Environmental Conditions in Plastic Film Covered Calf Facilities

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ABSTRACT

A fourteen-month study (August 1999 to September 2000, funded by Cornell University's PRO-DAIRY program) was conducted with the primary objective to quantify the environment in four similar central New York State plastic film covered facilities (greenhouses) used to house pre-weaned and recently weaned dairy calves. A secondary objective was to attempt to assess the effects of the environment on calf growth, health, and rearing costs and some of the health data is presented herein. Environmental assessment was accomplished by contrasting inside and outside black globe temperature, black globe-humidity index, humidity, and dry-bulb temperature. Data was collected for each monitored parameter using small, programmable, self-contained dataloggers.

The results indicate that greenhouses can at times provide a suitable calf environment in regards to the parameters measured. A quality environment was predicated on prudent management of the ventilation system. Most structures were overall cooler in the summer and warmer in the winter than the ambient conditions. Daytime solar heat gain occurred in each structure during all months to various degrees. All structures developed a daytime summer environment that subjected calves to marginal heat stress as indicated by the black globe humidity index values. Overall, the use of either clear plastic film overlaid with shade cloth or white plastic film without shade cloth as cladding appeared to be similarly affective at providing shade from the summer sun.

KEYWORDS: Calf housing, Alternative animal housing, Heat stress, Solar heating, Datalogger.

INTRODUCTION

The interest and application of plastic film covered metal-arched structures (commonly referred to as calf greenhouses by dairy producers) to house pre-weaned dairy calves has grown rapidly in the last several years in many dairy areas of the United States. Benefits of these structures include competitive initial capital investment, increased labor efficiency over individual calf hutches (Karszes, 1996), and flexibility with regards to future relocation due to farmstead change or disease outbreak. These benefits are all attractive to the dairy producer. However, justified concerns exist relative to the health and well-being of calves reared in such structures since no long-term research has been reported regarding their suitability for this application. A typical cross section of a calf greenhouse is shown in Figure 1.

By definition, a calf greenhouse has a unique component that is different from most traditional dairy housing systems—a translucent outer covering. Additionally, many calf greenhouses employ: a subsurface drainage system, shade cloth endwalls, and reversed curtain sidewalls

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(curtains that open from the bottom up). Each of these components affects the environment a calf experiences at any given time.

Energy transmitted through plastic film cladding has the potential to significantly increase the interior temperature of a structure if solar heat is allowed to accumulate. Increased interior air temperature results in the additional evaporation of free moisture (water bowls and urine), an increase production of manure gases, and increased air moisture from animal respiration.
If interior temperatures are sufficiently elevated, environmental heat stress will occur. Another potential complication of the solar heat gain is more prevalent in transition (early spring and late fall in the northeast) and cold weather conditions. During these time periods the calf caretaker may compromise a greenhouse barn ventilation system in order to maintain a comfort level suitable to humans. This compromise may be to the extent that insufficient air exchange takes place, resulting in the accumulation of moisture, pathogens, dust, and gases—all of which adversely affect calf health and well-being.

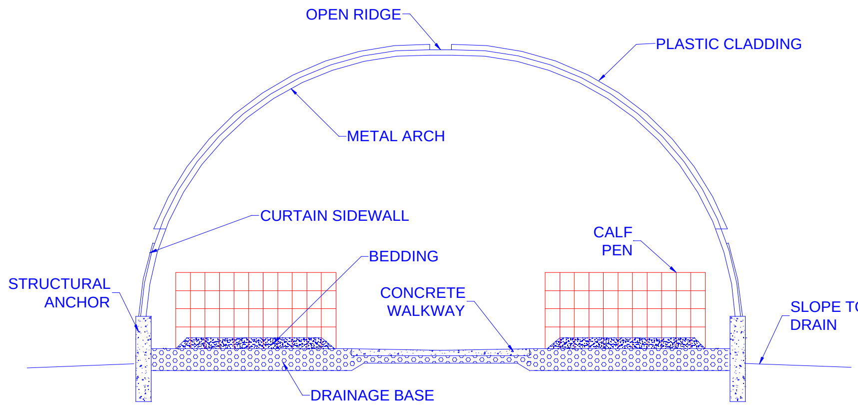

Figure 1. Typical cross section of a plastic film covered metal-arched calf facility.

LITERATURE REVIEW

There have been few documented studies to characterize a calf barn's environment and its implications on calf health and productivity. Wheeler et al. (1997) reported on a preliminary project to monitor veal calf conditions in four Pennsylvania production barns. Housing characteristics for each barn were described along with their general management information. Methodology for conducting the study was also reported. Subsequently, Wheeler et al. (2000) reported that the study barns were operated during the winter at temperatures lower than recommended for economical veal production.

Studies have shown that the most prevalent cause of death in calves from birth to weaning are scours (diarrhea) and respiratory disease (Roy, 1980; National Animal Health Monitoring System, 1993, 1996). A study conducted by the National Animal Health Monitoring System (1996) reported that calf scours accounted for 60.5% of calf moralities. Both scours and respiratory disease can be caused by poor calf environment.

Two environmental components that can affect calf lungs are air temperature and relative humidity (Heinrichs et al., 1994). Calves can contract viral pneumonia from exposure to drafty conditions or by being housed in a damp environment. Mitchell (1975) suggested that a draft is equal to an air speed at calf level greater than 0.25 m/sec (49 fpm) when the temperature is less than 10°C (50°F). Webster (1981) suggested that calves less than 12 weeks of age should not be exposed to air speeds greater than 0.5 m/sec (98 fpm). The duration the calf can be exposed to a drafty condition is a dependent variable that was not reported and certainly is based on other stressors that the calf is predisposed to. Martin (1975) reported that the wetting of calves due to inadequate bedding or poor drainage further increased the severity of pneumonia lesions in calves. Temperature fluctuations have been associated with increases in calf mortality (Martin, 1975). Calves exposed to a higher temperature and a low relative humidity or a higher relative humidity and low temperature are susceptible to respiratory disease (Roy et al., 1971).

