Ridge Vent Effects on Model Ventilation Characteristics

Donell P. Froehlich, Mylo A. Hellickson, Harvey G. Young
STUDENT MEMBER ASAE ASSOC. MEMBER ASAE MEMBER ASAE

CONTINUED and increased use of confinement systems for fattening beef cattle is practical for many reasons: surface runoff from feedlots is practically eliminated, the cost and labor required for bedding are decreased, problems with adverse surface conditions and manure accumulation are reduced, incidents of disease are usually decreased, and national and worldwide demands for red meat are augmenting. When animal densities are increased, maximum utilization can be made of the labor saving devices obtainable with increased capitalization. However, as animal densities increase, environmental maintenance within a confinement structure becomes an increasingly important design consideration. Therefore, accurate and pertinent information is needed that will allow livestock producers to employ ventilation system designs that will improve environmental conditions and allow maximum economic production efficiencies.

Various experiments, both winter and summer, show only slight advantages in rate of gain and feed efficiency for controlled environment confinement systems as compared to open front confinement buildings, which have natural ventilation systems. It is generally believed that the marginal profits realized from this slight advantage do not cover the amortized investment. This suggests the need for increased emphasis on improving the design of open front or cold confinement beef buildings.

Article was submitted for publication in August 1974; reviewed and approved for publication by the Structures and Environment Division of ASAE in April 1975. Presented as ASAE Paper No. 74-4055..

The authors are: DONELL P. FROEHLICH, Graduate Research Assistant, Agricultural Engineering Dept., Cornell University, Ithaca, N.Y.; MYLO A. HELLICKSON and HARVEY G. YOUNG, Associate Professors, Agricultural Engineering Dept., South Dakota State University, Brookings.

Approved for publication by the Director, Agricultural Experiment Station, South Dakota State University, Brookings, as Journal Article No. 1330.

Proper design of confinement structures, which utilize natural ventilation systems, are dependent upon the availability of representative data that describe the relationships between environmental, climatic, and structural characteristics of livestock housing systems. Therefore, a model study, employing the techniques of dimensional analysis, was initiated with the following objectives:

1 Evaluation of the effects of ridge vent design on airflow characteristics and temperature in a model of an open front beef confinement building under actual weather conditions.

2 Determination of prediction equations for the relationships between wind velocity and outlet velocity in a model of an open front beef confinement building.

LITERATURE REVIEW

Ventilation of Beef Production Buildings

Beef housing ventilation systems must be designed to provide airflow rates that vary with climatic conditions, livestock size and numbers, and ambient conditions. During hot weather operation, this includes providing air circulation gradients within the structure, Hellickson et al. (1973). Appleman and Owen (1970) reported that one of the primary deleterious effects of high temperatures in enclosed livestock housing is the resulting increase in water consumption, which increases water vapor production and increases urine output. The resulting influences on livestock housing systems design include increased bedding and ventilation requirements. In a hot atmosphere, a small air movement (8.0 to 16.1 km/hr) has been found to be beneficial to both lactating cows and steers in the feedlot. Hellickson et al. (1973) report that during cold weather operation, a ventilation system should be designed to remove excess moisture and noxious and corrosive gases without creating drafts on the livestock. The greatest hazard faced by livestock during cold weather is stress caused by a combination of low temperatures, moisture, and high air velocity, Appleman and Owen (1970).

Addison (1972) found in uninsulated buildings that there is a need for ventilation to provide animal comfort and reduce condensation and frost accumulation. Addison also stated that natural ventilation can provide sufficient movement of air within buildings to prevent condensation.

Open or semi-open beef shelters with no air conditioning are usually considered to have adequate air circulation. Closed barns are not recommended in most areas and for most production systems, Kelly (1960). Jedele and Andrew (1972), using Illinois data, concluded that natural air movement is adequate during both winter and summer in slotted floor, cold confinement barns. Excellent winter ventilation is provided in open front buildings with continuous ridges and rear wall eave openings. For summer operation, the winter ventilation system is supplemented by opening doors in the rear wall. Brevik (1971) stated that cold free-stall dairy barns are usually ventilated by natural air movement through openings under the eaves and open ridges. Also, with natural ventilation, a relatively flat roof will not permit as much air movement as a steeper roof; indicating that roof slope is important.

