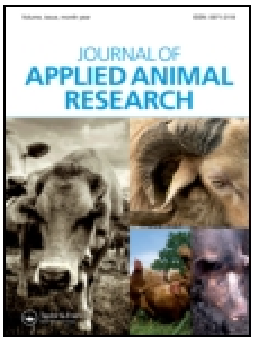

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An Evaluation of Differences in Mean Body Surface Temperature with Infrared Thermography in Growing Pigs Fed Different Dietary Energy Intake and Concentration

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Abstract

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Eighty pigs were used to determine the relationships among feed intake or diet composition and mean body surface temperature (MBST). In Exp. 1, 80 castrates (initially 24 kg) were allotted to one of the four feed intake levels [1.4×, 2.50×, 3.8× and ***ad libitum*** *or 4.7× ME maintenance (MEm)]. Infrared (IR) thermographic images were collected at 0700, 1100 and 1900 h on d 4, 5 and 6. Quadratic effects were observed for ADG and G/F ($P<0.05$) and linear effects for ADFI ($P<0.01$) as ME intake increased. Treatment × time interactions were observed for MBST ($P<0.01$). The interaction was because MBST increased linearly at 0700 and at 1900 h as daily ME intakes increased ($P<0.05$) but increased quadratically with a plateau at 2.5× MEm at 1100 h ($P<0.05$). At 0700 h, MBST increased linearly as daily ME intakes increased from 1.5× MEm to* ***ad libitum*** *($P<0.05$). In Exp. 2, pigs (initially 40 kg) were fed a common diet, and IR images were collected daily at 0700 h. Average daily gain was dependent upon changes in ADFI, mean body surface heat loss (MBSL) and the natural log of MBST (r^2=.38; $P<0.01$). In Exp. 3, pigs (initially 59 kg) were allotted to diets containing 11.5, 12.6, 13.6 and 14.6 MJ ME/kg. Increasing dietary ME increased ADG, G/F, ME intake, MBST and MBSL (linear, $P < 0.05$). The data indicate that IR thermography can detect MBST changes in pigs caused by changes in dietary intake or energy level. These changes can be detected under more variable environmental conditions than those used with a calorimeter and may be adapted as a low cost noninvasive tool to categorize factors impacting swine thermoenergetics.*

Key words: Infrared thermography, dietary energy, pigs.

Introduction

Recent advances in technology have allowed the development of infrared (IR) thermography as a diagnostic tool to assess animal health (Loughmiller *et al.*, 2001). Recent research has indicated that IR thermography can reliably identify pigs exhibiting a febrile condition following *A. pleuropneumonia* challenge or pigs with a mean body surface temperature (MBST)

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above the group mean (Bossow, 1996; Loughmiller *et al.*, 2001). The rise in MBST associated with the febrile state was detected by Loughmiller *et al.* (2001) in comparison to non challenged controls during an 18 h period of feed withdrawal. Additionally, Bossow (1996) did not control for the effects of feed intake and only identified pigs with elevated MBST *versus* the group average. Thus, because adaptive responses to disease or stress typically involve feed intake reductions, it is unknown if the elevated MBST associated with the febrile condition would mask the relative reduction in MBST associated with this feed intake reduction in comparison to healthy pigs with full feed consumption.

Additionally, in otherwise healthy pigs, different growth rates and changes in feed intake, dietary energy content and dietary crude protein levels can affect metabolic heat production (Sundstol *et al.*, 1979; Close *et al.*, 1983; Fuller *et al.*, 1987). Therefore, it may be possible to detect associated differences in MBST leading to a calculation of mean body surface heat loss (MBSL) and relate them to growth performance. This potential use would allow researchers the opportunity to develop predictive modeling based upon group aggregate tissue-accretion curves (Smith *et al.*, 1999) and metabolic growth potential.

Thus, the objective of the current study was to evaluate changes in MBST measured with infrared thermography associated with growth performance in healthy pigs subjected to changes in feed intake or dietary nutrient profile.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee approved this experimental protocol. Eighty crossbred castrates (line 326 × C22, PIC, Franklin KY) were used in three consecutive experiments with adaptation periods between two experiments. The pigs were housed in individual pens in an environmentally controlled finishing building with mechanical ventilation. Each pen (1.5 m × 1.5 m with totally slatted flooring) contained a single-hole, dry feeder and a single nipple waterer. Pigs were blocked at the start of each experiment by initial weight and allotted to dietary treatment. Treatments in Exp. 1 were based upon feed allowance, but all pigs in Exp. 2 and 3 were allowed *ad libitum* consumption of feed and pigs in all experiments were allowed *ad libitum* water consumption.