The four major environmental factors that influence effective temperature are dry-bulb temperature, humidity, net radiation, and air movement. Gebremedhin et al. (1981) reported that 29°C (84°F) was the upper level for thermoneutrality in newborn Holstein calves. Heat stress causes the calf to utilize energy to dissipate excess heat from its body, resulting in sub-optimal daily weight gains and compromised health. Additionally, heat stress lowers the blood serum Ig levels and can therefore increase mortality (Stott et al., 1976). Buffington et al. (1981) presented the black globe-humidity index (BGHI) as a way to incorporate the four environmental factors into a single value as a means of quantifying effective heat stress. The BGHI equation is as follows:

$$BGHI = t_{bg} + (0.36)(t_{dp}) + 41.5$$

where:

t_{bg} = black globe temperature, ^{o}C

t_{dp} = dewpoint temperature, ^{o}C

The BGHI threshold value for heat stress is hard to quantify because of biological variability involved. Buffington et al. (1981) reported that a BGHI value for lactating dairy cows of 70 or lower causes little to no thermal discomfort while a value of 75 or greater greatly reduces feed intake. Bucklin (2000), Buffington (2000) and the authors concur that a BGHI value of 75 may be too high for today’s dairy cows due to higher production levels, improved genetics, and the use of bovine somatotropin (bST). Buffington (2000) indicated that the threshold BGHI value of a calf would be higher than 75 because the calf does not have the heat of lactation to dissipate. Bucklin (2000) suggested the threshold BGHI value for a calf is probably below 78. Additional research is needed to develop a value that is current for today’s cows and to better define the threshold value for calves.

Elevated noxious gas concentrations have been shown to add additional stress or be terminal to calves. Commonly produced animal gases include ammonia, carbon dioxide, hydrogen sulfide, and methane. All of these have been implicated as an irritant to the respiratory system. Terminal concentrations of ammonia were reported by Russian research cited by Roy (1980) of 0.04 to 0.96 pph while 26 ppm was acceptable. Helickson and Walker (1983) indicated that the threshold level of ammonia is 50 ppm while Meyer (1991) stated that concentration should be below 10 ppm for veal calves. Ammonia and carbon dioxide also contribute to health problems by providing an environment for microorganisms to grow and multiply.

PROCEDURE

Description of Structures

Four calf greenhouse barns located on separate dairy farms of similar management style were monitored in the Finger Lakes Region of New York State. All farms were within a 30-mile radius and weaned Holstein calves (3 farms) or Holstein, Brown Swiss and mix bread calves (1 farm) at approximately 6 to 8 weeks of age. Key attributes that affect calf environment for each structure are summarized in Table 1.

The center caretaker walkway in Structure No. 1 was originally a stone material that was subsequently upgraded to asphalt in April 2000. Structure No. 2 had large asphalt driving and parking areas on two of the four sides. The caretaker walkways in Structure No. 3 were constructed from concrete and a few early-age transition calves (180 to 220 lbs. approximate body weight) were housed in one of two group pens with up to 10 calves per pen as shown in Figure 2. Structure No. 4 had a naturally sandy soil at the site and was used as a pen base material. A large area of the structure was rotor-tilled in multiple directions when a group of post-weaned calves was removed from the barn. Subsequent to tilling, soil was allowed to remain dormant for several days before sanitized pens were replaced and stocked with newborn calves. Rotor-tilling was performed by the caretaker with the goals to maintain the well-draining characteristics of the sandy soil and to break up disease cycles.

Table 1. Characteristics of calf greenhouses for the four study farms.

	Structure No. 1	Structure No. 2	Structure No. 3	Structure No. 4
Size	9.1m x 36.6m (30' x 120')	12.2m x 26.8m (40' x 88')	15.2m x 32.9m (50' x 108')	9.1m x 45.7m (30' x 150')
No. Pen Rows	2	4	4	2
Longitudinal Orientation	E – W	N – S	N – S	N – S
Curtain Configuration[1]	Reverse	Reverse	Conventional - W Reverse – E	Reverse
Curtain Size	1.52m (5')	1.52m (5')	1.22m (4')	1.52m (5')
Ridge Vent	Yes	Yes	Yes	No
Endwall Construction	40% shade cloth (top) 60% metal cladding (bottom)	100% shade cloth (summer) metal cladding (winter)	metal cladding	40% shade cloth (top) 60% metal cladding (bottom)
Plastic Film Color	White, 6 mil	White, 6 mil	White, 6 mil	Clear, 6 mil
Summer Shade Cloth	No	No	Yes - west side (unknown mesh)	Yes 80% mesh
Pen Size	1.22m x 2.44m (4' x 8')	1.22m x 2.44m (4' x 8')	1.22m x 2.44m (4' x 8')	1.22m x 2.44m (4' x 8')
No. Pens	58	69	96	67
Pen Drainage[2]	Subsurface	Subsurface	Subsurface	Natural
Surrounding Bldg. Density[3]	Medium	High	Low	Low

[1] Conventional opens from top - down. Reverse opens from bottom - up.
[2] Natural - uncompacted porous soil (sand). Subsurface - plastic drain tile.
[3] Low = No surrounding bldgs. within 300’, Medium = Surrounding bldgs. within 50’ on two sides, High = Surrounding bldgs. within 50’ on three sides.

Instrumentation

Characterization of the ventilation system for each structure was accomplished by monitoring dry-bulb temperature, black globe temperature, and humidity at multiple inside and outside locations. Interior locations were chosen that best represent the microenvironment the calf experiences, while exterior locations were chosen to reflect ambient air conditions. Field locations for sensor placement typical in each structure are shown in Figure 2.

