THE EFFECT OF FLUCTUATING TEMPERATURES ON LAMB PERFORMANCE

by

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INTRODUCTION

Research relating thermal stress to performance has been conducted using constant thermal environments. Exposure to both heat and cold depresses average daily gain and reduces feed efficiency when compared to thermal neutral condition. Increased maintenance requirements associated with both heat and cold reduces energy available for growth which in turn lowers level of performance.

Effects of temperature fluctuations on most species are not clearly defined. In an effort to obtain maximum performance and efficiency, confinement systems are designed to closely regulate ambient temperature. In cattle and small laboratory animals, it has been shown that a period of heat stress followed by a compensating cooling period results in performance equal to that obtained by constant cooling. If this tolerance of temperature fluctuations proves true in all species, close temperature regulation may prove unnecessary. Logically, periodic temperature control would prove more profitable than continuous control because of reduced construction and energy costs.

The goal of this study was to compare daily feed intake, average daily gain, and feed efficiency of lambs exposed to varying magnitudes of daily temperature fluctuations with those exposed to constant temperature.

LITERATURE REVIEW

Like man, domestic animals are homeothermic, that is, they attempt to maintain a constant body temperature through a balance of heat produced and lost (Esmay, 1969). As defined by Mount (1974), the effective temperature where an animal exerts the least thermoregulatory effort and has maximum growth rate is thermal neutral (comfort) zone. When exposed to temperatures above or below thermal neutral (heat or cold stress), an animal must increase heat loss or heat production. The ambient temperature when a specific animal is heat or cold stressed varies due to many factors. Young (1976) lists among those effectors, intake level, and coat insulation. Ames and Brink (1977) found growing shorn lambs were in the TNZ (as defined by maximum performance) at approximately 15 C.

The lower limit of the TNZ, where heat production increases to maintain a constant core temperature is called the critical temperature (Blaxter, 1967 and Mount, 1974). The effective temperature where an animal reaches the point of cold stress can be lowered by increased intake (Graham *et al*., 1959) and by increased external insulation (fleece, hair coat) (Webster, 1966). Likewise less external insulation can make animals more heat tolerant (Webster *et al*., 1969).

Cold Stress

As reviewed by Hardy (1961) an animal's first response to cold is increased heat production. Bennett (1972) observed lambs moved from an ambient temperature of 20-29 C to -2-1 C initially increased heat production by involuntary muscular activity. Following this initial adjustment, animals kept below critical temperature must increase metabolic rate (Graham *et al*., 1959). In lambs this increase was 115 cal per 24 hr per degree C fall in temperature. Young and Christopherson (1974) report cattle, after prolonged exposure to cold, increase resting heat production from 8 to 40%. The increased energy demand imposed by cold stress will increase appetite (Baile and Forbes, 1974). Webster *et al*. (1969) reported feed intake of sheep increased as equivalent air temperature fell. Kleiber and Dougherty (1934) observed growing chicks increased intake 100 Kcal/W $kg^{0.75}$ per day as temperature fell from 40 C to 21 C. As intake increases and temperature falls, fecal and urinary losses also increase (Graham *et al*., 1959) which lowers the metabolizable energy value of rations. As reviewed by Young (1976), the depressed digestibility coefficient of rations by ruminants is about 1.8 digestibility percent units for every 10 C drop in temperature. The combination of this depressed digestibility and increased energy requirements is a lowering of average daily gain. Brink and Ames (1977) reported a decrease in growing lamb average daily gain of 120 g per day as temperature decreased from 15 to -5 C.

Heat Stress

Increased metabolic rate of homeotherms during heat stress has been consistently reported. Ames *et al*. (1971) observed a 27% increase in O_2 consumption of sheep exposed when ambient temperature increased from 25 to 45 C. Similar results have been reported by Alhassan *et al*.

(1976) for small laboratory animals and Rogerson (1960) in cattle. Yousef _et al_. (1967) found heat production in cattle declined significantly after 42 hours exposure to 38 C.

