INTRODUCTION

Solar heat rise in attics has long been known to cause elevated temperatures in occupied spaces below, from infra red transmission, conduction as well as direct entry when the attic is used as an air supply plenum. Common techniques to reduce heat rise include the use of exterior white paint and some form of thermal barrier under the roof sheathing. Many livestock and poultry facilities utilize the attic air space as a plenum for air inlets and distribution. Solar heat rise in attic air spaces can be substantial. In many areas of North America, exterior roof sheathing is commonly specified as white painted steel. This does reduce gain substantially, however, gains are still large enough that under roof sheathing insulation is commonly added to further reduce attic gain.

Ceramic radiant barriers on roof surfaces can reduce surface and attic space temperatures dramatically. Ceramic barriers work by reflecting radiant energy away with little or no energy absorptivity. Reduced temperatures inside the barn on hot summer days will reduce heat stress on animals, therefore exerting less energy fighting the heat which causes less weight gain, feed conversion, and breeding efficiency.

LITERATURE REVIEW

Cummings (1991) experimented with ceramic coatings on top of an asphalt shingle roof of a Florida residence to observe the reduction in attic temperature and house cooling. Roof absorptivity decrease from 0.78 to 0.27 when the coating was applied. The bottom surface of the roof dropped from 130°F to 100°F and the attic temperature dropped from about 110°F to 88°F. Cooling energy use decreased by 10.5%.

Comprehensive Data Base, Inc. (1993) wrote a report on J. McKnight's testing on ceramic roof coatings. The ceramic coating was applied to 300 square feet of roof to observe surface temperatures of the original rusted metal roof surface versus the surface temperature of the ceramic coated area. Results showed that the ceramic coating gave a decrease of 42°F at the inside surface of the metal roof.

Fujita and Nara (1993) described insulating characteristics of 11 types of roof materials in livestock buildings. The results showed that white color had the highest reflectivity of total short wave radiation and superior insulation ability compared with other colors. The best result was from white glass fiber reinforced polyester coating which had a reflectivity of 70% of the total short-wave radiation.

Baccari et al. (1993) compared cooled gilts to non-cooled gilts to evaluate the effect of water cooling on growth rate and performance. At an average temperature of 35.8°C, the water-cooled gilts had a lower respiratory frequency, rectal temperature, higher feed intake, better feed conversion and gained 0.35 g more per day.

Nienaber et al. (1993) studied eating behaviors under cold and heat stress conditions. Temperature increases caused declines in feed consumption while temperature decreases cause feed intake to increase at heat stressed temperatures.

Pordesimo et al. (1993) took a general look at heat exchange between the animal and its thermal environment. Expressions and equations for feed intake, heat exchange, critical temperatures, thermoregulatory heat and metabolizable energy intake were given. Temperature stress reduces overall performance.

Hahn et al. (1993) found that Short-term changes in body temperature reflect the dynamics of energy exchanges and thermoregulation in animals. Thermoregulatory responses are strongly linked to thermal conditions, to feeding activities, and to metabolic heat production. Feeding activities are negatively effected by changes in temperatures.

Hahn and Nienaber (1988) measured feed intake, growth rate, heat production, and carcass composition showed for a range of constant environmental temperatures (5, 10, 15, 20, 25, 30°C). Results show that an average temperature range from 16.9 to 18.9°C should be set as a target for design and operation. A comparison of growth rate, feed intake, and feed conversion is graphed with increasing temperature showing decreasing performance.

Korthals et al. (1997) found there is a significant reduction in number of meals, time spent eating and feed intake for the day after compared to the day before the imposition of heat stress. Pigs ate 0.12 kg less feed for every 1°C increase in ambient temperature on the day after imposition of heat stress comparing to the day before imposing the heat stress. With this decrease in the amount of feed eaten, the animals ate fewer meals and spent 6.6 minutes less time eating for every °C temperature increase. Also, animals under cyclic conditions would quickly eat large meals, while the animals under constant conditions would visit the feeder more often for more leisurely feeding events. Hot cyclic conditions brought decreasing meals from 7.3 to 4.6 and less time eating from 114 minutes to 86.4 minutes. Feed intake was the same.

Nienaber et al (1997) compared swine of two genetic composites (moderate-growth and high-lean-growth under heat-stressed temperatures. Growth rates of the moderate-growth composites were reduced in proportion to feed intake with little effect on feed conversion. Growth rates of the high-lean-growth composites were drastically reduced with reduced feed treatments, causing poorer feed conversion. Back-fat and intramuscular leaf fat were increased by 10% to 25% for heat-stressed lean pigs. All animals were fed the same ration, therefore, there were apparently differences in utilization of that ration by the two genetic composites.

