final report

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Using infrared thermography as a proxy for measuring methane emissions

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Abstract.

The measurement of methane production and feed efficiency in ruminants is expensive; infrared thermography has been proposed as a proxy in cattle. A thermal imaging camera was used to record flank temperatures on cattle fed either wheat or corn based diet. The difference in temperature between left and right flanks is believed to be indicative of the heat of fermentation in the rumen, and hence methane production. The current project found a weak correlation between methane emissions and temperature variations but did find a difference in the average daily temperature between flanks (wheat fed cows 1.43°C vs. corn fed cows 0.71°C). This suggests a thermography might allow qualitative estimation of emissions but the relationship is strongly affected by nutritional interactions.

Executive Summary.

☐ when and how industry can benefit from the work
☐ who can benefit from the results

The measurement of methane production and feed efficiency in ruminants is an expensive and time consuming process and research into proxy measures have been taking place. Research has identified that infrared thermography has been proposed as a proxy to measure heat production, methane production and for the detection of physiological events (e.g. heat increment of feeding) in cattle. In particular, the difference in temperature between the left hand side of the animal and the right hand side may correlate with the heat of fermentation in the rumen, and hence with methane production. Research by Montanholi et al. (2010) in Canada found correlations of r^2=0.77 immediate after feeding and r^2=0.17 for the remainder of the day.

The current research project investigated the use of thermography in closed circuit calorimeters and under two different feeding regimes (either wheat- or corn-based). A thermal imaging camera was mounted above the animal inside the chamber and images remotely recorded at 5 minute intervals. The correlation between methane emissions and flank temperature immediately after feeding ranged between r^2=0.35 to 0.46 post feeding but no correlation across the day. The much weaker relationship is maybe indicative of the poorer environment for thermography image capture within the closed chamber compared to Montanholi's study that utilised head chambers and allowed access directly to each side of the animal.

However, the project did record average daily temperature differences between flanks of the animals (wheat fed cows 1.43°C vs. corn fed cows 0.71°C). Methane emissions though were approximately two fold higher in corn-fed cows though, giving a reversed relationship to the original hypothesis. It is likely that under certain conditions (such as the wheat diet), the heat of fermentation does not directly correlate with methane production but fermentation pathways lead to the creation of other by-products, leading to a dietary interaction. More fundamental research examining flank temperature under different feeding regimes is needed to elucidate the relationships. This research does suggest that thermography might allow qualitative estimation of emissions at this point but the relationship is strongly affected by nutritional interactions. Quantitative estimates of methane emissions using thermography at this point are extremely difficult to make based on current data sets.

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Background.

Livestock production is responsible for 18% of total global greenhouse gas emissions from human activity. Methane from livestock is approximately 66% of Australian greenhouse gas emissions derived from agriculture. Therefore, improvements in feed efficiency will bring economic benefits through a reduction in emissions intensities (kg/kg saleable product) and greater environmental sustainability. Feed efficiency traits have received attention in animal selection programs, especially residual feed intake (RFI). This trait is assumed to reflect the ‘‘true’’ metabolic difference between animals; however it is expensive to measure. Studies on energy metabolism have demonstrated that more efficient cattle have both lower heat loss and methane production.

Infrared (IR) thermography is the measurement of the body's surface temperature and may be related to several physiological processes associated with feed efficiency. Changes in surface temperature reflect 73% of total heat loss (radiant and convective losses) and it has been demonstrated that more efficient animals have lower body surface temperatures than less efficient animals. IR thermography of the body surface is a simple procedure that is non-invasive and relatively inexpensive. Montanholi et al. (2010) demonstrated the temperature difference between left and right flank is a good indicator of CH_4 production at certain times of the day. The correlations observed between flank temperature differences and CH_4 over the day (r^2=0.53), immediately after feeding (r^2=0.77) and in the remainder of the day (r^2=0.17) indicating that the postprandial period (up to 100 min after a meal) is the best period to assess CH_4 using IR thermography. Infrared thermography has been proposed as a proxy to measure heat production, methane production and for the detection of physiological events (e.g. heat increment of feeding) in cattle. The use of multiple body locations infrared scanning with the measurement of the animals' gaseous exchange may provide a rapid assessment for assessing heat and methane production.