Increased heat production reduces net energy available for production. Additionally, intake is lowered due to heat stress. Soderquist and Knox (1967) noted a 25% decline in intake between 23 and 35 C. Gengler _et al_. (1970) observed similar intake reduction in dairy cattle from 18 to 37 C as did Alhassan _et al_. (1976) in small lab animals.

The combination of increased heat production and lowered intake suggests decreases in average daily gain. This was observed by Brink and Ames (1977) who reported a reduction of 75% in average daily gain of lambs exposed to 35 C compared to those at 15 C. Morrison (1971) reported growing pigs decreased in average daily gain from .80 kg/day at 20 C to .45 at 33 C.

Olbrich _et al_. (1973) showed that digestibility in cattle did not change as temperature increased from 9 to 31 C. Holmes (1973) reported dry matter digestibility decreased in growing pigs when they were subjected to temperatures above 25 C. Brink and Ames (1977) reported a 60% reduction in feed efficiency at 35 C compared to 15 C.

Temperature Fluctuations

Magnitude and duration of thermal stress are both important considerations when relating performance and thermal environment. Slee and Sykes (1967) subjected growing lambs to short term cold stress with temperatures gradually decreasing from 30 to 20 C. They reported an immediate rise in rectal temperature, indicating summit metabolism was quickly attained. After their second exposure to cold, 37 of 40 individuals had slower responses, indicating acclimatization following initial exposure if it lasted at least 8 hours. When mature, shorn wethers were exposed to lowered temperatures from 14 to -4 C. Mears and Groves (1969) observed no significant change in metabolic rate or rectal temperature for at least 12 hours. After 12 hours, there was a marked increase in adrenal cortical response. Harrison and Biellier (1969) subjected white leghorn hens to temperatures lowered from 35 to 5 C, and reported initial spasmic shivering, but no effect on metabolic rate for 12 hours. Yousef et al. (1967) reported cattle, when exposed to a change in ambient temperature from 18 to 1 C, took 60 hours to significantly increase heat production, indicating metabolic rate and thyroid activity were not involved in acute responses to cold exposures.

When exposing animals to acute heat stress, Riek et al. (1950) reported that sheep, moved from TNZ to temperatures up to 45 C, increased core temperatures, but showed no metabolic response for 24 hours. Johnson (1971) exposed mature goats and sheep to temperatures increasing from 20 to 45 C and after 4 hours saw rectal temperature increase 1 C with concurrent increases in respiratory rate. He concluded that sheep did not exhibit passive body temperature lability as an adaption to short term heat stress. Harrison and Biellier (1969) working with white leghorn hens, observed maximum oxygen consumption within 2 hours when hens were exposed to increasing temperatures from 5 to 35 C. Oxygen consumption increased 41.4% per 1 degree C rise in body temperature indicating a Q_{10} effect on metabolic rate. Small laboratory animals were subjected to 3 different temperature regimes by Alhassan *et al.* (1976). They reported weanling rats kept at constant 21 C outperformed rats kept at 30 C, but, when the 30 C rats were exposed to 21 C for 7 hours per day, average daily gain was equal to that at continuous 21 C. Feed efficiency was similar for all 3 groups. Morrison and Mount (1971), working with growing barrows, saw a 50% decline in feed intake and a reduction in average daily gain from .8 to .45 kg 24 hours after the temperature rose from 20 to 33 C. When returned to 20 C, it took 12 days for the parameters to return to pre-stress levels. When Kamal and Johnson (1971) exposed growing dairy calves to increasing temperatures from 18 to 32 C for 3 days, they observed no significant change in feed intake, but a 15% decrease in body dry matter. Total body water increased 10 liters, helping to prevent increases in rectal temperatures. They concluded the high specific heat of water allowed the animal to store heat during the day and dissipate it during the evening. Yousef *et al.* (1967) increased the ambient temperature surrounding mature cattle from 18 to 38 C and reported it took 60 hours for significant changes in thyroid activity and heat production. Mendal *et al.* (1971) exposed 6 groups of feedlot cattle to ambient temperatures of 38 C and cooled 5 groups for different time periods during 24 hour intervals. Equal performance and efficiency were realized from 3 groups, those cooled to 25 C for all 24 hours, those cooled for 18 hours, and those cooled for 12 hours during the day. Average daily gain was reduced from peak levels when cattle were kept at constant 33 C, cooled for 6 hours, and cooled for 12 hours during the evening. A 21% lower average daily gain was observed when cattle were cooled for 12 hours at night than when they were cooled for 12 hours during the day. Mendal attributed this difference to changes in feeding behavior. Cooling during the day increased intake during that time, while cooling during the evening had no effect on intake.

