)/(Rdk-a) [W] 1

Where Tk and Ta are the air temperatures inside and outside of the kennel and Rdk-a is the thermal resistance to dry heat flow from the kennel to the ambient. Similarly the heat (Qk_evap) transferred by water vapor (p) from inside sources to the outside can be expressed as:

Qk_evap=(Pk-Pa)/(Rpk-a) [W] 2

where Pk and Pa are the water vapor pressures inside and outside of the kennel cover, and Rpk-a is the resistance to vapor heat flow from within the kennel to the outside. The dry and vapor heat are transported mainly by diffusion/mixing mechanisms and thus are relatable through the Lewis analogy (ASHRAE, 2005). The dimensionless vapor permeability metric (im) of the cover is calculated as the ratio of dry to vapor heat resistances: imk-a = (Rdk-a)/(LR*(Rpk-a)) where LR = 2.2 °C/Torr is the Lewis relation. Values of im range from 0 for impermeable materials to 1.

Dog model Belgian Shepherds and similar working dogs are the focus here. An adult is about 35 kg and about 1.2 m long not including tail. For modeling purposes the Belgian Shepherd is somewhat like a small human with fur. However their thermoregulatory system, though similar to the human, relies on panting for evaporative cooling from tongue, nose, throat and respiratory surfaces rather than eccrine sweating of the skin.

This dog model evolved from Gagge (1986), Kraning (1997) and Yokota (2006) human thermo-physiological models with added or modified physiological mechanisms for the dog. The model (Figure 2) represents the animal as two concentric lumped parameter physiological compartments (core and skin) surrounded by fur. The fur was modeled like clothing and the kennel cover was modeled as a passive compartment surrounding the dog.

The core generates all the metabolic energy and has a uniform temperature Tc. The core losses heat to the skin by passive conduction through the tissues and by actively controlling the flow of warm core blood to the skin for cooling. It also loses heat directly to the immediate surroundings by respiration which includes panting.

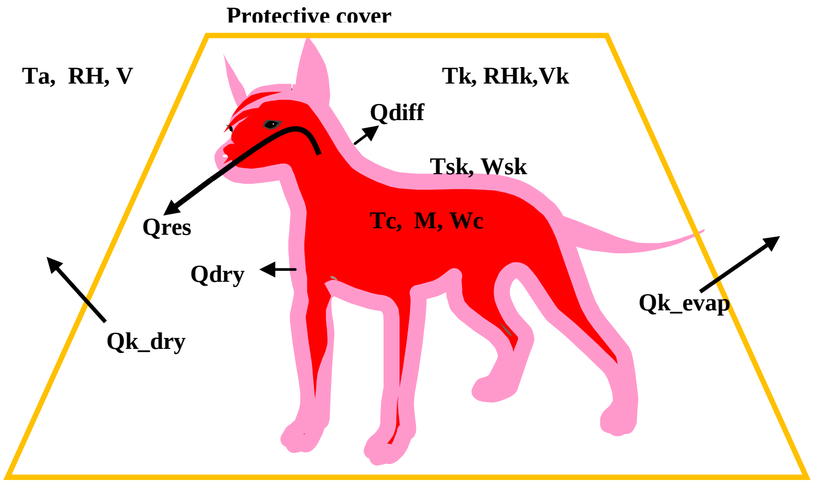

Figure 2. Schematic of dog model in covered kennel

Physiological control mechanisms

The skin blood flow and shivering controls of the human models are proportional to deviations in core and skin temperature (Tsk) from their respective set point temperatures (Tcset, Tskset). These human model controls are used for the dog but their body temperatures in neutral conditions are about 1.5°C higher than those of the human (Kanno, 1982; Refinetti, 2003). The computer model allows the user to adjust the set points by adding an increment (dTset) to the human (TTC = 36.8°C) set points (Tcset = TTC+dTset). dTset is the same for both skin and core.