Ridge Vent Design

Basically, two sets of factors are involved in the design of ridge vents. First, there are the external climatic effects of rain, wind, and snow; and secondly, the internal effects of air movements, including convective airflows, Mitchell (1972).

An open ridge vent is recommended by the Midwest Plan Service (1971) in open front confinement buildings. In the United States and Canada the infiltration of snow through open ridges on naturally ventilated buildings has been a problem. From research conducted with models in a water

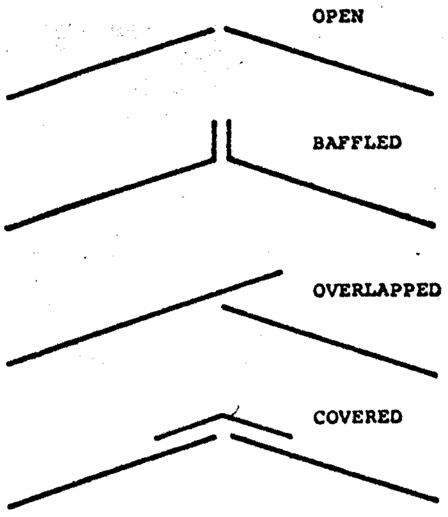

FIG. 1 Types of Ridge Vents.

flume, it was found that the best design for uncapped ridge vents was a upstand which formed a chimney like structure continuously along the ridge, Theakston and Underwood (1965). Dutch workers, Harretsen and Prinsen (1968), suggest that the upstand along an open ridge should be at an angle of 45 deg to the roof slope to prevent the entry of rain forced up the roof during windy conditions. In England and Iceland open ridge vents are covered to prevent entry of gentle rain, Mitchell (1972). These studies indicate that ridge vent design varies with external climatic conditions.

A study of the effect of ridge vent design on ventilation characteristics by Dybwad (1972) in a one-twentieth scale model of an open front building revealed that ridge vent geometry had a highly significant effect on ridge vent velocities. Highly significant linear relationships were developed between the reciprocal of Reynolds number and the ratio of outlet velocity to wind velocity for four types of ridge vents.

Observed flow patterns from water flume studies suggest that open ridges can act both as air inlets and outlets. In practice it appears the ridge covers should be omitted in areas where driving snow is likely to be a problem. Mitchell (1972).

PROCEDURE

Appropriate design conditions and functional relationships among influencing parameters using dimensional analysis were employed in designing a one-sixth size model open front beef confinement building. The model was distorted so that temperature difference in the model was equal to temperature difference in the prototype. The prototype was a 293 m by 22 m open front beef confinement building capable of housing 200 head of 263.2 to 544.8 kg beef cattle, Froehlich (1973).

The model was designed and constructed with the assumption that the same materials and fluid would be used in the model and prototype. The model was open on the south with an eave inlet on the north. Trusses, purlins, and poles were made of wood and the sides and roof were constructed of 26 gauge corrugated galvanized steel. Corrugations were flattened mechanically to represent corrugations one-sixth the depth of normal corrugations. The four ridge vents (Fig. 1) were constructed of 26 gauge galvanized metal and reduced so that the four inch ridge outlet of the prototype corresponds to a two-thirds inch outlet for the model. Total animal heat production, 4032 kcal/hr, was simulated by using electric resistant heating wire.

All experimental tests were performed under natural weather conditions in an open field north of the South Dakota State University Agricultural Engineering Building, selected because of its apparent lack of unnatural turbulence. During all tests the model was orientated so that the direction of the wind was normal to the eave inlet along the major axis of the model. To reduce the effects of wind gusts, simultaneous readings of outlet and wind velocities were taken every 10 sec over 4 to 6 min test intervals. Ventilation distribution patterns within the model were evaluated using smoke candles placed at selected locations. During all tests, pi terms describing the materials and geometry of the model were held constant, while pi terms describing environmental conditions varied with dry bulb and wet bulb temperatures and wind and outlet velocities.