TEST SITE DESCRIPTION

The Arkell Swine Research facility is an approximately 300 sow farrow-finish facility constructed in 1980-81. The facility is located near Guelph, Ontario with 97.5% design of -17 EC and 2.5% of 29.5 EC. The rooms are constructed as follows:

Ceiling - 3.0 m high, with steel sheathing, 13 mm drywall and 25 cm of blown in rockwool insulation
Walls - 23 cm foundation wall with 5 cm embedded rigid insulation - 5 cm x 15 cm studded wall framed with 10 mm plywood interior and steel exterior, 15 cm of fibreglass batt insulation
Doors - One 80 cm x 2.4 m door per room, to centre hall way
Windows - None
Flooring - partial slatted

The finisher section is oriented to north-south. Partial ventilation renovations were completed in 1996. These centred on a new air inlet system operating on static pressure. Air is drawn via the soffit and then through the attic air space, by-passing the original centre duct system (the original air inlet system had air inlets at one end of the room only). A light green metal roof sheathing, with no insulation underneath caused a temperature rise above outside ambient into the rooms on hot sunny days. Options were evaluated to correct this, including under roof insulation, 100% white paint, or ceramic paint on the outside roof surface. Facility management agree to a ceramic paint evaluation.

Two identical rooms on the test site were used for the comparison. Each room had 12, 4.5 m x 2.1 m pens on both sides of a centre alleyway. See Figure 1. All air is brought into the rooms via soffit and attic air space. Each room has a plywood partitioned attic space to ensure no cross contamination of intake air flow, an ideal set up for this type of evaluation.

Room N10 was completely pressure washed and then coated with ceramic paint. A slight overspray was done onto the adjacent Room N-8 roof surface, to reduce potential conductive heat transfer from this section of roof and distorting results.

The rest of Room N-8 was left as is to prevent any impact on the control test Room N-6. The west side of the true north facing facility was chosen as this would typically experience the highest heat gain.

TEST PROCEDURE

The test was set up with the following data loggers

C Outside ambient air relative humidity, with a data logger located under the soffit of a north facing section of the facility, protected from precipitation and soalre gain effects.

C The coated and uncoated sections had sensors located as follows:
-intake air at the soffit
-inside ambient, centrally located in the attic about 1 m off the attic floor and about 2 m below the roof.
-at a centrally located air inlet

See Figure 1 and 2.

This method of testing was employed to provide a 'control' where all other variables such as building envelope, etc., remained constant. Pig densities were essentially the same, resulting in maximum ventilation rates during the hot days for both rooms. The only differences between rooms was the roof coating.

RESULTS

Summer 2000

Graph 1: Summer Comparison of Roof Surface Temperature

The underside of the uncoated roof has a substantial range of temperatures versus that of the coated roof. The uncoated temperatures generally range from 16 to 22EC *above* outside temperatures during daytime. This indicates the radiant solar gain that occurs with an uncoated roof.

The uncoated temperatures generally range from 3 to 6EC *below* outside temperatures during night time. This is an indication of the fact that there are radiation heat losses to the sky, particularly on cloudless nights.

The coated temperatures generally range 4 to 6EC cooler from outside temperatures during daytime. During night time the roof temperatures range is 3 to 6EC *below* outside temperatures, which is directly similar to the uncoated. This indicates the ability of the coating to maintain a stable roof temperature, unaffected by either solar heat gain or night time radiant heat losses.

Graph 2: Summer Comparison of Roof Surface Temperature (August 13/00)

This graph shows a close up view of a short time period from Graph 1. The underside roof sheathing of the uncoated roof shows a maximum temperature increase of 25.6°C from that of the coated roof. This is a classic example of the reflective characteristics of the ceramic coating when measuring the temperature of a surface exposed to a radiant heat source. The temperature range of the uncoated varies considerably on some days for certain time periods due to cloud cover.

The underside roof sheathing of the coated roof stays consistently lower in temperature during the daytime compared to the outside temperature by approximately 4°C.

Graph 3: Summer Comparison of Attic Space Temperature

The attic space temperature of the uncoated roof zone stayed warmer than the attic with the coated roof. The uncoated side attic space temperatures generally range from 0 to 3EC *below* outside temperatures during daytime to roughly the same temperatures during night time.

The coated roof attic space temperatures generally range 4 to 7EC *below* outside temperatures during daytime to roughly the same temperatures during night time. The day-time attic temperatures indicate that the uncoated attic is generally warmer than the coated attic because of the increased solar heat gain as shown in Graph 1. There is some lead and lag of temperatures on the roof surfaces due to thermal capacitance.

Graph 4: Summer Comparison of Attic Space Temperature (August 13/00)

This graph shows a close up view of a short time period from Graph 3. The differences of uncoated and coated roof attic space temperatures are clearly seen during the day time. At the highest outside temperature of the day, the attic space temperature difference is 4.4°C between the uncoated and coated roof surfaces.