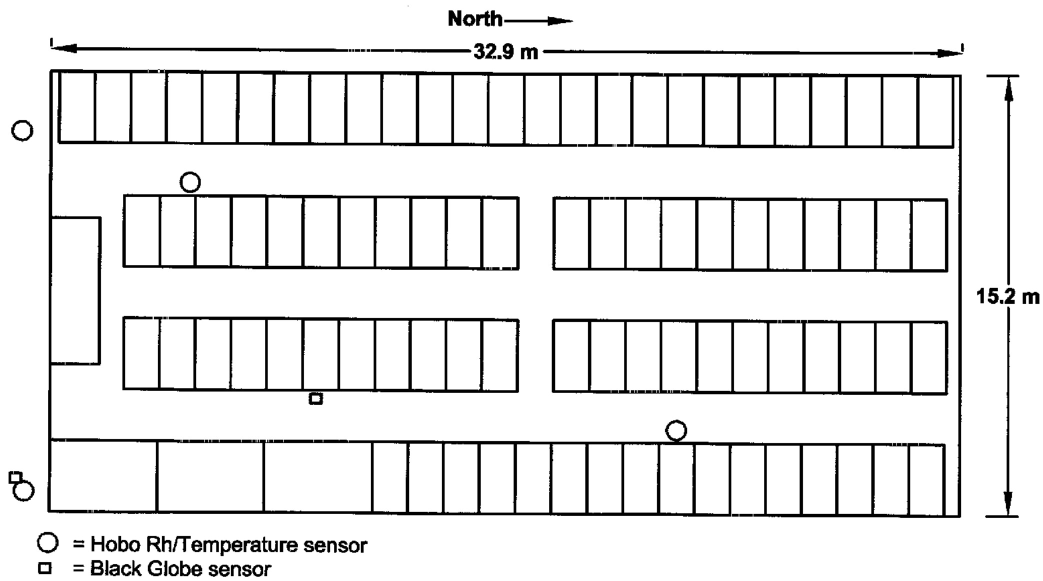

Figure 2. Plan view of Structure No. 3 and approximate datalogger locations.

Small, programmable, self-contained dataloggers (Onset Hobo® Pro™) were used to monitor and record dry-bulb temperature and relative humidity values. The datalogger's temperature units utilized a thermistor with accuracy of ±0.2ºC maximum total error at the temperature range under study, while the relative humidity sensors had an accuracy of ± 3% at 20°C. Dry-bulb temperature measurements were obtained by shielding dataloggers from incident solar radiation. Small, three-sided wooden boxes, designed to preclude direct sunlight on the datalogger, were wrapped with Alcoa's Everbright 95 lighting sheet. This reflective aluminum product had a total reflectance value of 95% according to Alcoa's technical data sheets as tested following ASTM E-1651-94.

Dataloggers were initially checked for relative humidity calibration by following the procedure described by the ASTM standard E 105-85. At 25ºC a saturated salt solution produces a relative humidity inside a sealed test container of 75.3% (ASTM, 1999).

Black globe temperatures were recorded using a separate programmable datalogger (Onset Hobo® H8 outdoor/industrial 4-channel external logger). Black globe temperature was measured by inserting an Onset TMC6-HA temperature sensor into the center of a copper toilet bowl float painted flat black. Accuracy of the sensor was ±0.5ºC at 20ºC.

All dataloggers were programmed to record values at 15-minute intervals. Dataloggers were downloaded periodically in the field with an Onset Hobo® data shuttle. Data was transferred from the shuttle to a microcomputer for analysis and synthesis. Information collected was used to assess the air quality within each structure relative to ambient conditions.

To determine how the natural ventilation system was managed, calf managers at each facility were provided a log to record times when sidewall and ridge curtains were repositioned, and when endwall cladding was installed or removed. Managers also recorded in logs when shade cloth was installed and removed, when applicable.

The four calf greenhouses were outfitted with the described environmental monitoring equipment from August, 1999 to September, 2000. Collected data was checked for reliability and select data is reported herein. Difficulty was experienced maintaining relative humidity sensor accuracy during winter conditions and with obtaining complete records of environmental control adjustments and calf health for some of the structures.

RESULTS AND DISCUSSION

Figures 3 –11 discussed below represent a macro analysis approach to environmental assessment of the miroenvironment found at calf level. Average hourly data points were created for each month from collected data. This approach provides an overall picture of environment for each hour of the day during the months evaluated.

Environmental Conditions

Summer BGHI

During the summer months, concern existed relative to overheating within the greenhouses due to excessive solar heat gain resulting in calf heat stress conditions. The average hourly inside and outside BGHI values for the month of August 2000 are shown in Figure 3. BGHI plots for other summer months showed similar trends and comparisons between structures, but with slightly less daytime peak magnitudes. Structure No. 3 had the highest BGHI inside/outside

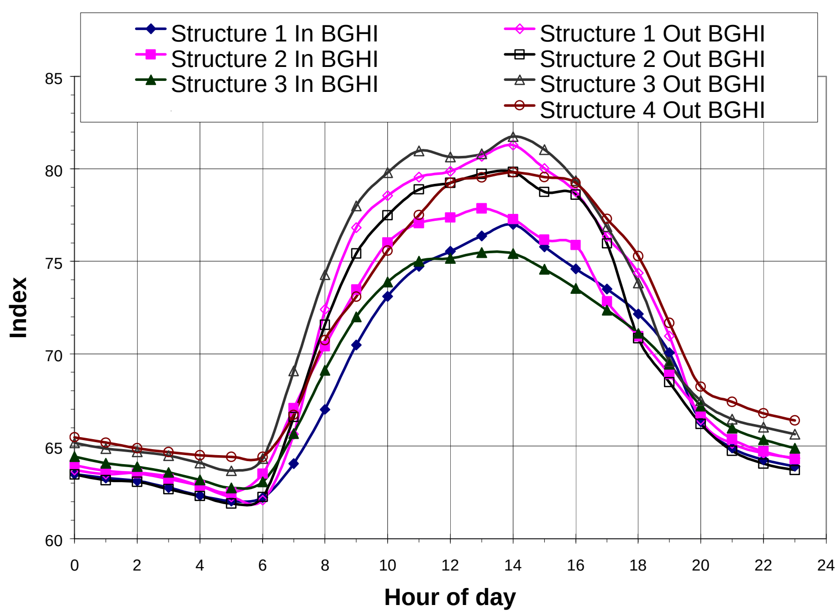

Figure 3. Average hourly inside and outside black globe humidity index values for August 2000.

differentials and the lowest interior BGHI values in the afternoon hours. Structure No. 3 had well managed curtains, relatively little obstruction blocking prevailing summer winds, and had a white plastic film covering overlaid with shade cloth material on the western side. The BGHI value exceeded 75 on average from approximately 9:30 a.m. to 4:45 p.m. for Structure No. 2 (worst case) and from 11 a.m. to 3 p.m. for Structure No. 3 (best case). All greenhouse environments subjected calves to marginal heat stress conditions but not to the same extent as if calves where not provided with any shade.