MATERIALS AND METHODS

Forty-eight crossbred ewe lambs, approximately 4 months of age, with initial weights averaging 30 kg were used in this study. Two Forma Scientific Walk-In Chambers (11 m x 15 m x 8 m) with a temperature sensitivity of ± 0.5 C were used to control temperatures. There were 4 pens per chamber and 2 lambs per pen, with lambs randomly assigned to treatment and pen prior to initiation of the trial.

There were 3 trials in the study, each having an acclimation period of one week, during which lambs were exposed to TNZ (15 C) and allowed to adjust to confinement in the chambers. Initial weights were taken after the acclimation period and weekly over the following 4 weeks. In all instances, lambs were taken off free feed and weighed immediately. Intake, average daily gain, and feed/gain were determined. Lambs were fed a pelleted ration (3/8" diameter) *ad libitum*, and insulation effects on TNZ were removed by shearing the lambs at the onset of each trial and every other week thereafter. Composition and proximate analysis of the ration are in Table 1.

Each trial had a control chamber kept at TNZ and a second chamber averaging TNZ, but resulting from 12 hour variations above and below TNZ. During Trial 1, the experimental chamber averaged 15 C but ran at 20 C for 12 hours and at 10 C for 12 hours. Trials 2 and 3 also averaged 15 C, but the 12 hour fluctuations above and below TNZ were 10 C and 15 C respectively.

Analysis of variance was used to analyze the data, using the General Linear Model procedure of the Statistical Analysis System (SAS 76). Duncan's new multiple range test (Steele and Torrie, 1960) was used for mean separation.

RESULTS AND DISCUSSION

Average daily gain (ADG), feed intake, and feed efficiency (F/G) were not different ($P<.05$) for lambs exposed to fluctuating temperatures compared with controls housed at thermoneutral temperature. These observations are reported in Tables 2-4. Lambs in fluctuating environments gained .35, .35 and .35 kg/day for fluctuations of 10, 20 and 30 C respectively. Control groups gained .41, .33 and .35 kg/day housed in constant thermoneutral temperature. The temperature fluctuations used in this study did not have the same effect on weight gains as constant temperature extremes. Constant cold causes increased heat production (Hp) in response to increased rate of sensible heat losses. Increased energy for maintenance results in lowered ADG. Constant heat also increased Hp, with less energy available for growth, resulting in lowered ADG.

Lambs in fluctuating environments consumed 1.47, 1.52 and 1.49 kg/$W^{.75}$/head/day with F/G of 4.94, 4.56 and 4.70 for fluctuations of 10, 20 and 30 C respectively. Control lambs housed at the thermoneutral temperature consumed 1.56, 1.56 and 1.46 kg/$W^{.75}$/head/day, with F/G of 4.00, 4.78 and 4.62. Constant cold would have increased intake, and since it reduces ADG, feed efficiency would be sacrificed. Constant heat lowers intake, but F/G would again be sacrificed because of increased heat production.

Previous studies of fluctuating temperatures, although limited, concur with the observations of this study. Mendal (1971) observed that cattle exposed to constant heat (33 C) for 12 hours could avoid negative effects of heat stress if they were housed at their thermoneutral temperature for 12 hours. Alhassan *et al.* (1976), working with laboratory rats, also observed equal daily gains between groups exposed to constant thermoneutral temperature and those exposed to acute fluctuations. These rats were housed at 30 C for 17 hours, then exposed to their thermal neutral temperature for 7 hours. Fluctuations to a lower temperature alleviated the negative effects of heat on performance. Both Mendal and Alhassan speculated that the adverse effects of heat stress were avoided because the animals had a chance to radiate excess body heat to a cooler environment. This hypothesis is substantiated by Johnson (1971), who studied dairy calves moved from 18 C to 32 C. Calves at 32 C decreased body dry matter 15%. This prevented large increases in rectal temperature, and maintained optimum levels of intake. Johnson's explanation was that the high specific heat of water allowed animals to absorb heat during the day, but dissipate it at night, without altering heat production or intake. Mendal (1971) reported animals cooled to TNZ for 12 hours during the day had higher ADG than those cooled for 12 hours during the evening. Cooling during the day changed feeding patterns, resulting in increased intake.