Project Objectives

1. An evaluation of the IR thermography system to determine if IR thermography methods will provide accurate, repeatable data on methane yield from ruminants.

2. Provision of information on the relationship between heat production and RFI, thus improving our ability to screen animals for differences in these traits rapidly.

Methodology

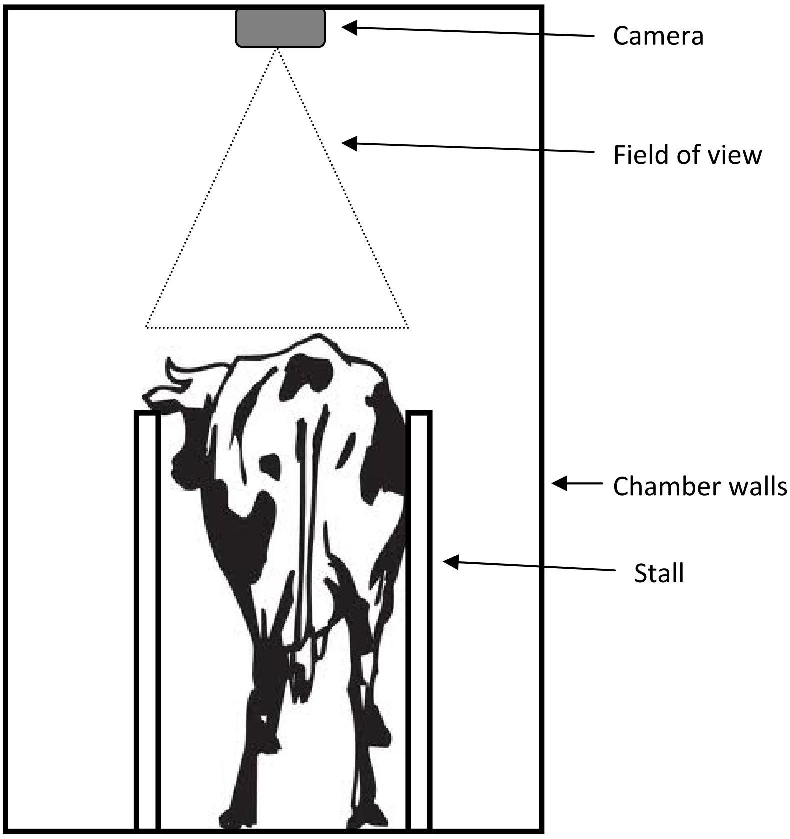
The camera used for BCCH1085 is a FLIR T640 coupled to a FLIR IR lens f=13.1mm, mounted in the chamber using a Camzilla CZ1 mounting kit. Images were collected using FLIR Research IR version 3.Max software connected to the camera via a hard wire (USB) to a laptop. Two laptops were used to collect data – specifications can be found in Table 1 (see technical comments in discussion). Collected images are analysed using FLIR Research IR version 3.Max. Images were collected every 5 minutes for the whole 48h period that the animal was confined to the chamber (total of 576 images per animal per chamber session). After an initial trial, a direct overhead position for the camera was used (as discussed in Milestone 2 (Figure 1).

A total of 12+ days of chamber images have been collected at the conclusion of the Ellinbank experiment in late March 2012. Preliminary data from the chamber work suggests differences in methane production, coupled with differences in temperature in certain locations within the rumen (as measured by weighted bolus) – both factors offered the best possible chance of a successful outcome for thermal imagery in BCCH1085.

Table 1. Specification of laptops used to collect thermal images from camera mounted in chamber.