Winter 2001

Graph 5: Winter Comparison of Roof Surface Temperature

The underside of the uncoated roof has a wider range of temperatures versus that of the coated roof. The uncoated temperatures generally range from 5 to 10EC *above* outside temperatures during daytime. This indicates the solar gain that occurs during hot summer conditions also occurs in cold weather. Although it could be stated that this is wasted solar energy, it would be relatively insignificant in terms of benefits to the heat load due to: 1) relatively smaller total gains compared to hot weather. 2) shorter daylight hours in winter. 3) on days that the heat gain was highest corresponded to warm outside conditions overall. In many cases, the barn would be under higher ventilation rate already, negating the solar benefit and actually increasing electrical energy consumption.

The uncoated temperatures generally range from 2 to 4EC *below* outside temperatures during night time. This is an indication of the fact that there are radiation heat losses to the sky, particularly on cloudless nights. This is a heat energy loss, although relatively small in value.

The coated temperatures generally range ±2EC from outside temperatures during daytime to 2EC *above* outside temperatures during night time. This clearly indicates the ability of the coating to maintain a stable roof temperature, relatively unaffected by either solar heat gain or night time radiant heat losses.

Graph 6: Winter Comparison of Roof Surface Temperature (Jan. 20/01)

This graph shows a close up view of a short time period from Graph 5.

The underside roof sheathing temperature change of the uncoated roof shows a definite *time-lead* response of maximum and minimum temperatures of approximately 2 hour compared to both the coated and outside temperatures. This indicates the rapid effects on the roof of solar heat gain.

The underside roof sheathing temperature change of the coated roof shows a definite *time-lag* of maximum and minimum temperatures of approximately 1 hour compared to both the uncoated and outside temperatures. This indicates that the coating is causing a thermal lag to occur. Essentially, the roof sheathing warms up due to convective heat gain from the surrounding air. The solar effect on heat rise is minimal.

Graph 7: Winter Comparison of Attic Space Temperature

The attic space temperature of the uncoated roof zone was generally warmer than the attic with the coated roof. The uncoated side attic space temperatures generally range from 0 to 4EC *above* outside temperatures during daytime to 2 to 4EC *above* outside temperatures during night time.

The coated roof attic space temperatures generally range 2 to 4EC *below* outside temperatures during daytime to 1 to 3EC *above* outside temperatures during night time.

The day-time attic temperatures indicate that the uncoated attic is generally warmer than the coated attic. This is in large part due to the increased solar heat gain as shown in Graph 5.

The night-time attic temperatures indicate that the uncoated attic is generally warmer than the coated attic. This variation (although very insignificant) is more than likely due to the heat loss from the livestock rooms below into the attic air space. Ventilation rates during cooler weather are relatively low. As well, there is potential for air leakage from the livestock room below into the attic air space, further raising space temperatures.

Graph 8: Winter Comparison of Attic Space Temperature (Jan. 20/01)
This graph shows a close up view of a short time period from Graph 7. The temperature differences in this graph provide additional clarity of observations shown in Graph 7.

Table 1 shows a summary of the maximum and average differences between uncoated and coated roof surfaces and attic space temperatures during daytime hours from 7:00 am to 9:00 pm. It is clearly shown that increases in roof surface temperatures have dramatic effects on the attic space temperatures.

Table 1: Temperature Differences between Uncoated and Coated.

Date	Location	Maximum Temp. Difference	Avg. Temp. Difference
August 13/00	Roof Surface Temperature	25.6 °C @ 2:25 PM	9.8 °C
August 13/00	Attic Space Temperature	4.4 °C @ 2:33 PM	2.2 °C
January 20/01	Roof Surface Temperature	10.6 °C @ ~2:24 PM	4.0 °C
January 20/01	Attic Space Temperature	3.9 °C @ ~2:44 PM	3.0 °C

CONCLUSIONS

The following conclusions can be made from the successful testing of ceramic coatings and their ability to reduce solar heat gain:

1) The underside of the coated roofing temperature remained more constant than the uncoated roofing throughout changes in outdoor temperatures. The ceramic coating kept roof and attic space temperatures close to ambient temperatures. Meanwhile without a ceramic coating, high fluctuating temperatures occur from the sun's radiant energy. In addition, a great benefit to this is decreased thermal expansion/contraction and a resulting improvement in life span of the roof and fasteners and all joints and overlaps.

2) The attic temperatures in the area of the coated roofing generally remained cooler than the uncoated attic during both daytime and night-time. This shows the ability of the coating to stabilize temperatures and minimize both daytime solar heat gain and night time radiation heat loss effects.

3) Reducing attic space temperatures will also reduce air temperature that flow through air inlets and into the rooms. This will decrease the chances of heat stress in animals, as well as improving their performance during the summer months.