For each experiment, feed was prepared and mixed from common bulk quantities of ingredients. Diets were formulated to meet or exceed NRC (1998) recommendations with the exception of dietary ME (Exp. 3: Table 1). Total and true digestible nutrient values from NRC (1998) were used, allowing similar calculated true digestible lysine:Mcal ME ratios across treatments within Exp. 3.

Imaging equipment consisted of a high resolution, short-wave (3-5 μm), radiometric IR thermal imaging camera (Inframetrics Inc. PM-250 Thermacam, N. Billerica, MA). The camera is equipped with a 16º FOV lens and the images are displayed in a focal plane array. Images were taken at a distance of 2 m perpendicular to the side of each pig while it was standing unrestrained in its pen and collected on a 10 Mb PCMCIA card for image data processing. If a pig was not standing at the time it was to be imaged, it was forced to rise and the image obtained one minute from the time the pig began standing. The collected digital images were analyzed by a certified technician using analytical software (Thermagram® Pro 95, N. Billerica, MA).

Mean body surface temperature was calculated from an approximately 3,500 pixel image of a 15 H × 25 W cm area extending anterior to posterior from the middle of the scapula to near the midpoint of the rear leg and dorsoventral from the point of the shoulder to the olecranon and the tuber coxa to the stifle of each pig. The area of measurement was selected to avoid areas with extremes in high surface temperature

Table 1
Diet composition (as fed basis)[a]

Ingredients, g kg^{-1}	Exp. 1 & 2	Experiment 3, MJ ME kg^{-1} of diet			
		11.5	12.6	13.6	14.6
Maize	644.6	327.4	502.0	622.3	564.1
Soya bean meal, 465g CP kg^{-1}	325.3	213.9	268.5	315.9	354.1
Soya bean oil	—	—	—	—	52.0
Alfalfa meal	—	309.4	181.0	33.0	—
Wheat middlings	—	132.0	25.0	—	—
Monocalcium phosphate	11.7	9.9	12.1	11.9	11.8
Limestone	11.0	—	4.0	9.5	10.5
Salt	3.5	3.5	3.5	3.5	3.5
Vitamin premix[b]	2.0	2.0	2.0	2.0	2.0
Trace mineral premix[c]	1.5	1.5	1.5	1.5	1.5
Medication[d]	0.5	0.5	0.5	0.5	0.5
Diet composition, MJ kg^{-1}[e]					
Calculated DE	14.5	12.2	13.3	14.3	15.4
Calculated ME	13.8	11.5	12.6	13.6	14.6
Calculated NE	—	7.1	8.1	9.0	9.8
Crude protein, g kg^{-1}					
Calculated	204.8	200.2	201.3	204.1	211.5
Analyzed	213.8	225.1	228.7	235.8	236.7

[a]All diets were formulated to contain 7.5 g Ca kg^{-1} and 6.5 g P kg^{-1}.

[b]Provided the following per kilogram of complete diet: vitamin A, 11,023 IU; vitamin D_3, 1654 IU; vitamin E, 44 IU; menadione (menadione sodium bisulfate complex), 4.4 mg; riboflavin, 9.9 mg; pantothenic acid, 33 mg; niacin, 55 mg; vitamin B_{12}, 44 mcg.

[c]Provided the following per kilogram of complete diet: Mn, 40 mg; Fe, 165 mg; Zn, 165 mg; Cu, 17 mg; I, 298 μg; Se, 298 μg.

[d]Provided 44 mg tylosin per kg of complete diet.

[e]Calculated values were based on ingredient values suggested by NRC, 1998.

such as the ham and shoulder region and low temperature represented by the extremities (Schaefer *et al.*, 1989). The calculation used the mean of the pixels in each image, with each pixel having a precision of 0.2C. The mean temperature for the area was calculated to compare changes in MBST as affected by experimental treatment. In addition, ambient temperature was collected at each sampling time by IR from six high emissivity targets (E = 0.97) positioned at pig height and equally spaced throughout the room. These ambient temperatures were used to correct the daily MBST of the pigs using an adjustment factor of ± 0.4 per degree above or below 20C ambient temperature (Loughmiller *et al.*, 2001). In addition, the ambient temperatures within each experiment were pooled by location across day for use as the average absolute radiant environmental temperature values to calculate the MBSL.