RESULTS AND DISCUSSION

Outlet Velocity

Step-wise multiple linear regression analyses revealed significant relationships between the dependent and independent pi terms for all four types of ridge vents. Coefficients of determination ranged from 72.6 percent for the overlapped ridge vent to 87.0 percent for the baffled ridge vent. Relationships involving π_7 $(k\Delta t/NLV_{W3})$ and π_{12} $(\varrho V_W L/\mu)$ predicted the most variation in the covered and baffled ridge vents, and significantly affected V_O/V_W in the open and overlapped ridge vents. Therefore, to facilitate the determination as to whether ridge vent type significantly influenced outlet velocity, linear relationships between V_O/V_W, π_7, and π_{12} were analyzed for each of the four ridge vents. These equations (Table 1(accounted for less of the total variation in the ratio of outlet velocity to wind velocity, but are significant, straightforward, and facilitate comparisons among the ridge vent types.

Analyses of variance using F-tests revealed that ridge vent type significantly affected outlet velocity for wind velocities ranging from 0 to 12.2 m per sec. The general equation predicting the variation in V_O/W_W for the four ridge vents studied is

$$\frac{V_o}{V_w} = a + b_1(k\Delta t/NLV_w{}^3) - b_2(\rho V_w L/\mu).$$

The symbols are defined by Dybwad et al. (1974). Analyses revealed highly significant linear relationships between Δt and V_W, indicating temperature difference decreases as wind velocity increases for all four ridge

TABLE 1. RELATIONSHIPS FOR PREDICTING π_1 (V_o/V_w) FROM k7 (kCt/NLVw3) AND π_{12} $(\rho V_w L/\mu)$.

Ridge vent type	Equation	R^2
Covered	$\pi_1 = 27(10)^{-2} + 36(10)^2\pi_7 - 83(10)^{-9}\pi_{12}$	70.1*
Baffled	$\pi_1 = 28(10)^{-2} + 50(10)^2\pi_7 - 67(10)^{-9}\pi_{12}$	84.3*
Open	$\pi_1 = 21(10)^{-2} + 72(10)^2\pi_7 - 39(10)^{-9}\pi_{12}$	55.0*
Overlapped	$\pi_1 = 21(10)^{-2} + 13(10)^2\pi_7 - 46(10)^{-9}\pi_{12}$	51.0*

*Significant at the 5 percent level.

TABLE 2. RELATIONSHIPS BETWEEN TEMPERATURE DIFFERENCE (Ct), F, AND WIND VELOCITY (Vw), M/sec, FOR THE FOUR RIDGE VENTS.

Ridge vent type	Equation	R^2
Covered	$\Delta t = 3.13 - 12(10)^{-2}V_w$	64.8**
Baffled	$\Delta t = 3.79 - 23.2(10)^{-2}V_w$	84.4**
Open	$\Delta t = 4.22 - 25.6(10)^{-2}V_w$	70.9**
Overlapped	$\Delta t = 4.0 - 31(10)^{-2}V_w$	79.0**