Laptop 1	**Laptop 2**
HP Compaq 620	HP Pavilion dv6 Notebook
Pentium DualCore CPU T4500 @ 2.30 GHz	Intel Core i7 CPU Q720 @ 1.60 GHz
4 GB RAM (2.90 GB available)	8 GB RAM
32 bit OS Windows 7	64 bit OS Windows 7

Figure 1. Thermal imaging camera position in calorimetry chamber.



Results.

Data from two corn cows and two wheat cows is presented below; there remains some further analysis to be known prior to presenting the information in other formats (such as publication). Unfortunately, by pure happenstance, technical issues with the thermal camera, software and cow withdrawal from the experiment affected the treatments unequally with no further wheat cow data being available. As this means a potentially unbalanced design with only corn cow images left, it was decided at this point to include two data sets; the corn cow data sets were chosen for image processing and analysis at random from the available animals.

Body temperatures.

The mean temperature of the cows as measured by thermography on different treatments was different and the temperature difference between the two flanks differed according to treatment as well (Table 1). Measured body temperature varied through out the day (Figures 2 and 3) although the data was very variable and it was hard to distinguish notable events, besides a circadian rhythm.

Table 1. Mean flank temperature (°C) of cows on corn or wheat diet as measured by thermography.

		Wheat cows	Corn cows
Daily	Left hand flank	31.47	29.86
	Right hand side	30.33	29.07
	Mean difference	1.14	0.67
Postprandial period	Left hand flank	32.78	31.26
	Right hand side	32.26	30.57
	Mean difference	1.43	0.72

Figure 2. Body temperature in corn fed cow across the experimental period.