The MBST from the defined area measured on each pig was used as an estimate of the average whole body surface temperature to calculate the mean body surface heat loss (MBSL). Mean body surface heat loss from each pig was calculated from the equation described by Curtis (1983) as $Qr = Ar\ E\ \sigma\ (Ta^4 - Ts^4)$, where Qr = radiant heat exchange; Ar = effective radiant surface area (Kelley *et al.*, 1973); E = emissivity (assumed to be 1.0; Curtis, 1983); σ = Stefan-Boltzman constant; Ta = average radiant ambient temperature, K; and Ts = average radiant surface temperature, K.

In Exp. 1, eighty castrates (initially 24 ± 3 kg) were blocked by initial weight and allotted to one of four feed intake levels. The feed intake levels were based upon the NRC (1998) maintenance ME, J calculated as 443.8 J × $BW^{0.75}$ where BW is in kg. Pigs were allowed 1.4× ME of maintenance (MEm), 2.5× MEm, 3.8× MEm and 4.7× MEm (*ad libitum* access). Feed was provided between 0730 and 0800h. Orts were collected daily to determine net feed intake. Following a 4-d adaptation period, IR images were collected at 0700, 1100, 1900 h daily on d 5, 6 and 7. These image collection times were positioned to represent the fasting state, peak of digestion and the fed state after completion of the major portion of digestion, based on the dynamics of the thermal effects of digestion as described by van Milgen and Noblet (2000).

Data were arranged in a randomized complete block design. Growth performance ANOVA was conducted using a PROC MIXED procedure with a Satterthwaite error correction (SAS, 1996). For analysis of change in MBST and heat loss over time, a PROC MIXED procedure with repeated measures and a Satterthwaite error correction was used (Mead, 1994, Littell *et al.,* 1996; SAS, 1996). The repeated measures model included the treatment effect (animal within treatment variance) and the effects of time period (0700, 1100 and 1900 h) and the treatment × time period interaction.

Following Exp. 1, the same 80 castrates (initially 40 ± 4 kg) were allowed a 5 d period of readjustment to *ad libitum* feeding and then were allotted randomly based on body weight to individual pens. Growth performance during the imaging period was determined by weighing pigs and feeders on d 7 and d 14. Infrared images were collected daily at 0700 from d 10 through d 14 using the same imaging and analysis procedures described earlier. Data were analyzed using multiple factors linear regression with a best subset backwards factor selection procedure of SAS (1996). The log transform as described by Meyers (1990) and Myers and Montgomery (1995) was used to transform the data and bring a constancy of response within the data limits.

In Exp. 3, the same 80 pigs (initially 59 ± 5 kg) were blocked by initial weight and assigned within block to one of four dietary treatments. Diets were formulated to provide moderately low (11.5 MJ ME kg^{-1}), slightly low (12.6 MJ ME kg^{-1}), adequate (13.6 MJ ME kg^{-1}) and moderately excess (14.6 MJ ME kg^{-1}) levels of daily energy intake based upon expected daily feed intake and calculated dietary nutrient content using nutrient values from the NRC (1998). Pigs were allowed to adjust to dietary treatment for 14 d and then IR images were taken daily at 0700 from d 14 through 20. The MBST and MBSL were obtained and calculated in a similar manner as in Exp. 1.

Data from Exp. 3 were analyzed in a randomized complete block design. Linear and quadratic polynomials (Peterson, 1985) were used to determine the effects of increasing dietary energy content on growth performance, MBST and MBSL.