Panting, which the dog uses in place of sweating, is different from any human heat loss mechanism. The literature indicates that panting is approximately a three position on-off respiratory mechanism with two levels of air flow depending on body temperatures (Goldberg, 1981). When panting, the breathing rate increases to the approximate natural elastic frequency of the respiratory system (Hemingway, 1961; Crawford, 1962; Meyer, 1989). Analysis of literature data generated the following expressions for panting pulmonary ventilation (PantVent1, 2):

$$\mathrm{PantVent1}= (0.0137\cdot \mathrm{Wt} + 0.4457)\cdot \mathrm{Wt} \quad \text{and} \quad \mathrm{PantVent2}=1.5\cdot \mathrm{PantVent1} \quad [\mathrm{L/min}] \qquad 3$$

where Wt is dog’s weight (kg). The dog model’s panting control inputs are similar to those of the human model’s sweat control, adjusted for the dog’s set-point temperatures, to start, stop, and adjust panting levels. PantVent1 starts when compartment temperatures exceed the set-points by 0.1°C and goes to the higher panting level when temperatures rise another 0.1°C. The heat loss by respiration or panting depends on the difference in energy content between exhaled and inhaled (i) air. Data in the literature indicates that thermal and moisture ventilation effectivenesses (EffrT and EffrP) are about 0.82 and 0.84 respectively enabling the exhaled temperature (Tex) and vapor pressure (Pex) to be estimated.

$$Tex = Ti + EffrT\cdot(Tc-Ti) \text{ and } Pex = Pi + EffrP\cdot(Ps(Tex)-Pi) \qquad 4$$

If the dog's exhaled air was at core temperature and saturated the ventilation effectivenesses for temperature and moisture would both be 1. Further, the dog's higher Tc enhances its respiratory heat loss potential.

The model quantifies metabolism with the dimensionless met unit (met = actual metabolism/resting metabolism), where resting or basal metabolism (ASHRAE, 2005) in W is $BasalM = 3.5\cdot Wt^{0.75}$. Walking is in the 2 to 3 met range depending on speed. In the kennel metabolism is estimated to be in the 1 to 2 met range.

The thermal insulation of the dog's fur depends on its thickness (Folk, 1974; Hammel, 1955; Schmidt-Nielsen, 1979). The model estimates the dry heat resistance of fur in $m^2\cdot°C/W$ as $Rdf = 0.155\cdot3.19/(thick/25.4)$ where thick is the fur thickness in mm on the back. The energy resistance to vapor flow through the fur (Rpf) in m^2Torr/W is estimated by the Lewis relation using a vapor permeability value (ipcl=0.45) common for woven fabrics as $Rpf=Rdf/(LR\cdot ipcl)$.

Energy balances on each compartment enable the rate of energy and temperature gain of the compartment to be determined. The energy balance for the core compartment is:

$$met\cdot BasalM/BSA= qres\_pant + qkc + qskbf +Wc/BSA\cdot Cc\cdot dTc/dt \qquad 5$$

where qres_pant is the heat loss from normal respiration or panting, qkc is heat loss by conduction through body tissue to the skin, qskbf is heat loss from core by blood flow to the skin. The last term is the rate of energy storage in the core where Cc is specific heat (W h/(kg °C)) of core and BSA is body surface area(Cowgill,1927). $BSA = 0.0002268\cdot Wt^{0.667}\cdot Lgth$ in m^2 where Lgth (m) is dog length from nose to beginning of tail. The rate of compartment temperature changes dTc/dt and dTsk/dt is step-wise integrated over small time steps (Δt) to find the core (Tc_2) and skin temperature (Tsk_2) after the time step as $Tc_2 = Tc_1+[dTc/dt]_1\,\Delta t$ and $Tsk_2 = Tsk_1+ [dTsk/dt]_1\,\Delta t$. By this stepping process the time responses of Tc, Tsk and related physiological can be rationally predicted. Energy balances on the kennel results in a similar step wise integration of kennel's inside temperature (Tk) and vapor pressure (Pk).

RESULTS

CBP enclosure Heat transfer measurements were made with chamber environments of 20, 25 and 30°C and 50%RH, air speed 0.4 m/s, with the kennel cover's ventilation exhaust fan on and off and the head dry and sweating with a skin temperature of 33°C (Table 1).