<u>Fall – Winter inside warming sequence</u>

The average hourly inside black globe/dry bulb temperature differentials for the month of September 1999 are shown in Figure 4. Positive ordinate numbers indicate a black globe temperature greater than the dry-bulb temperature, suggesting a net positive solar heat gain. The graph shows approximately a 4°C differential between black globe and dry bulb temperatures during peak solar hours for all structures. There was an increased early in the day solar heat gain in Structure No. 4 over and above that experienced in the other structures presumably due to incident solar radiation striking the clear plastic film sidewall below the shade cloth. Structure No. 1 had less solar heat gain the in morning hours when compared to the other structures due to its orientation (E-W vs. N-S for others) and the presence of morning shade provided by an adjacent structure. Structure Nos. 2 and 3 also experienced comparatively increased solar heat gain in the morning hours due to the lack of shade cloth on the eastern side. In the afternoon hours, Structure No. 3 had a reduced solar heat gain when compared to that experienced by the other structures, presumably due to the presence of white plastic overlaid with shade cloth on the western side. The presence of shade cloth over clear plastic film or white plastic without shade cloth appeared to function similarly well.

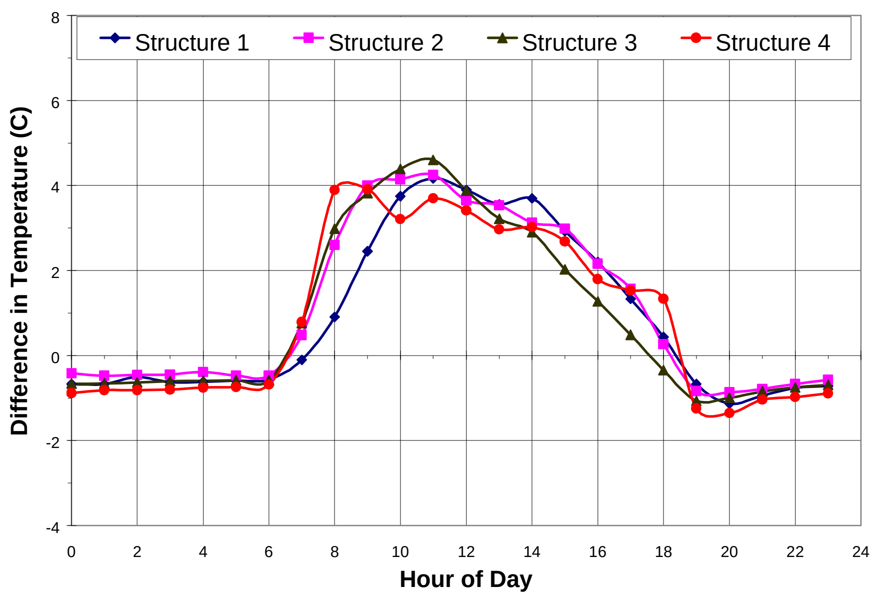

Figure 4. Average hourly inside black globe/dry-bulb temperature differentials for September 1999.

As ambient temperatures decreased in the fall, concern existed relative the presence of amble air exchange as indicated by the increased interior/exterior dry-bulb temperature differentials – presumably to moderate the environment for the caretakers. The management practice for Structure No. 1 was to permanently close the sidewall curtains in early fall and rely on the shade cloth endwalls and adjustable ridge opening to provide ventilation until mid spring. As shown in Figure 5, the heat gain of Structure No. 1 is greater than that experienced by the other structures that continue to moderate ventilation utilizing curtain sidewalls.

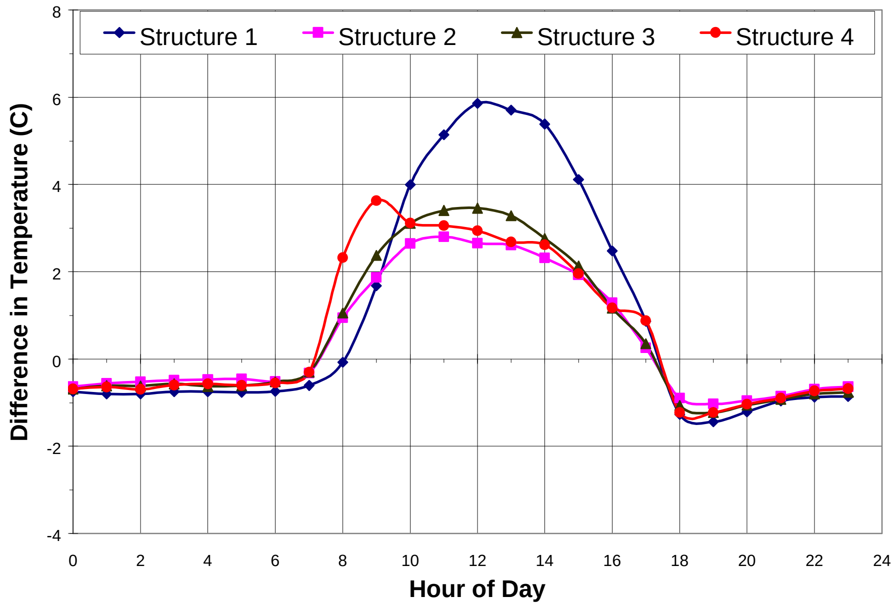

Figure 5. Average hourly inside black globe/dry-bulb temperature differentials for October 1999.

A further decline of average air temperatures during the month of November 1999 results in even greater interior black globe/dry-bulb temperature differentials for Structure No. 1 as shown in Figure 6. Structure No. 1 experienced an increased solar heat gain as compared to Nos. 2 and 3 apparently due to the reduced air exchange (curtains closed). Structure No. 4 had an increased differential as compared to the previous month due to the removal of the summer shade cloth. Similar trends existed for the month of December, 1999 (graph not shown). In January 2000, Structure Nos. 1 and 4 had significant interior temperature differentials above those experienced by the other two structures as shown in Figure 7. The reversal of maximum peak differentials between Structure Nos. 1 and 4 may be the result of more realized solar gain in Structure No. 4 due the clear plastic film cladding (shade cloth removed for winter).