Studies on animal performance may substantiate our results, but they do not explain them. In previous research, temperatures fluctuated only above or only below TNZ. Our study observed the effect of fluctuations both above and below TNZ during a 24 hour period. The fluctuations used in our study approximated daily temperature ranges. There is no clearcut explanation for optimum performance levels in fluctuating temperatures of up to 30 C. One hypothesis is that effects of heat and cold compensate for each other. For example, it is plausible that increased intake during cold may compensate for decreased intake associated with heat. Analysis of results of this study make this explanation possible, since intake was comparable in treatment versus control for all trials. However, if cold and heat both had normal effects on Hp, it would have increased. This along with intake being equal between groups, would have reduced ADG of lambs exposed to temperature fluctuations. Therefore, not only is intake equal in fluctuating versus control groups, but Hp also seems to have been unaffected.

Another reasonable explanation is that length of temperature fluctuations, more than their magnitude, determines their effect on performance. Yousef (1967) housed cattle at 18 C until acclimated. When moving them from 18 C to 1 C or 30 C, he observed a delay before physiological responses were initiated. Cattle took 60 hours before thyroid activity, metabolic rate or intake were affected by cold or heat. Mears and Groves (1969) reported sheep, when moved from 14 C to -4 C did not alter metabolic rate for 12 hours. Riek _et al_. (1950) reported sheep took 24 hours before showing any metabolic response to changing temperatures from TNZ to 45 C. Harrison and Biellier (1969) observed white leghorn hens, when moved from 35 to 5 C took 12 hours before altering metabolic rate. If one assumes a lamb can tolerate at least 12 hours of heat or cold stress, it could explain our results. Twelve hours of heat stress (20, 25 or 30 C) may cause the animal to pant, allowing him to lose excess heat by insensible heat loss. However, heat stress could have been terminated before it affected intake or metabolic rate. Similarly, 12 hours of cold stress (10, 5 or 0 C) may cause the animal to shiver, trying to maintain body temperature. However, cold stress also could have been terminated before it affected intake or metabolic rate. Even if this is the case, this hypothesis still depends partially on the previous explanation. Panting from heat or shivering from cold are stopped by cold and heat respectively. Therefore, the theory of compensating extremes must again be considered. Assuming heat and cold stress are compensating for each other, but have their effects limited by time periods, raises other questions. The consequence of longer periods (12 hrs.) of heat or cold followed by the other extreme are still unknown. Other areas needing to be investigated are the effects of more than two temperature fluctuations in a 24 hour period, what magnitude of fluctuations could be tolerated, and for how long a duration.

The weekly format used in the 3 trials allowed analysis of weekly results of fluctuating versus control lambs within each separate trial. These observations, graphically depicted in Figures 1-6, for Trials 1-3 showed no significant difference ($P<.05$) between weekly means of ADG or feed intake, and subsequently F/G within any of the 3 trials.

A hypothesis that the initial week of fluctuating temperatures would cause acclimatization by the animal is discredited by these results. The absence of reduced performance during the first week of each trial indicated sudden exposure to fluctuating temperatures that averages thermal neutral temperature apparently did not cause acclimatization. Nor, does it appear there was any need for adjustment. In fact, the largest weekly ADG, in 2 of 3 trials, was observed during the first week. This difference was not significant ($P<.05$) nor was it accompanied by any increase in appetite. Subsequent reduction in performance can be attributed to the growth pattern of the lambs. It appears initial exposure to fluctuating temperatures has no more effect on performance than does prolonged exposure.