Table 1. Average heat transfer properties for the protective cover.

Fan	Rdk-a (°C/W)	Rpk-a (Torr/W)	imk-a
on	0.1083	0.336	0.2174
off	0.1299	0.272	0.2171

The ventilation air flows measured with the tent door sealed and open were 6.33 and 7.06 L/min or opening the door with the fan running only increases flow by about 12%. These values and the imk-a values imply that when fan is off or disabled some ventilation will occur.

Simulation The CBP cover's thermal and moisture properties were used with the dog model to simulate a dog's responses to various conditions and activities. Simulated responses of the dog going through a sequence of intermittent resting and moving about activities outside and inside the kennel with fan-on and fan-off are displayed in Figures 3 a,b.

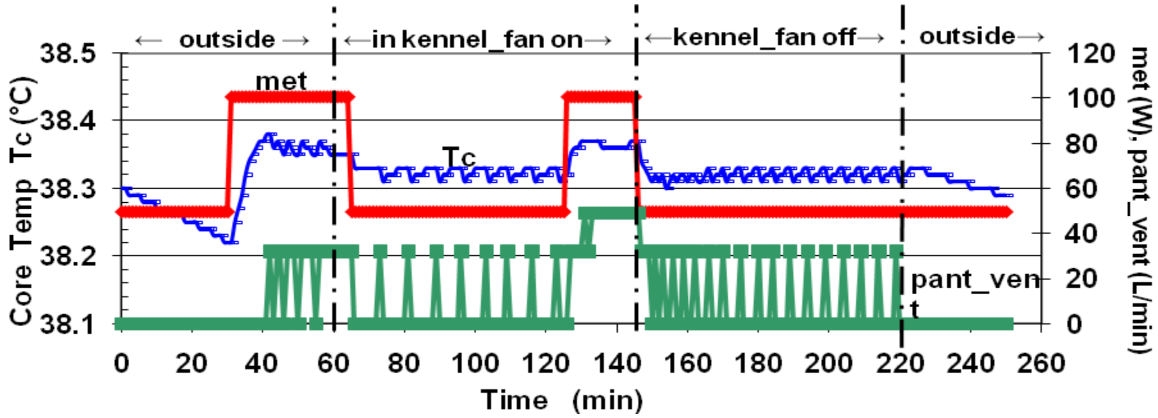

Figure 3a. Transient responses with outside conditions of 25°C, 50 %RH and 0.4 m/s wind.

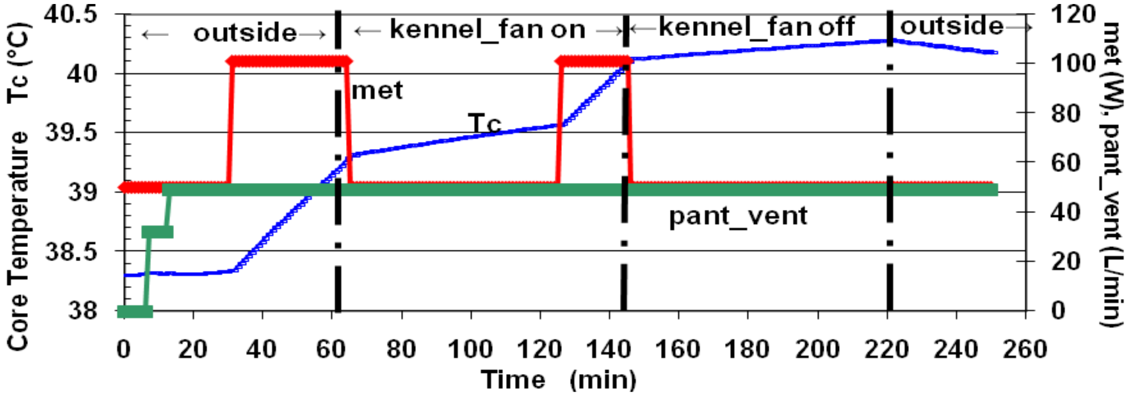

Figure 3b. Transient responses with outside conditions of 40°C, 50 %RH and 0.4m/s wind.