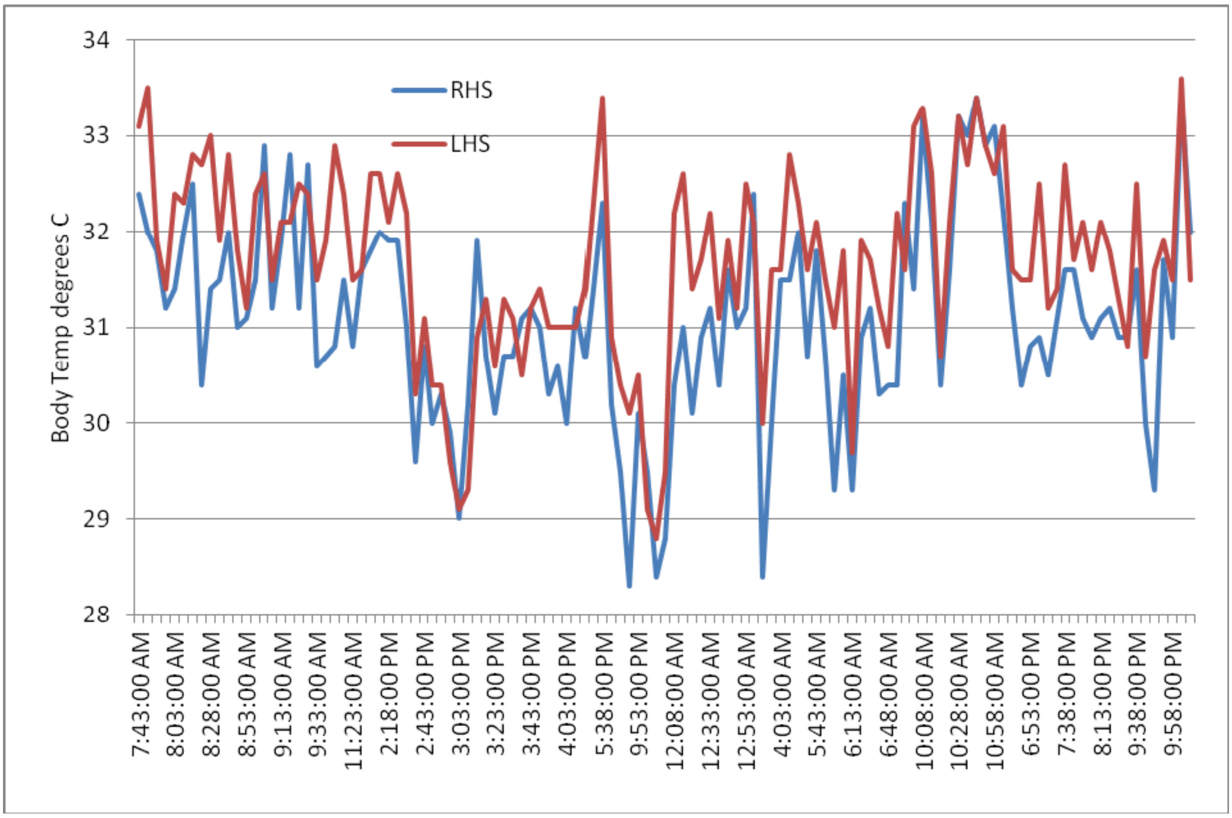
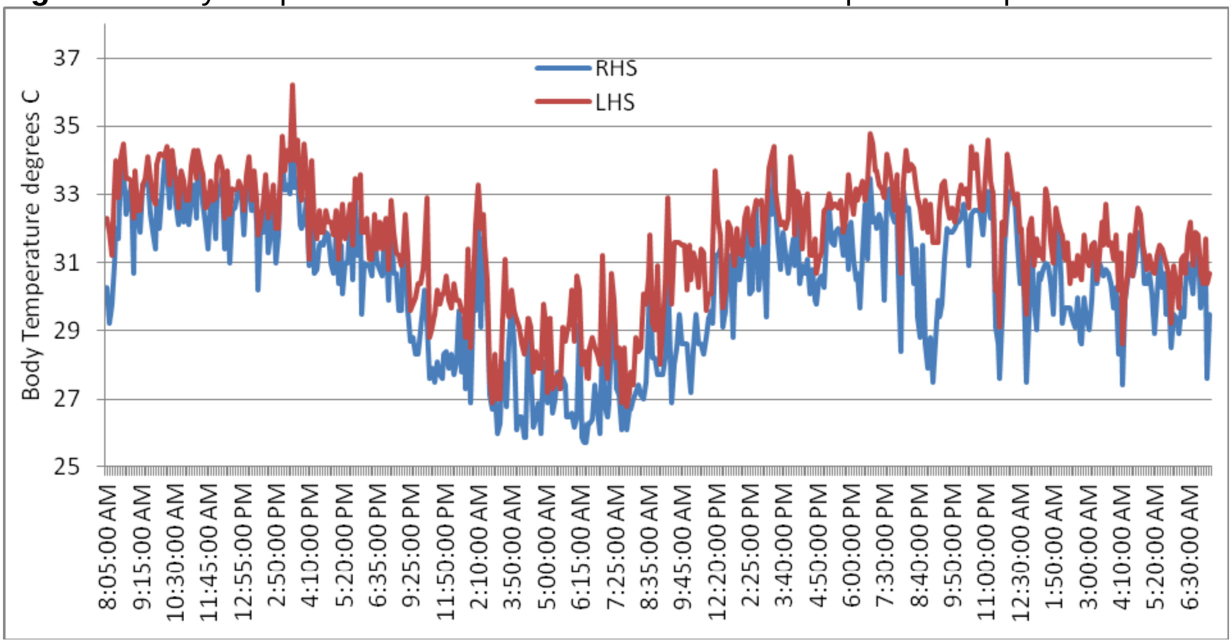


Figure 3. Body temperature in wheat fed cow across the experimental period.



Correlation of body temperature as measured by thermography and methane emissions.

Methane emissions (g/min) were provided by DPI Ellinbank, based upon instantaneous sampling over 12-15 minute periods. The thermography measurements and the methane emissions were correlated both over the whole day and over the postprandial period. There was no correlation between methane and thermography across the whole experimental period. During the postprandial period, the correlation between flank temperature difference and methane emissions was correlated but not strongly (Table 2, Figures 4 and 5).