Results and Discussion

In Exp. 1, quadratic effects were observed for ADG and G/F ($P<0.001$; Table 2) and linear effects for ADFI ($P<0.001$). These effects resulted from the increased growth performance and feed intake observed as calculated daily ME intake increased from 1.4 × MEm to *ad libitum* consumption. A treatment × time interaction was observed for MBST ($P<0.001$; Fig. 1). This interaction resulted from treatment effects differing by time period. The MBST increased as daily ME intakes increased from 1.4 × MEm to *ad*

Table 2
Effect of feed intake regimen on growth performance of 24 kg pigs (Exp. 1)[a]

Item	Feed intake level, x MEm[b]				SEM
	1.4	2.5	3.8	4.7	
ADG, kg[cd]	0.37	0.75	0.90	1.07	0.03
ADFI, kg[c]	0.47	0.86	1.34	1.64	0.04
G/F[cd]	0.79	0.88	0.68	0.65	0.03

[a]Eighty pigs (initially 24 ± 3 kg) were blocked by initial weight and allotted in a randomized complete block design. Results are the means of a 5-d growth assay that was concurrent with the temperature collection period reported in Table 3.
[b]Metabolizable energy per day for maintenance (MEm) calculated as 443.8 J × $BW^{.75}$ where BW is in kg (NRC, 1998).
[c]Linear treatment effect (P<0.001).
[d]Quadratic treatment effect (P<0.05).

libitum (linear, P<0.05) at 0700 and 1900 h. At 1100 h, while MBST increased in a quadratic (P<0.05) manner as daily ME intakes increased. Similar results were noted for calculations of MBSL.

As the pig increases its growth rate and feed intake, heat production associated with increased digestion and growth processes increases the body temperature and the heat loss to the surrounding environment (Curtis, 1983; McCracken and McAllister, 1984; Fuller *et al.,* 1987). Although these effects are well known, it appears that this research is the first evaluating the use of IR to detect temperature differences associated primarily with feed intake.

Recent research using IR has focused on detecting changes in MBST associated with

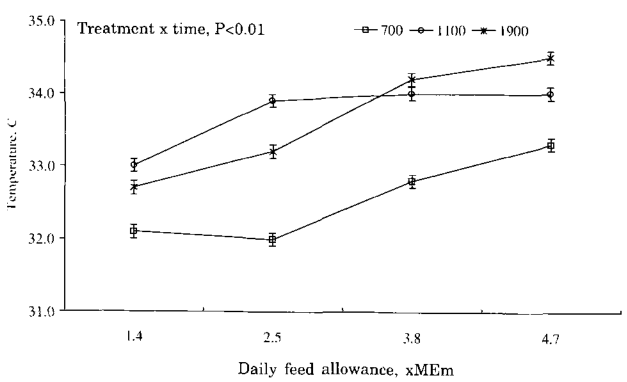

Fig. 1: Effects of daily feed allowance on mean body surface temperature of 24-kg pigs (Exp. 1). Restricted-fed pigs were fed daily at 0730.

a febrile response to disease (Bossow, 1996; Loughmiller *et al.,* 2001). However, these studies have either withheld feed during the disease challenge or have not controlled for differences in MBST due to feed intake during a suspected disease challenge. Because of this lack of information it is not possible to determine if healthy pigs on full feed would have thermal profiles similar to those of febrile pigs who are not eating. The interaction between treatment and time period indicates that the time of scan in relation to feed intake is important for interpretation of the thermographic response. It remains to be seen if IR can detect differences in MBST of healthy pigs *versus* febrile pigs when both have *ad libitum* access to feed and water. However, this research and that of Loughmiller *et al.* (2000) are the initial steps taken to answer this question.

The growth performance results are consistent with previous research evaluating the effects of altering feed intake or dietary nutrient profile on the growth performance of growing pigs. Consistent with our results in Exp. 1, reviews of feed intake research clearly indicate that as daily energy intake decreases below that necessary to support maximum growth performance, reductions in ADG and G/F occur (NRC, 1987; 1998). Also, pigs with *ad libitum* feed allowance had an average intake of 4.7 × MEm. These results are in good agreement with NRC (1998) estimates of the ME maintenance requirement and the *ad libitum* intake for growing pigs.

In Exp. 2, a linear relationship was observed among ADG and ADFI, natural log transformation of MBST and MBSL ($P<0.01$). The relationship can be expressed as ADG = $0.34 \times$ ADFI - $2.64 \times \ln$ MBST - $58.6 \times$ MBSL + 8.87 ($r^2 = 0.38$), where ADG and ADFI are in kg, ln MBST = natural log transformation of MBST in degrees C and MBSL expressed as Jh^{-1}. The SE for each parameter estimate was 0.083, 1.548, 0.007 and 5.076, and P-value was 0.001, 0.09, 0.05 and 0.09 for ADFI, ln MBST, MBSL and the intercept, respectively.