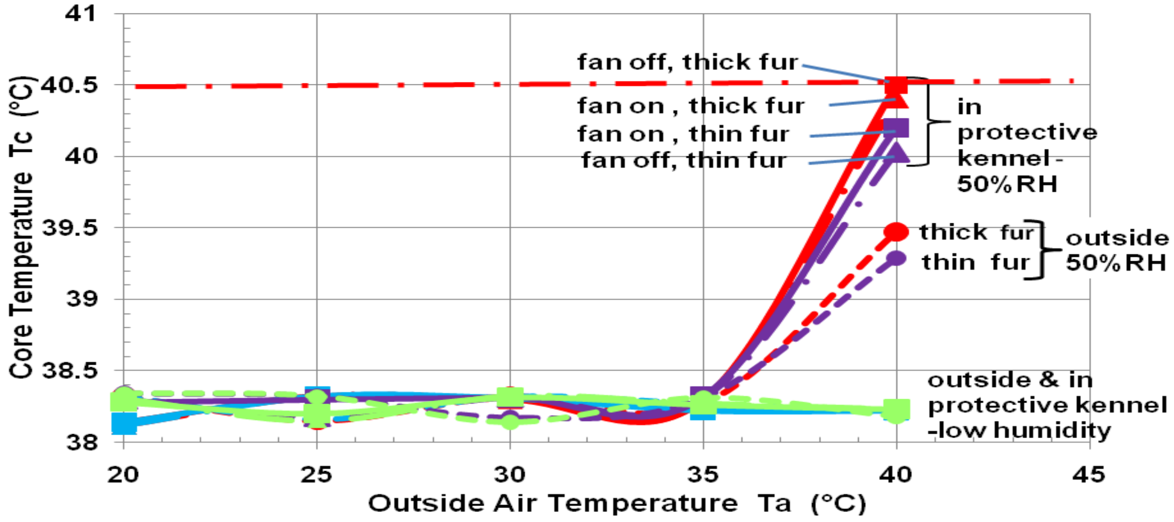

Figure 4. Simulated quasi steady state responses of resting Belgian shepherd, wind 0.4m/s

Quasi steady Tc responses to constant conditions (Figure 4) indicates reducing humidity from 50 %RH to a dryer (9°C dew point) level and also reducing fur thickness from thick (10mm) to thin (5mm) can lower Tc, particularly for Ta>35°C. Further activities above resting can substantially increase Tc for Ta>25°C and shorten safe stay times (Table 2).

Table 2. Safe Stay Times (SST) for Tc<=40.5°C

Outside environment				SST (min): Resting - 1 met			SST(min): Standing & moving-2 met		
Ta		RH	Tdp	outside	fan on	fan off	outside	fan on	fan off
20	humid	49	9	>720	>720	>720	>720	>720	>720
25		50	13	>720	>720	>720	>720	>720	>720
30		50	18.5	>720	>720	>720	>720	459	327
35		50	23	>720	>720	>720	384	141	132
40		50	27.5	>720	>720	>720	95	87	81
20	dry	49	9	>720	>720	>720	>720	>720	>720
25		36	9	>720	>720	>720	>720	>720	>720
30		27	9	>720	>720	>720	>720	>720	>720
35		20	9	>720	>720	>720	>720	393	304
40		16	9	>720	>720	>720	533	175	163

CONCLUSIONS

The measured CBP cover properties were used together with a thermo-physiological dog model to estimate a dog's responses to being caged under the protective cover in a variety of conditions. The simulated responses indicate that with 35°C 50%RH outside conditions, a Belgian Shepherd would not experience heat related illnesses if quietly resting in the CBP kennel. But if restless and moving about in the kennel, a 30°C 50%RH outside condition could cause the dog's core temperature (Tc) to exceed 40.5°C after about 4 hours. Tc>40.5°C is a level where heat related illness can begin to occur with heat stroke at Tc>=43.4°C (Bynum, 1977). The model is simple in comparison to the real dog and the results should be used as a guide.

Opinions, interpretations, conclusions, and recommendations contained herein are those of the author and are not necessarily endorsed by the U.S. Army.

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