**Significant at the 1 percent level.

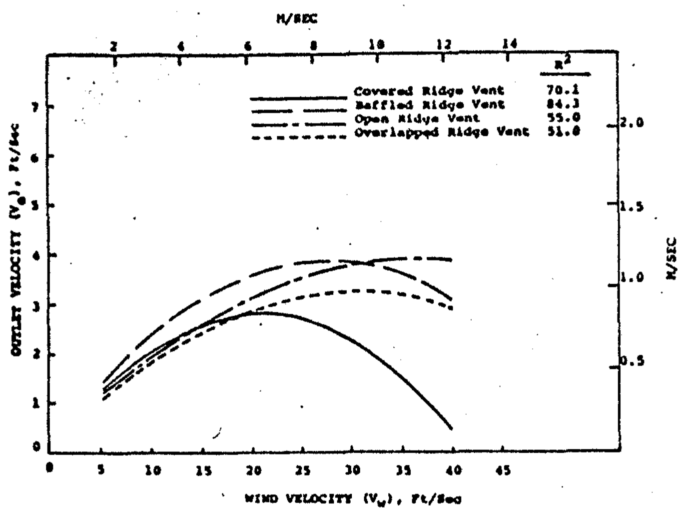

FIG. 2 Outlet velocity based on wind velocity and temperature difference.

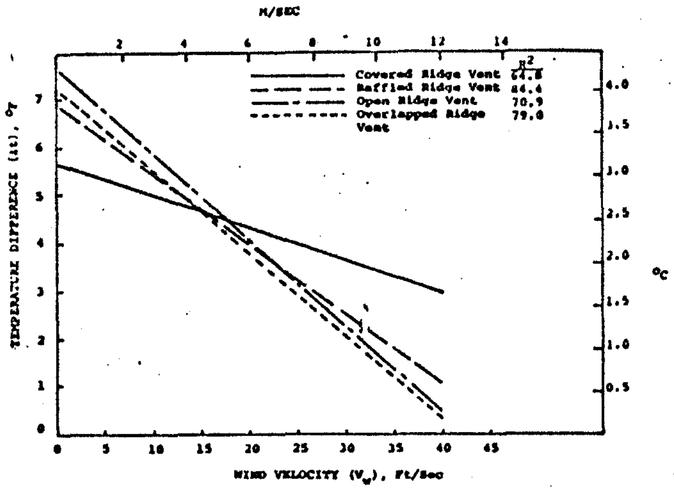

FIG. 3 Temperature difference as affected by wind velocity.

vents (Table 2). Coefficients of determination for the covered, baffled, open, and overlapped ridge vents were 64.8, 84.4, 70.9, and 79.0 percent, respectively.

After significant prediction equations for the relationship between V_O, Δt, and V_W and highly significant linear relationships between Δt and V_W were established, outlet velocity was computed using these relationships for the four ridge vents (Fig. 2). Out let velocities equal to 0.305, 0.305, 0.40, and 0.229 m/sec were measured for the covered, baffled, open, and overlapped ridge vents, respectively, at zero wind velocity. For wind velocities from 0 to 6.1 m/sec outlet velocities increased nearly linearly for all four ridge vents with little difference noted between the covered, open, and overlapped ridge vents (Fig. 2). For wind velocities 6.1 to 12.2 m/sec outlet velocity varied curvilinearly with wind velocity for all ridge, vents, and a considerable variation in outlet velocities was noted between the four ridge vents. Indications were that greater amounts of turbulence and correspondingly lesser amounts of flow occurred with the covered ridge vent. Therefore, as wind velocity increased above 6.1 m/sec, outlet velocity decreased. Similar but less pronounced results were noted with the baffled and overlapped ridge vents.

Assuming zero airflow through the open side of the model, comparisons were made between actual outlet velocity and an ideal outlet velocity (an airflow that would prevent condensation in the model). For the test trials on April 23, 1973, the dry bulb and wet bulb inside and outside temperatures for the covered, baffled, open, and overlapped ridge vents were 20, 12.2, 16.1, 10.0; 18.3, 11.1, 14.4, 8.3; 19.4, 12.2, 16.1, 10.0; and 18.9, 11.7, 15.0, 9.4 C, respectively. Using these temperature values and psychrometric relationships the calculated ideal outlet velocities, which would be sufficient to rid the internal environment of the model of 1.70 kg of water vapor per hour, were 0.40, 0.43, 0.43, and 0.46 m/sec, while the average actual (measured) outlet velocities were 0.40, 0.43, 0.37, and 0.37 m/sec for the covered, baffled, open, and overlapped ridge vents, respectively. The actual outlet velocities are slightly smaller than the ideal outlet velocities; however, during all tests condensation was never observed in the model, indicating airflow occurred through the open side of the model.