The results of this study substantiate the theory that close thermostatic control in confinement is unnecessary to realize optimum performance, as long as daily fluctuations move about the TNZ. The equality of performance between lambs exposed to fluctuating temperatures that averaged TNZ and those exposed to constant TNZ indicates that the main determinant of temperature performance interaction is the average temperature. Whether that average comes from short term (12 hrs in this study) fluctuations or from a constant temperature made no difference. The effects of different length or magnitude of fluctuations are still unknown. But, metabolic responses, such as intake, and Hp to cold or heat appear to be delayed for at least 12 hours. This allows lambs to tolerate 12 hours of heat or cold if they are followed by the alternating or compensating extreme.

Future studies should consider effects of varying times and magnitude of heat and cold on performance. We also need to know if animals can tolerate a higher or lower average temperature than constant temperature. Answering these questions may allow us to cool animals once or twice a day during the summer and still have an optimum temperature performance relationship. In the winter a building may be heated periodically with similar results. Controlling ambient temperature on a periodic basis without drastic reduction in performance from TNZ levels, would lower fuel and initial construction costs.

Table 1. Composition of Ration Fed To Lambs.

Ingredient	%
Soybean meal	5.0
Ground sorghum grain	39.4
Molasses	5.0
Dehy. alfalfa	50.0

Proximate Analysis

% Ash	Mg N/gm	% Protein	% Dry matter	% Ether extract	% Crude fiber	Energy cal/gm
6.41	21.59	13.50	87.18	2.35	15.37	4057

Table 2. Trial 1 Results.

	ADG (kg/Da)	Intake (kg/W$^{.75}$)	F/G
Control (15 C)	0.41	1.56	4.00
Fluctuating (10-20 C)	0.35	1.47	4.94
Difference	0.06 ± 0.04	.09 ± 0.09	0.94 ± 0.71

Table 3. Trial 2 Results.

	ADG (kg/Da)	Intake (kg/W$^{.75}$)	F/G
Control (15 C)	.33	1.56	4.78
Fluctuating (5-25 C)	.35	1.52	4.56
Difference	0.02 ± 0.04	0.04 ± 0.09	0.22 ± 7.1

Table 4. Trial 3 Results.

	ADG (kg/Da)	Intake (kg/W$^{.75}$)	F/G
Control (15 C)	.35	1.46	4.62
Fluctuating (0-30 C)	.35	1.49	4.70
Difference	0.00 ± .04	0.04 ± 0.09	0.08 ± .71