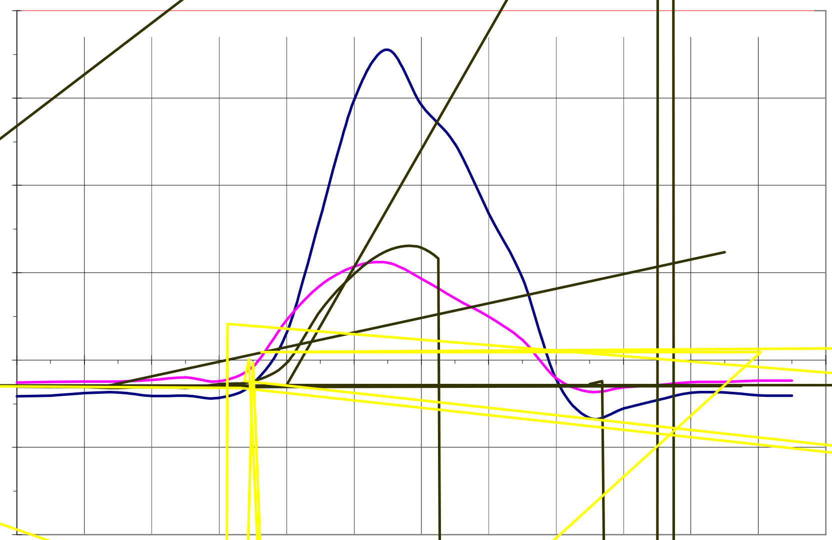

Figure 6. Average hourly inside black globe/dry-bulb temperature differentials for November 1999.

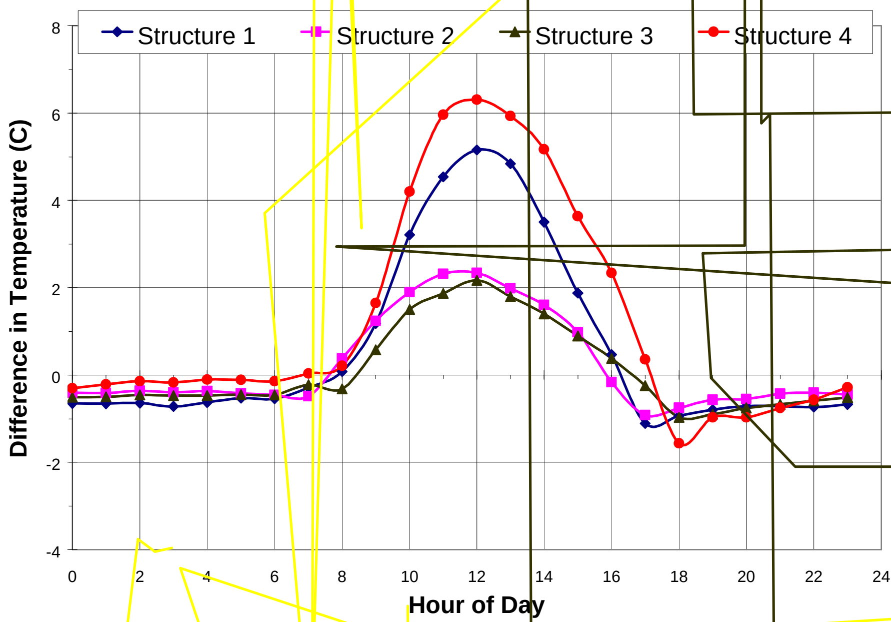

Figure 7. Average hourly inside black globe/dry-bulb temperature differentials for January 2000.

Dry-bulb temperature comparisons

Comparing the inside dry-bulb temperature of a structure to the ambient dry-bulb temperature can be used as an indicator of ventilation. Properly ventilated animal housing structures that have minimal interior/exterior temperature differentials can be considered well ventilated. During two consecutive summers, the average hourly interior and exterior dry-bulb temperature graphs for each month are well represented by the graph shown for August 1999 (Figure 8). Interior/exterior temperatures tracked well, indicating ventilation was taking place. Generally the barns were warmer at night and cooler during the day, as may be expected. The interior average daytime dry-bulb temperature for Structure No. 4 was noticeably above that of the exterior, while the outside temperature for Structure No. 2 was above the interior.

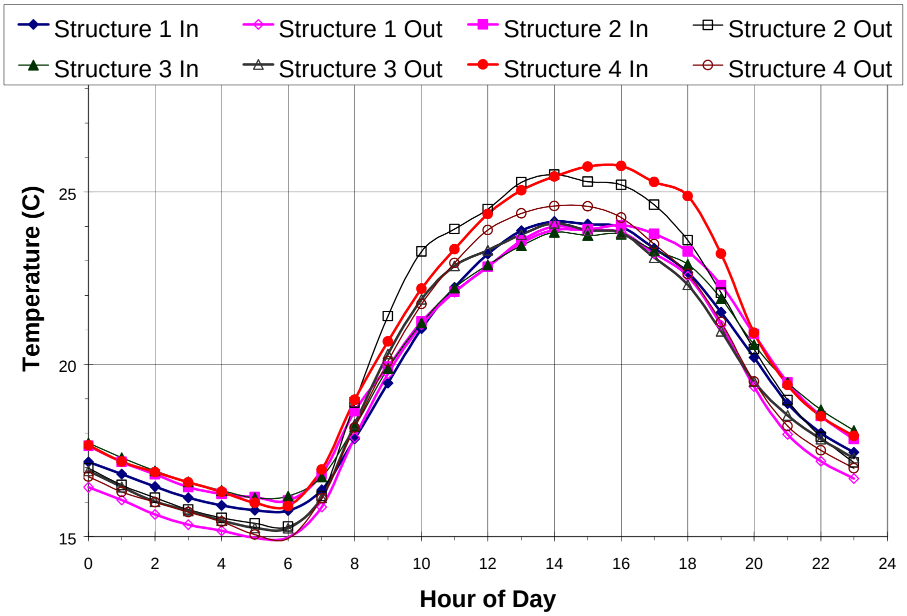

Figure 8. Average hourly interior and exterior dry-bulb temperatures for the month of August 1999.