Ventilation distribution within the model building was studied at wind velocities of 0 and 4.6 m/sec for all four ridge vents using smoke candles. Observed airflow patterns were essentially the same for all four ridge vents with differences in outlet velocity as previously cited. At zero wind velocity (airflow influenced only by convective forces) the north eave inlet acts as an outlet and the estimated flow percentages through the ridge vent, eave vent, and open side were 65, 10 and 25 percent, respectively. When wind velocity equalled 4.6 m/sec there was more turbulence under the open ridge vent than under the baffled ridge vent. During all smoke tests the windward corners of the model remained stagnant and only slight airflow movements were noticed at cattle level.

Temperature Difference

Temperature difference decreased with increasing wind velocity for all ridge vents (Fig. 3) with similar responses evident for the baffled, open, and overlapped ridge vents. The least change in temperature difference over wind velocities ranging from 0 to 12.2 m/sec occurred with the covered ridge vent. Temperature differences for the covered, baffled, open, and overlapped ridge vents at zero wind velocity were 3.1, 3.1, 4.2, and 4.1 C; at a 4.6 m/sec wind velocity: 2.6, 2.6, 2.8 and 2.6 C; and at a wind velocity of 9.2 m/sec: 2.0, 1.4, 1.2, and 1.1 C, respectively. Ridge vent geometry significantly affected temperature difference for wind ranging from 0 to 12.2 m/sec.

Comparisons With Previous Study

Comparisons with a laboratory study by Dybwad (1972), who used a one-twentieth size model, were performed. Over the wind velocity range of 0 to approximately 6.1 m/sec in the one-twentieth size model, outlet velocity related linearly to wind velocity. This was also the case in the one-sixth size model. For wind velocities from 0 to 9.2 m/sec the open ridge vent had the highest outlet velocity in the one-twentieth size model, while in the one-sixth model the baffled ridge vent had the highest outlet velocity. The covered ridge vent had the least outlet velocity in the one-twentieth size model. In the one-sixth size model the least outlet velocity was found for the overlapped ridge vent for wind velocities from 0 to 4.6 m/sec and for the covered ridge vent for wind velocities from 4.6 to 12.2 m/sec. In both models temperature difference decreased with increasing wind velocity and ridge vent geometry had a significant effect on outlet velocity and temperature difference.

To analyze distortion, outlet veloc-

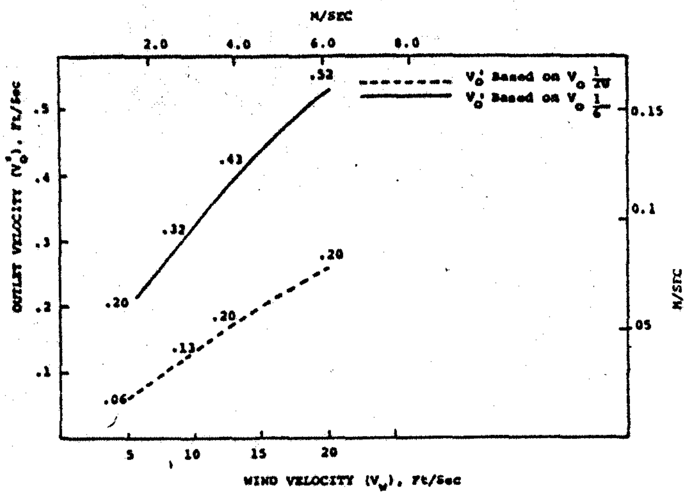

FIG. 4 Prototype outlet velocity predicted by 1/6th and 1/20th size models.

ities in the one-twentieth size and one-sixth size models were compared using the significant relationships developed in each test, the dependent variable (V_O/V_W), and Reynolds number ($\varrho V_W L/\mu$). Fig. 4 presents prototype outlet velocities calculated for the one-sixth and the one-twentieth size models plotted against wind velocity ranging from 1.52 to 6.1 m/sec. Distortion is present, since these two relationships do not predict the same prototype outlet velocity at corresponding wind velocities. The effects of distortion need to be further analyzed by applying the pi term functional relationships for the models to a prototype, as stated by Murphy (1950). However, the fact that distortion is present and has not been defined does not invalidate the results of this study.