The relationship observed among ADG, ADFI, natural log of MBST and MBSL is consistent with research in pigs and mice to evaluate the relationship among metabolic heat production, heat loss and growth rate (Sundstol *et al.,* 1979; Nielsen *et al.,* 1997). Sundstol *et al.* (1979) indicated that leaner, faster growing pigs had higher fasting metabolic heat production than fatter, slower growing pigs when measured in environmentally controlled calorimetry chambers. Nielsen *et al.* (1997) also used calorimetry and determined that mice selected for high heat loss over 15 generations were leaner and faster growing and ate more than their counterparts selected for low heat loss and unselected controls were intermediate between the other two groups. Although the results indicate that MBST and MBSL can be used in predictive equations of ADG, it is important to recognize that ADFI had the largest influence on the predictive ability of the equation. The partial r^2 of ADFI alone was 0.34 and the entire equation r^2 was 0.38. This effect of ADFI on ADG is consistent with previously reviewed research indicating that higher rates of tissue accretion stimulate higher ADFI (NRC, 1998). Thus, the use of these IR techniques to model ADG based upon changes in MBST presently are constrained by an accurate determination of ADFI. Although limited in scope, the results observed in this experiment confirm that higher rates of gain in pigs of the same genotype are dependent upon increased feed intake, and increased body temperature and heat loss are associated with increased metabolic rates of tissue synthesis.

In Exp. 3, increasing dietary energy density from 11.5 MJ ME kg^{-1} to 14.6 MJ ME kg^{-1} improved ADG (linear, $P<0.001$) and G/F (linear, $P<0.05$) and tended to affect ADFI (quadratic, $P<0.08$; Table 3). Average daily feed intake was lowest for the pigs fed 11.5 MJ ME kg^{-1} and highest for the pigs fed 12.6 MJ ME kg^{-1}. Calculated ME intake per day also increased as dietary energy density increased (linear, $P<0.001$). Additionally, MBST and MBSL increased as dietary energy density increased from 11.5 MJ ME kg^{-1} to 14.6 MJ ME kg^{1} (linear, $P<0.001$).

The effects of increasing dietary energy density were similar to our results in Exp. 1, where increased daily feed allowance of a common diet resulted in increased MBST and the resulting calculation of MBSL. In Exp. 3, the increases in MBST and MBSL were similar to those reported by Gurr *et al.* (1980) and Close *et al.* (1983), which were obtained using more controlled environmental conditions in calorimetry chambers. Both of those studies observed increased rates of heat production in growing pigs as dietary energy levels increased. This consistency of response indicates that energy intake below that necessary for the maximal rate of protein synthesis (Fuller *et al.,* 1987) influences MBSL as calculated from MBST.

The growth performance responses observed in Exp. 3 are also consistent with long established theories concerning pig feeding behavior and dietary energy density (ARC, 1981; NRC, 1987; 1998). Our results further corroborate that high fiber, low energy diets will reduce feed intake and growth performance, but that the pig will

Table 3
Effects of dietary energy regimen on growth performance, mean body surface temperature and mean body surface radiant heat loss of 59 kg pigs (Exp. 3)[a]

Item	Dietary energy, MJ ME kg^{-1}[b]				Probability (P<)		
	11.5	12.6	13.6	14.6	SEM	linear	quad.
ADG, kg	1.07	1.14	1.24	1.28	0.06	0.001	0.76
ADFI, kg	2.92	3.29	3.11	3.13	0.10	0.31	0.08
G/F	0.37	0.35	0.39	0.41	0.02	0.05	0.39
Calculated ME intake, MJ d^{-1}	33.6	41.5	42.3	45.7	0.33	0.001	0.12
MBST, C[c]	32.1	32.5	32.6	32.8	0.16	0.001	0.33
MBSL, W[c]	-78.2	-82.2	-84.9	-87.0	1.3	0.001	0.34

[a]Eighty pigs (initially 59 ± 5 kg) were blocked by initial weight and allotted in a randomized complete block design.
[b]Ingredient values suggested by NRC (1998) were used to calculate dietary ME content.
[c]Initial BW was used as a covariate in this analysis.

adjust its daily feed intake to compensate for moderate differences in dietary energy content (NRC, 1987). This regulation of feed intake relative to dietary energy density is apparent from the increased feed intake of the pigs fed 12.6 *versus* pigs fed 13.6 or 14.6 MJ ME kg^{-1}. Additionally, pigs did not reduce their feed intake as dietary energy increased above 13.6 MJ ME kg^{-1}. Thus, the higher energy supported higher ADG, leading to higher G/F *versus* the pigs fed lower energy diets.