During the cooler months, the daytime hourly average interior dry-bulb temperatures generally rose above that of the exterior, similar to that shown in Figure 9 for the month of November 1999. Structure No. 4 was warmer inside than outside and had the largest average interior/exterior dry-bulb temperature differential during the afternoon hours. The explanation possibly lies in the fact that Structure No. 4 did not have a ridge opening to allow heated air to escape and utilized clear plastic allowing for increased solar heat gain.

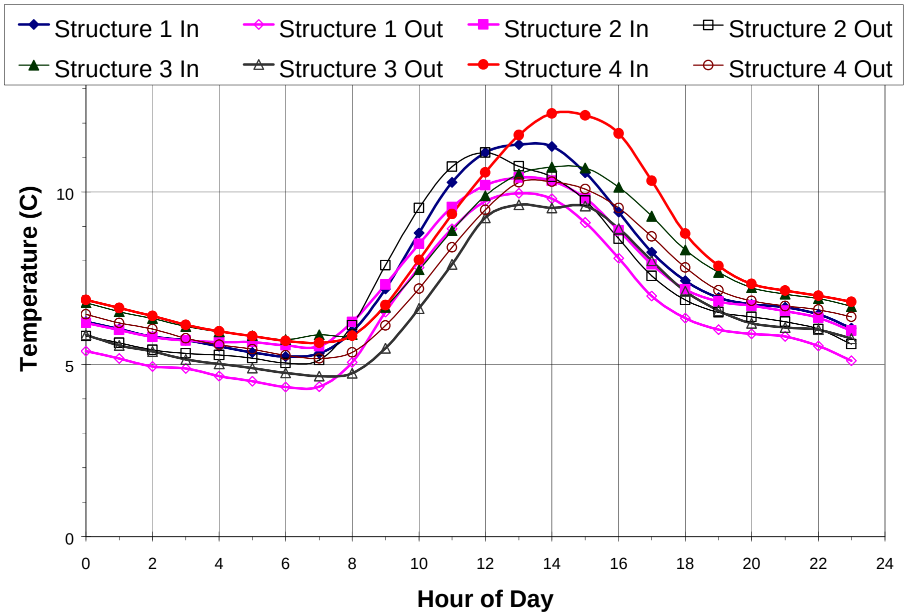

Figure 9. Average hourly interior and exterior dry-bulb temperatures for the month of November 1999.

During cold conditions, the interior/exterior dry-bulb temperature differentials become more pronounced, especially during daytime hours. All structures had significantly greater daytime dry-bulb temperatures inside than outside as shown in Figure 10, indicating the need for additional ventilation. Preferential management of the inside environment by the calf caretaker for their comfort appears to have been taking place. Again, Structure No. 4 had the greatest daytime dry-bulb temperature differential.

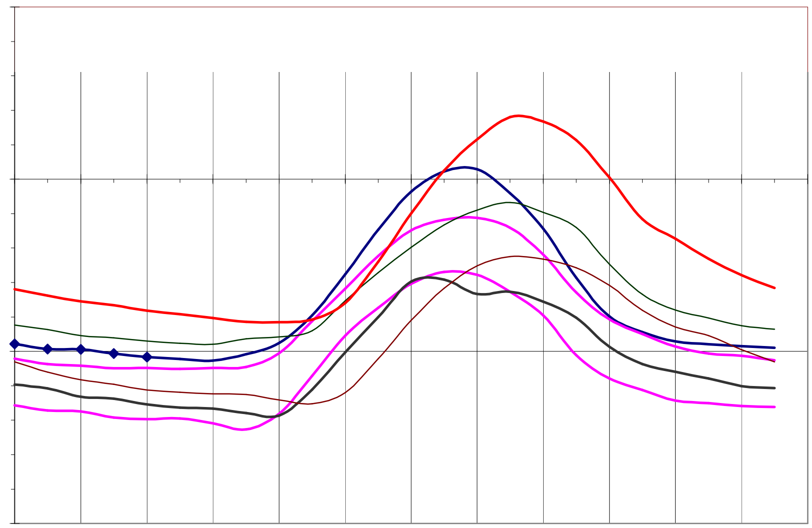

Figure 10. Average hourly interior and exterior dry-bulb temperatures for the month of January 2000.

Early spring temperatures resulted in a similar average hourly graph for the month of April 2000 (Figure 11) as that developed for November 1999. Slightly greater daytime interior/exterior temperature differentials existed in November for Structure No. 4 than for the other structures.

<u>Parameter extreme range comparisons</u>

The results discussed above are a macro analysis of the environmental conditions monitored and provide an overall understanding of the conditions present in the study greenhouses. The range of values for all monitored parameters for the months discussed above are shown in Table 2. These values also represent the extreme of the ranges recorded over the duration of the study, except in one isolated case. Missing table entries represent times when data was unreliable.

A few observations can be made relative to the table values. The BGHI value for Structure No. 1 exceeded a stress threshold value of 75 in months when heat stress is not traditionally considered to be a factor. Secondly, the maximum inside/outside difference for the black globe temperature and the BGHI for Structure Nos. 3 and 4 during January, 2000 is extreme. During this time, there was significant solar heat gain in Structure No. 4 and good solar protection in Structure No. 3. Finally, Structure No. 2 had higher unexplained maximum differences when compared to Structure Nos. 1, 3 and 4 while their high-low temperatures are fairly consistent with each other.

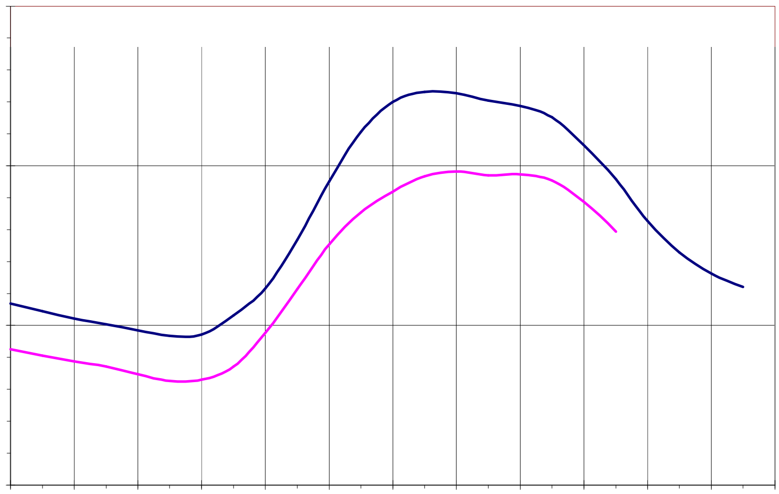

Figure 11. Average hourly interior and exterior dry-bulb temperatures for the month of April 2000.