CONCLUSIONS

The following conclusions were reached in this study:

1 Ridge vent design has a significant effect on outlet velocity.

2 The linear relationships developed between outlet velocity, wind velocity, $k\Delta t/NLV_3^3$, and Reynolds number reveal similar trends in outlet velocity through the open and overlapped and through the baffled and covered ridge vents.

3 The baffled ridge vent had the highest outlet velocity for wind velocities from 0 to 9.2 m/sec. For wind velocities from 9.2 to 12.1 m/sec the open ridge vent had the highest outlet velocity.

4 Ridge vent geometry has a significant effect on the difference between inside and outside temperature.

5 The linear relationships developed between temperature difference and wind velocity reveal similar trends for the open, baffled, and overlapped ridge vents.

6 Model studies of ventilation and temperature characteristics of open front beef buildings indicate a preference for the open and baffled ridge vents.

7 A comparison study between a one-twentieth size and a one-sixth size open front beef confinement model revealed distortion effects; however, pi term functional relationships should be studied on a prototype before any conclusive trends can be established.

References

1 Addison, J. N. 1972. Condensation in farm buildings. Agriculture 79(4):173-174.

2 Appleman, R. D. and F. G. Owen. 1970. Relationships of the environment, including nutrition to calf health: a review. ASAE Paper No. 70-355, ASAE, St. Joseph, Mich. 49085.

3 Brevik, T. J. 1971. Avoid condensation in free stall barns. Hoards Dairyman 116(19): 1066.

4 Dybwad, Ivar R. 1972. Similitude study of airflow characteristics for an open front beef barn. Unpublished M.S. Thesis, Agricultural Engineering Department. South Dakota State University, January.

5 Dybwad, Ivar R., Mylo A. Hellickson, Clarence E. Johnson and Dennis L. Moe. 1974. Ridge vent effects on model building characteristics. TRANSACTIONS of the ASAE 17(2): 366-370.

6 Froehlich, Donell P. 1973. Ridge vent influence on airflow characteristics in a model open front beef confinement building. Unpublished M.S. Thesis, Agricultural Engineering Department, South Dakota State University, December.

7 Haartsen, P. I. and L. Prinsen. 1968. Conclusions and suggestions on the insulation and ventilation of cubicle buildings for cattle. Rep. Instituut voor Landbouwbedrijfsgebouwen, Wageningen.

8 Hellickson, Mylo A., Harvey G. Young and William B. Witmer. 1973. Baffled center ceiling ventilation inlet. TRANSACTIONS of the ASAE 16(4):758-760.

9 Jedele, D. G. and F. W. Andrew. 1972. Slotted-floor cold-confinement beef-cattle housing. ASAE Paper No. 72-448, ASAE, St. Joseph, Mich. 49085.

10 Kelly, C. L. 1960. Effects of thermal environment on beef cattle. AGRICULTURAL ENGINEERING 41(9):613-614.

11 Midwest Plan Service. 1971. Publication No. TR-4, Midwest Plan Service, Agricultural Engineering Building, Iowa State University, Ames.

12 Mitchell, C. D. 1972. Open ridges for natural ventilation. Farm Building Progress 29(7):11-14.

13 Murphy, G. 1950. Similitude in engineering. The Ronald Press Company, New York, p. 185-196.

14 Theakston, F. H. and T. A. Underwood. A scientific approach to farmstead planning for environmental control. ASAE Paper No. 65-407, ASAE, St. Joseph, Mich. 49085.