Table 2. Correlation values (r^2) of methane emissions measured in closed circuit calorimeter and the difference in flank temperature as measured by thermography.

		r^2 value
Daily	Wheat cows	0.05
	Corn cows	0.05
Postprandial period	Wheat cows	0.37
	Corn cows	0.43

Figure 4. Relationship between flank temperature difference (°C) and methane emissions (g/min) during the postprandial period in a wheat fed cow.

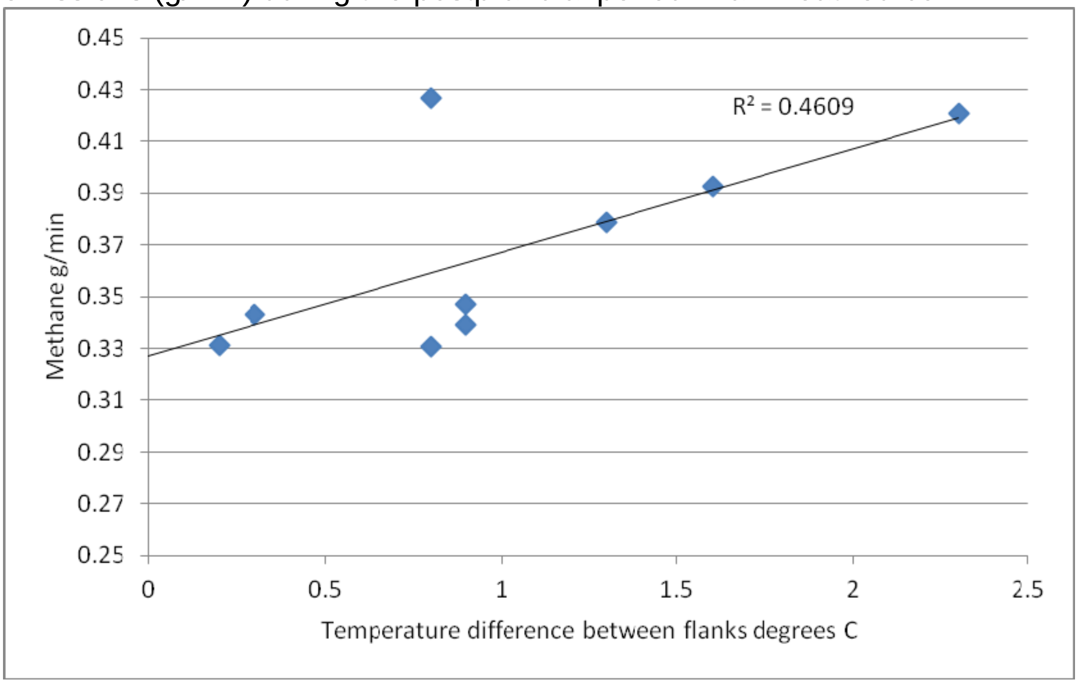
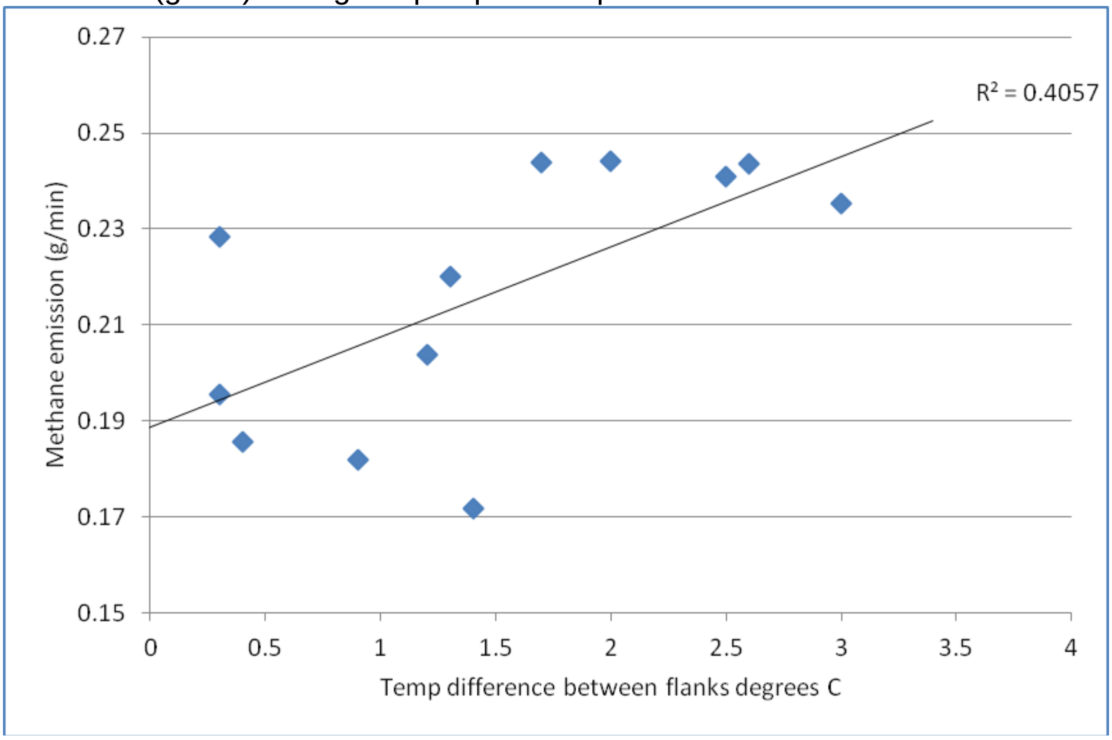