Figure 1. TRIAL1 10-20 C
AVERAGE DAILY GAIN

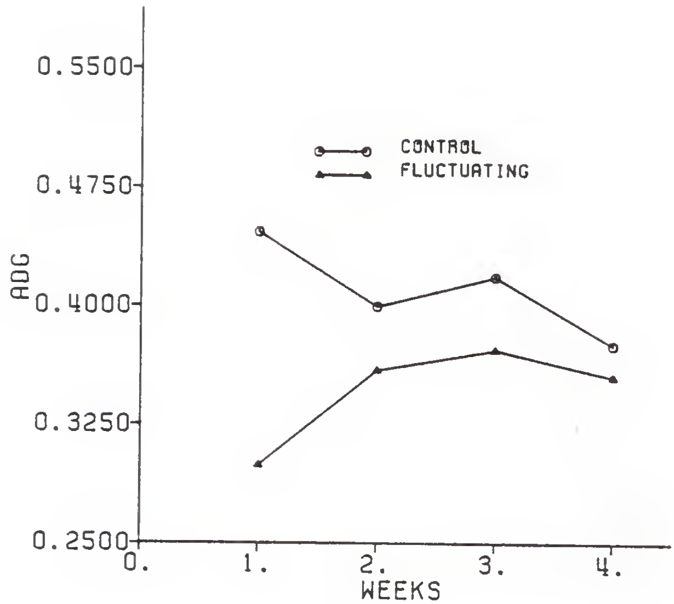


Figure 2. TRIAL1 10-20 C
WEEKLY METABOLIC INTAKE

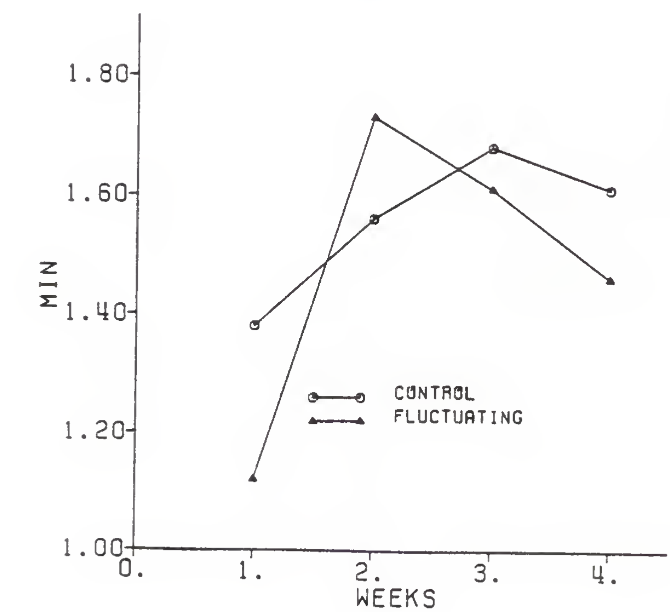


Figure 3. TRIAL2 5-25 C
AVERAGE DAILY GAIN

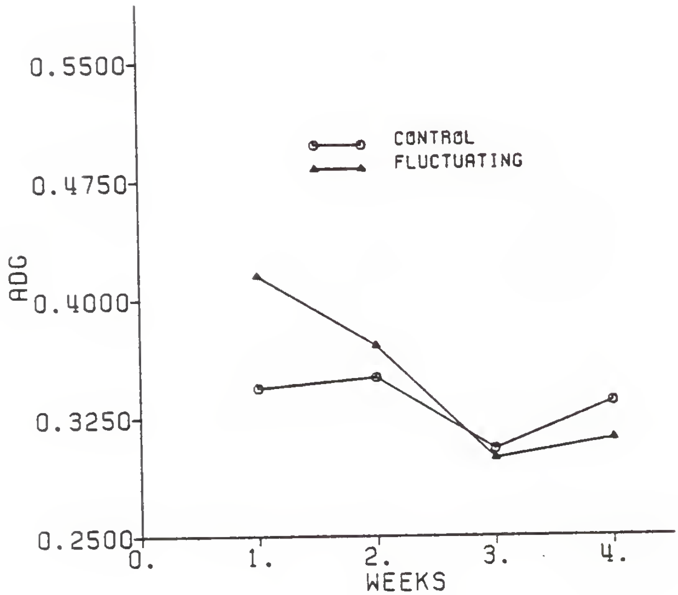


Figure 4. TRIAL2 5-25 C
WEEKLY METABOLIC INTAKE

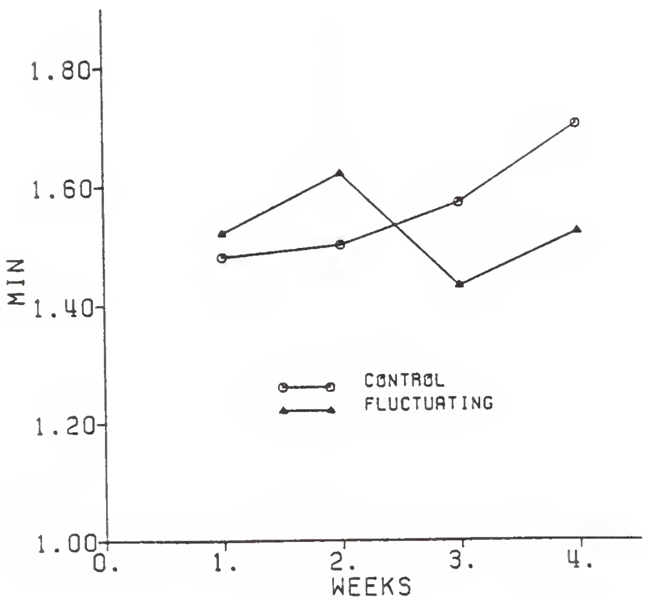


Figure 5. TRIAL3 0-30 C
AVERAGE DAILY GAIN

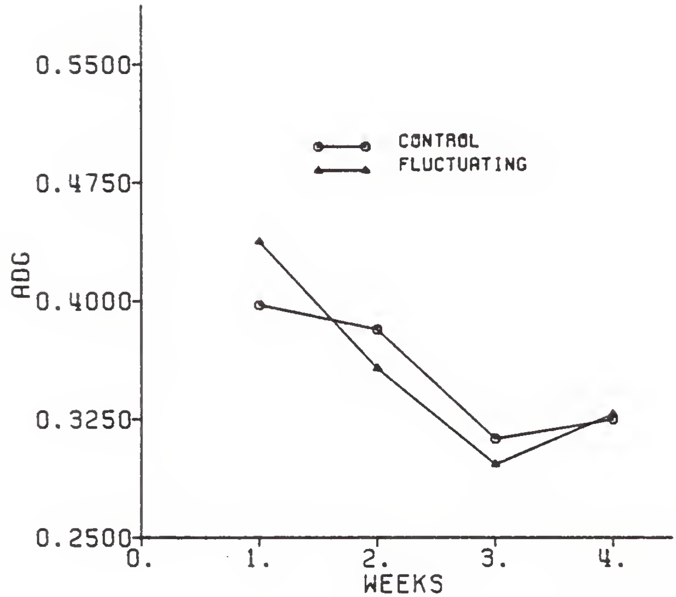
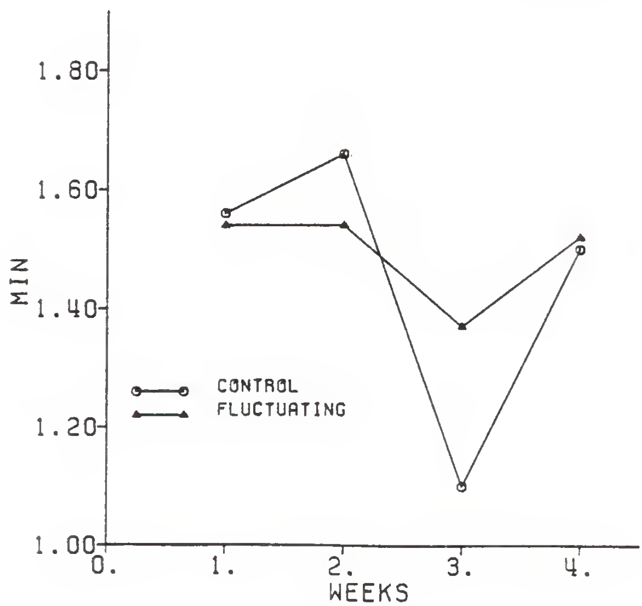


Figure 6. TRIAL3 0-30 C
WEEKLY METABOLIC INTAKE



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Forty-eight ewe lambs averaging 30 kg were used in 3 trials. Each trial consisted of a control group of 8 lambs housed at constant 15 C (thermal neutral zone) and 8 lambs exposed to fluctuating temperatures in order to measure effect of fluctuating temperatures on average daily gain, feed efficiency, and intake per unit of metabolic size. Fluctuating environments also averaged the thermal neutral temperature, but resulted from equal variations above and below thermal neutral zone (TNZ) every 12 hours. During Trial 1 the fluctuating chamber averaged 15 C, but ran at 20 C for 12 hours followed by 10 C for 12 hours. Trials 2 and 3 also averaged 15 C but the 12 hour fluctuations above and below TNZ were 10 and 15 C respectively. Each trial was preceded by an acclimation period of one week, with data recorded weekly over the following 4 weeks. Lambs were fed ad libitum and weighed without fasting. They were shorn biweekly to eliminate effect of wool growth on TNZ. Average daily gain, intake, and feed efficiency were not significantly affected ($P<.05$) by treatments. Results indicate no effect from 12 hour temperature fluctuations when mean temperature approximates TNZ. Apparently, equal time and magnitude of alternating temperature extremes can alleviate the negative effects of either extreme on a constant basis. When considering the use of temperature control in confinement systems, periodic adjustments may be all that are required to maintain optimum performance. Emphasis can be placed on average daily temperature rather than on a constant daily temperature.