Table 2. Average hourly interior and exterior dry-bulb and black globe temperatures (°C) and black globe humidity index for selected months.

Month		Structure 1			Structure 2			Structure 3			Structure 4		
		Range		Max. Diff.[A]	Range		Max. Diff.[A]	Range		Max. Diff.[A]	Range		Max. Diff.[A]
		Low	High		Low	High		Low	High		Low	High	
Sept. 1999	T-O[1]	3.93	32.98	-2.86	4.84	35.45	6.96	5.91	32.12	3.40	4.20	32.83	-4.58
	T-I[2]	6.49	32.10		6.60	30.99		7.41	31.03		5.96	33.73	
	BGT –O[3]	2.35	45.64	11.59	3.63	51.26	17.05	4.47	45.15	11.70	2.89	44.77	8.51
	BGT-I[4]	5.40	37.78		5.40	35.28		6.72	35.51		4.78	38.11	
	BGHI-O[5]	48.80	84.73	-11.09	46.60	97.88	16.76	47.74	91.74	11.59	45.92	91.36	8.34
	BGHI-I[6]	45.21	92.34		48.69	82.26		50.12	82.85		48.14	85.01	
Oct. 1999	T-O[1]	-2.81	25.30	-3.78	-1.95	24.57	5.19	-0.82	23.67	-3.15	-1.84	23.89	-4.56
	T-I[2]	-0.07	24.29		-0.78	23.32		1.24	23.16		-0.19	25.87	
	BGT –O[3]	-3.61	33.29	6.73	-3.02	33.59	12.93	-0.05	26.83	10.29	-3.25	32.86	-14.23
	BGT-I[4]	-0.61	31.32		-1.51	27.03		-2.09	31.22		-1.06	26.54	
	BGHI-O[5]	40.45	77.07	6.69	37.66	78.21	13.05	38.42	76.09	10.09	37.80	79.15	-14.98
	BGHI-I[6]	36.87	76.87		39.39	72.12		40.83	72.74		40.11	72.88	
Nov. 1999	T-O[1]	-7.42	21.95	-6.16	-5.93	23.01	5.78	-7.30	21.84	-4.27	-5.61	21.91	-8.45
	T-I[2]	-3.88	21.50		-4.06	21.22		-3.02	20.87		-2.79	22.74	
	BGT –O[3]	-8.51	30.61	-8.01	-6.44	31.02	16.63	-8.25	30.82	9.68	-6.95	32.66	-8.77
	BGT-I[4]	-4.94	32.15		-4.21	22.86		-3.85	23.82		-3.37	26.83	
	BGHI-O[5]	34.74	78.65	9.03	32.15	77.75	16.98	29.76	77.27	9.55	30.78	79.53	-9.80
	BGHI-I[6]	29.75	77.14		34.87	68.80		35.24	69.30		37.01	72.23	
Jan. 2000	T-O[1]	-21.33	15.49	-7.71				-19.16	15.53	-6.97	-20.33	15.63	-11.28
	T-I[2]	-15.54	15.37		-17.08	14.87		-15.17	15.17		-14.05	15.39	
	BGT –O[3]	-23.44	17.71	-7.91	-22.40	17.71	13.35	-20.24	19.55	18.49	-22.01	23.94	-14.10
	BGT-I[4]	-18.05	19.52		-17.53	15.52		-17.02	15.72		-14.26	20.47	
	BGHI-O[5]	16.82	61.81	10.36				14.31	61.99	17.58	11.75	61.72	-18.24
	BGHI-I[6]	9.77	61.59		17.00	61.74		18.23	61.80		21.40	62.73	

1 T-O = Outside dry-bulb temperature, °C
2 T-I = Inside dry-bulb temperature, °C
3 BGT-O = Outside black globe temperature, °C
4 BGT-I = Inside black globe temperature, °C
5 BGHI-O = Outside black globe humidity index
6 BGHI – I = Inside black globe humidity index
A Max. Diff. = The maximum difference between interior and exterior parameter at any time during the month. A negative value represents an inside parameter value greater than the corresponding exterior value.

Calf Health

Environmental conditions within a calf facility are a dependent variable relative to overall calf health and well-being. Complete and reliable health records were kept for calves reared in Structure No. 3 by the calf facility managers, and the incidence of respiratory and scour treatments are summarized by month in Figure 12. Adequate colostrum anti-body transfer to calves was confirmed prior to introducing them to the greenhouse by checking blood IgG levels using a refractometer. Only calves that had suitable IgG blood levels were included in the analysis. This check helped ensure that only initially healthy calves were part of the analysis. The occurrence of respiratory disease and scours were prevalent in this facility despite the environment that was documented relative to air temperature and solar heat gain. This suggests that perhaps another environmental parameter that was not monitored caused high incidences of problems or another health dependent variable was responsible.

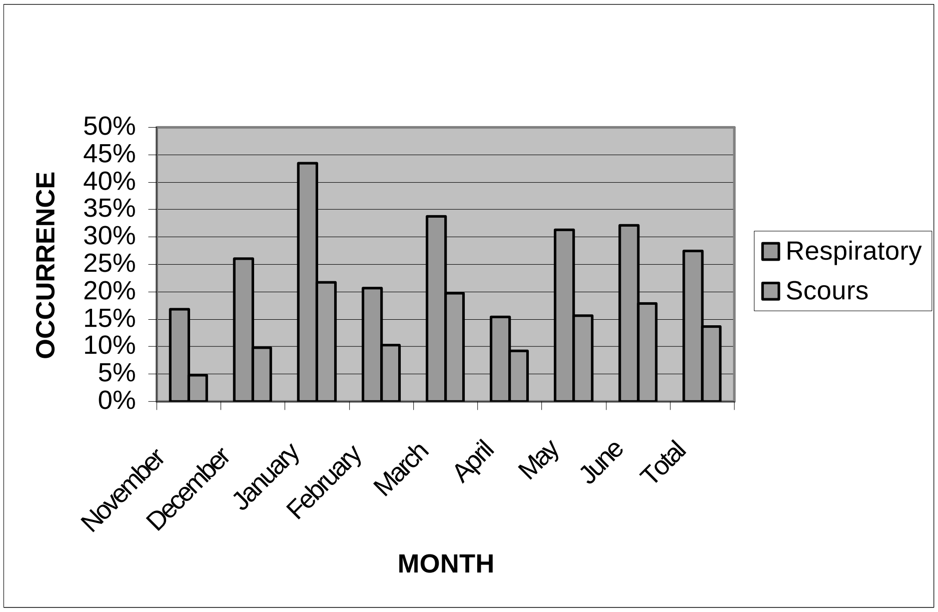

Figure 12. Percent incidence of treatment in Structure No. 3 from November 1999 to June 2000.