Figure 5. Relationship between flank temperature difference (°C) and methane emissions (g/min) during the postprandial period in a corn fed cow.



Discussion.

Compared to the original correlations with the work of Montanholi et al. (2010), the relationship between flank temperature differences and methane emissions was weaker in this present study. Montanholi et al. (2010) established correlations of r^2=0.53 over the entire day and r^2=0.77 over the postprandial period (100 minutes after feeding). This study found almost no correlation over the day and correlations of between r^2=0.35 to 0.47 for the postprandial period. The weaker relationship was expected given the more restrictive environment for the thermography image collection.

However, there was a difference between the two treatments in the average difference in temperature between the left and right flank. Corn cows averaged a 0.67±0.10°C difference over the day and 0.72±0.13C over the postprandial period. Wheat cows averaged a 1.14±0.12°C difference over the day and 1.43±0.13°C over the postprandial period. The difference, as well as the overall higher temperature of the wheat animals, was reversed in relation to the methane emissions, with the corn cows producing almost twice as much methane as wheat-fed cows. It is likely that the relationship between the heat of fermentation and methane production becomes uncoupled under certain dietary conditions; wheat-fed cows may produce different by-products during fermentation; increased heat production being registered on the flank without any corresponding increase in methane production.

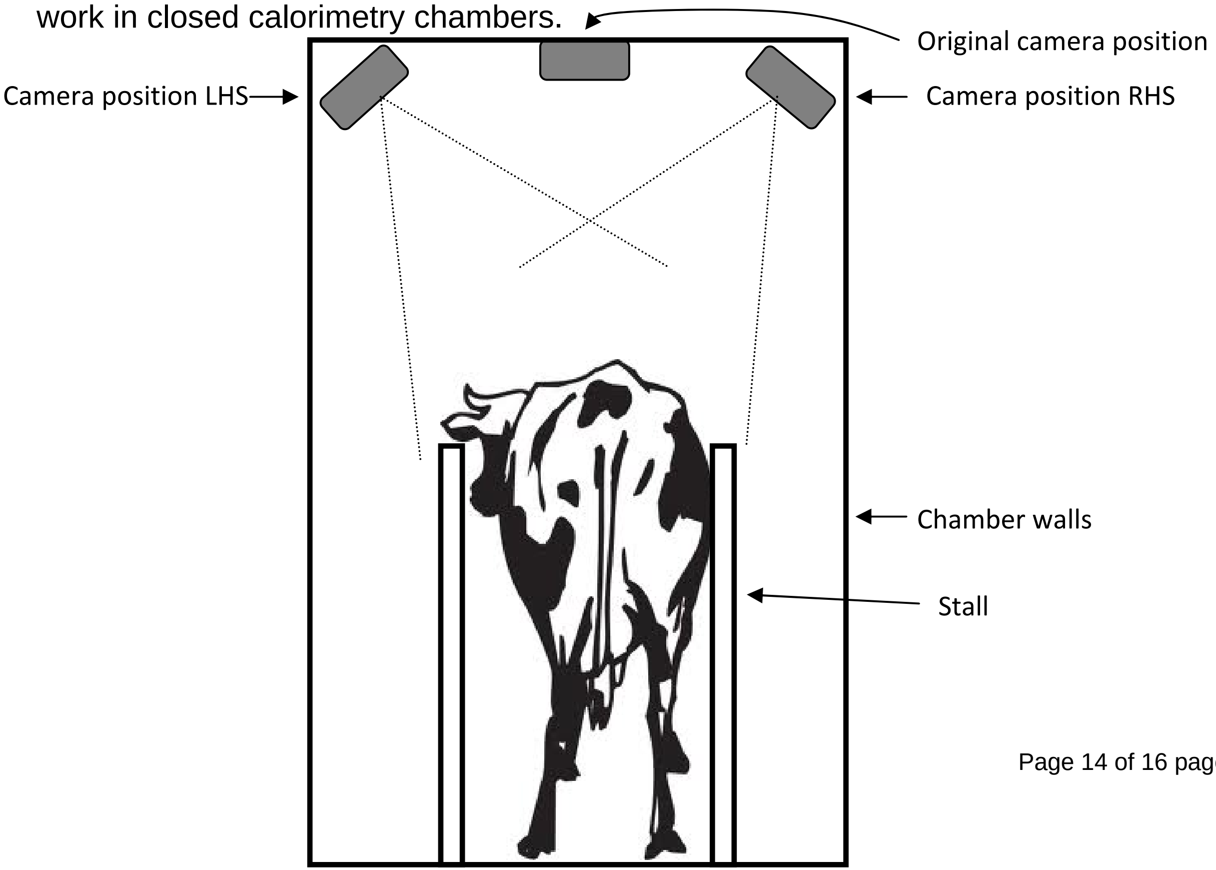
The noise in the current data would make it extremely difficult to predict methane emissions on a point sample, but collection of temperature differences over the postprandial period, or indeed over a day, would enable a qualitative estimation of methane emissions from animals. Further refinement of the thermography image collection might allow a quantitative estimation as well although must likely restricted to the postprandial period.

1. Location of camera.

In determining out the original relationship between methane emissions and thermography, Montanholi *et al*. (2010) housed their animals in head chambers (cow's head enclosed in a sealed box connected to gas analysis equipment. They were able to take thermal images from both sides of the animal, with the camera located perpendicular to the flank. The camera was moved from one side of the animal to the other to allow images to be taken of each flank (Figure 1). The use of a head chamber allowed free access to the flanks of the animal and manipulation of the chamber during the animals' 24h of confinement. With the current experiment at Ellinbank, cows are confined for 48h entirely within the sealed chamber. This has necessitated a different experimental approach to that of Montanholi *et al.* (2010) as both access to the cow and the camera is not possible once the chamber is sealed. A single camera cannot be moved from side to side as it is sealed inside the chamber. The overhead angle used in BCCH 1085 represents a "best case compromise" (Figure 1). Other angles have been discussed in Milestone 2.