It may be concluded that infrared thermography can be used to detect differences among individual pigs in mean body surface temperature associated with feed intake, growth rate and dietary energy content in more variable environmental conditions than those used with calorimetry. Development of infrared thermography applications in swine research and production may allow direct estimates of changes in swine thermoenergetics in response to treatment or environment. These direct estimates may be useful information in traditional growth assays, growth modeling and commercial production situations.

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जे.ए. लाफमीलर, एम.एफ. स्पायर, एम.डी. टोकच, एस.एस. ड्रीट्ज, जे.एल. नेल्सेन, आर.डी. गुडबैण्ड, एस.बी. होग। विभिन्न आहारीय ऊर्जा उपभोग और सांद्रता के आहार भक्षण करने वाले वर्धमान शूकरों की शारीरिक सतह के औसत तापक्रम में अंतर का अवरक्त ऊष्मलेखन द्वारा मूल्यांकन।

आहार ग्रहण अथवा आहार की संरचना से शारीरिक सतह के औसत तापक्रम में संबंध ज्ञात करने के लिए 80 शूकरों का उपयोग किया गया। प्रथम परीक्षण में 80 बधिया शूकरों (24 किग्रा) को चार स्तर के आहार भक्षण (क्रमशः 1.4x, 2.5x, 3.8x और ऐच्छिक या 4.7x निर्वाह हेतु चयापचयी ऊर्जा (निचऊ)) पर वितरित किया गया। आहार प्राशन के 4थें, 5वें और छठे दिन 700, 1100 और 1900 बजे अवरक्त ऊष्मालेखन आकृतियां ली गयी। चयापचयी ऊर्जा ग्रहण में वृद्धि के साथ औसत दैनिक भार वृद्धि और शरीर भार वृद्धि : खाद्य उपभोग अनुपात में द्विघातिक प्रभाव और औसत दैनिक आहार भक्षण में रैखिक प्रभाव पाया गया। औसत शारीरिक सतह तापक्रम पर उपचार x समय में पारस्परिक क्रिया पायी गयी। प्रतिदिन चयापचयी ऊर्जा भक्षण में वृद्धि से 0700 और 1900 घंटे से औसत शारीरिक सतह तापक्रम में रैखिक वृद्धि के कारण पारस्परिक क्रिया हुई, परन्तु द्विघातिक वृद्धि में 1100 घंटे पर 2.5x निचऊ वर्ग में अंतर नहीं आया। प्रतिदिन 1.5x निचऊ से इच्छानुसार ऊर्जा से 0700 बजे से ही औसत शारीरिक सतह तापक्रम में रैखिक वृद्धि हुई। दूसरे परीक्षण के शूकरों (40 किग्रा) में प्रतिदिन 0700 घंटे से अवरक्त ऊष्मालेखन के बिम्बों का संग्रह किया गया। औसत दैनिक आहार भक्षण, औसत शारीरिक सतह तापक्रम हानि और औसत शारीरिक सतह तापक्रम के स्वाभाविक लाग पर औसत शरीर भार वृद्धि निर्भर पायी गयी। तीसरे परीक्षण में शूकरों को 11.5, 12.6, 13.6 और 14.6 मेगाजूल चऊ प्रति किग्रा खाद्य वाले आहारों पर वितरित करके खिलाया गया। आहारीय ऊर्जा बढ़ाने से औसत भार वृद्धि, भार वृद्धि : खाद्य अनुपात, चऊ उपभोग, औसत शारीरिक सतह तापक्रम और औसत शारीरिक सतह ताप हानि में वृद्धि हुई। आकड़ों से पता चलाता है कि आहार भक्षण अथवा आहारीय ऊर्जा स्तर में परिवर्तन से औसत शारीरिक सतह तापक्रम परिवर्तन उष्मालेखन से ज्ञात हो सकता है। इन परिवर्तनों को कलारीमिति की अपेक्षा अधिक विविधता की दशा में ज्ञात किया जा सकता है और इसका उपयोग शूकरों के ताप-ऊर्जा को प्रभावित करने वाले कारकों के वर्गीकरण हेतु एक हानि रहित मितव्ययी यंत्र की तरह किया जा सकता है।