CONCLUSIONS

The results indicate that greenhouses can at times provide a suitable calf environment in regards to the parameters measured. A quality environment was predicated on prudent management of the ventilation system. Data shows that the environment within most structures was overall cooler in the summer and warmer in the winter than the ambient conditions. Various degrees of daytime solar heat gain occurred in each structure during all months with significantly more realized gain in the fall and winter in Structure Nos. 1 and 4. Attention to curtain sidewall management and the presence of a ridge opening seemed to be governing variables in moderating solar heat gain. All structures developed a daytime summer environment that marginally created heat stress for calves as indicated by the black globe humidity index values. Greater degrees of heat stress can be expected in more southern climates or in other similar climatic regions that do not experience as much summer cloud cover. Overall, the use of clear plastic film covering completely overlaid with shade cloth or white plastic film without shade cloth would appeared to function similarly well at providing protection from the summer sun.

Internal vs. external dry-bulb temperatures tracked well for summer months, indicating that ventilation was occurring. More temperature spread was found during fall, winter, and spring periods, indicating that ventilation was compromised during these time frames. Calf health, as measured by the incidence of treatment for respiratory disease and scours, was overwhelmingly high during several months of the study on at least one of the farms.

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REFERENCES

ASTM Standard E 105–85. 1999. Standard practice for maintaining constant relative humidity by means of aqueous solution.

Bucklin, R.A. 2000. Personal Communication. Professor, Department of Agricultural Engineering. University of Florida.

Buffington, D.E. 2000. Personal Communication. Professor, Department of Agricultural and Biological Engineering. Penn State University.

Buffington, D.E., A. Collazo-Arocho, G.H. Canton, D. Pitt, W.W. Thatcher, and R.J. Collier. 1981. Black Globe-Humidity Index (BGHI) as comfort equation for dairy cows. Transactions of the ASAE 24(4): 711-714.

Gebremedhin, K.G, C.O. Cramer, and W.G. Porter. 1981. Predictions and measurements of heat production and food and water requirements of Holstein calves in different environments. Transactions of the ASAE 24(4) 715.

Heinrichs, A.J., D.P. Ross, N.T. Place. 1994. The effects of housing and environment on health of dairy calves. In *Dairy Systems for the 21st Century*. Proceedings of the Third International Dairy Housing Conference. pp. 775-780.

Hellickson, M, and J. Walker. 1983. *Ventilation of Agricultural Structures.* ASAE Monoghraph No. 6. pp 152-165.

Karszes J. 1996. Economic Impacts of Heifer Housing. In *Calves, Heifers, and Dairy Profitability, Facilities, Nutrition, and Health*. NRAES-74. Natural Resource, Agriculture and Engineering Service. 152 Riley-Robb Hall, Ithaca, NY 14853.

Martin, S.C., C.W. Scwabe, and C.E. Franti. 1975. Dairy calf mortality rate: the association of daily meteorological factors and calf mortality. Can. J. Comp. Med. 89-377.

Meyer, D.J. 1991. Environmental control for veal facilities. In *Special-Fed Veal Production Guide.* NRAES-17. Natural Resource, Agriculture and Engineering Service. 152 Riley-Robb Hall, Ithaca, NY 14853.

Mitchell, C.D. 1975. Climatic Calf Housing. A study of the feasibility of naturally ventilated calf housing. Ph. D. thesis, University of Aberdeen. In: Ventilation and Airflow Patterns in Climatic Calf Houses. 1986. *J. Agric. Eng. Res.* 33. pp. 187-203.

National Animal Health Monitoring System. 1996. *Part 1: Reference of 1996 Dairy Management Practices.* Ft. Collins, CO: USDA:APHIS:VS.

National Animal Health Monitoring System. 1993. *National Dairy Heifer Evaluation Project: Dairy Herd Management Practices Focusing on Preweaned Heifers.* Ft. Collins, CO: USDA:APHIS:VS.

Roy, J.H.B. 1980. The Calf. (fourth edition) Butterworths. London, England. In: Heinrichs, A.J., D.P. Ross, N.T. Place. 1994. The effects of housing and environment on health of dairy calves. *Dairy Systems for the 21st Century*. Proceedings of the Third International Dairy Housing Conference. pp. 775-780.

Roy, J.H.B., I.J.F. Stobo, H.J. Gaston, P. Ganderton, S.M. Shotton, and D.C. Ostler. 1971. The effect of environmental temperature on the performance and health of the pre-ruminant and ruminant calf. Br. J. Nutr. 26-363.

Stott, G.H., F. Wiersma, B.E. Menefee, and F.R. Radwanski. 1976. Influence of environment on passive immunity in calves. J. Dairy Sci. 59-1306.

Webster, A.J.F. 1981. Optimal housing criteria for ruminants. *Environmental Aspects of Housing for Animal Production.* Ed. Clark, J. A. Butterworths, pp 217-232.

Wheeler, E.F., R.E. Graves, L.L. Wilson, J.L. Smith, and J.L. Shufran. 2000. Winter ventilation case study in three veal barns. *Applied Engineering in Agriculture* 16(1):67-76.

Wheeler, E.F., L.L. Wilson, and J.L. Smith. 1997. *Veal calf environmental control case studies. Livestock Environment V*: Proceedings of the Fifth International Symposium. Vol. 2. pg. 899.