Ideally, a better system might involve the positioning of two cameras, slaved to one laptop, to allow a greater coverage of the flanks of the animal (as Figure 2). Preliminary data from sensors within the rumen suggests temperature differences within the rumen, particularly the sensor at the base of the rumen compared to the sensors at the top and floating within the rumen. Better thermal imaging of the flank of the animal might resolve the differences in correlations seen between the Montanholi *et al.* study and BCCH 1085. The disadvantage is the duplication of cabling required using the current system (but see postscript in the next section).

Figure 2. Possible alternative camera angles for future thermal imaging capture work in closed calorimetry chambers.



2. Collecting images from camera by computers.

The current version of the firmware and software offered by FLIR allows a variety of connection methods to the camera in order to obtain the thermal images. BCCH 1085 used a USB cable connection to allow for remote control image collection. Wireless collection is possible, using IPad connectivity but does not allow remote control. If a certain time point was of interest (say the first 180 minutes of chamber time, including an eating bout) then using a wireless system would be feasible. Certainly, the wireless signal was able to penetrate the stainless steel chamber. Whilst removing cabling constraints, the lack of remote control data collection increases experimenter input. The camera would still need access to a mains power source as the batteries last between 2-4 hrs, depending upon power usage.

BCCH 1085 used two different laptops to collect images from the camera. The first laptop was used for the first four sessions of data collection then switched over to the second laptop after that point (Table 1). The switch was necessitated by the first laptop being unable to maintain image collection. The collection software should maintain a live image at all times when collecting using the “record” function – freezing of that image meant real time images were not being recorded. Whilst both laptops were able to run the camera and associated software, it may the more capable (yet slower) i7 CPU and additional RAM in laptop two that allowed more successful data collection. A significant trial period would be necessary prior to collection with different computers to ensure functionality.

Postscript: Following the conclusion of the data collection period, the thermal camera was updated by the manufacturer (FLIR) with new firmware (during a camera service). The remote control function that was present in early versions of the firmware has been re-enabled. It is now possible to programme the camera itself to record images at set time intervals and record to an internal memory card. This removes the necessity to have cabling out of a chamber to a laptop and removes issues with laptop specification. Power supply to the camera would still need to be arranged – the calorimeters at Ellinbank have power accessible within the chamber itself. This progress would have simplified the process and logistics during the data collection although further testing would have to be carried out to ensure images were being collected properly.

3. General comments on applicability of thermography as a proxy measure of methane.

Milestone 2 discusses some of the technical issues with using thermal imagery. Colour of the surface being photographed; environmental factors such as solar radiation, wind speed and temperature per se; reflection of infrared from surrounding surfaces and so forth all impact upon the ability to collect and analyse accurate animal temperatures. The calorimeter offers a unique situation in that the total control of environmental factors makes analysis relatively straightforward – in fact, the lack of solar radiation negates the surface colour effects as well and the reflection can be assumed to be equal across both sides of the animal. It may well be possible to compensate for these effects but additional environmental data would have to be collected alongside the thermal images – further work would have to be completed to establish the correction factors needed to use thermography as an effective and efficient proxy measure for methane production. Ideally, thermography under the current conditions should be combined with at surface temperature logging (using thermistors or similar) under a number of different dietary conditions to elucidate the relationship between flank temperature and methane emissions. Undertaking thermography is more restrictive calorimeters would be difficult, certainly the Ellinbank DPI represent as close to ideal close circuit calorimeters in terms of available space/distance around the animal to allow thermal imaging. Smaller closed circuit calorimeters would present focal length complications and head chambers (as used by Montanholi et al. (2010)) may not have as comprehensive methane collection as the current system.

Conclusion.

The use of thermography to estimate methane emissions may be a useful qualitative tool at present, but further work evaluating the relationship between flank temperature and emissions under different conditions is necessary before a quantitative measure can be determined. The role of nutritional interactions also requires further investigation prior to thermography being used as a proxy.