C S A E S C G R
#6373
CANADIAN SOCIETY OF AGRICULTURAL ENGINEERING
SOCIÉTÉ CANADIENNE DE GÉNIE RURAL

Paper No. 92 - 216

DESIGN CRITERIA AND LEVELS OF SATISFACTION FOR NATURALLY VENTILATED LIVESTOCK BUILDINGS

Y. Choinière[1], J.A. Munroe[2],
A. S.-Tremblay[3], S. Tremblay[4]

[1]Unité des ressources d'ingénierie, Direction de gestion des ressources, Collège de technologie agricole et alimentaire d'Alfred, Alfred (Ontario) K0B 1A0.
[2]Centre for Food and Animal Research, Agriculture Canada, Ottawa (Ontario) K1A 0C6.
[3]Collège de technologie agricole et alimentaire d'Alfred, Alfred (Ontario) K0B 1A0.
[4]Département de génie rural, Collège de technologie agricole et alimentaire d'Alfred, Alfred (Ontario) K0B 1A0.

For presentation to the
CANADIAN SOCIETY OF AGRICULTURAL ENGINEERING
at the Agricultural Institute of Canada Annual Conference
July 5 - 9, 1992 - Brandon, Manitoba

ABSTRACT:

Three different criteria were used to evaluate the performance of naturally ventilated buildings as predicted by the NatVent software package. These criteria included the average proximal ventilation rate and the frequency of occurrences of 1h and 3h periods when the predicted ventilation rate was below the minimum recommended. Farmers are concerned with low ventilation rates due to low wind speeds as well as the lengths of time these low ventilation conditions persist. Knowledgeable experts were asked for their opinions regarding the expected performance (excellent, very good, good, fair, not recommended) of these same building designs. These opinions were correlated with predicted performance criteria to establish criteria levels that could subsequently be used in the software to evaluate other building designs according to the expected performance.

RÉSUMÉ

Le logiciel de conception pour les bâtiments agricoles ventilés naturellement "NatVent" utilise trois critères d'évaluation pour prédire le "Niveau de Satisfaction" que le producteur agricole obtiendra avec la ventilation naturelle durant l'été. Ces critères sont basés sur le taux moyen pondéré de ventilation et les fréquences de périodes de 1 et 3 heures consécutives où les taux de ventilation sont au-dessous du taux minimum de ventilation désiré. Les producteurs sont surtout concernés par les fréquences et durées des périodes de vitesses basses du vent causant de bas taux de ventilation. Plusieurs experts ont été consultés pour exprimer leurs opinions sur leur "Niveau de Satisfaction" (excellent, très bon, bon, acceptable et non recommandé) basées sur des bâtiments agricoles types. Leurs opinions ont été correlées pour établir une base utilisable par le logiciel "NatVent" pour prédire les "Niveaux de Satisfaction" que l'on pourra espérer pour de futurs bâtiments ventilés naturellement.

INTRODUCTION

Traditionally, the sizes of sidewall and ridge openings for naturally ventilated buildings were determined by trial and error. When a producer built the first naturally ventilated barn in a region, this barn became an experiment site for the distributors of natural ventilation equipment. Over a period of one or two summers, the distributor would receive comments from the producer on the ventilation performance and adequacy of the opening sizes. This information was then retained to be used to benefit future construction projects.

It is now feasible to use existing knowledge relating to the performance of naturally ventilated barns already built across Ontario and Québec to predict performance in other geographic areas.

To do this systematically, design criteria must be selected to evaluate the performance of naturally ventilated barns. The recently developed computer software, NatVent, uses such criteria to provide the user with expected Levels of Satisfaction for new building designs.

OBJECTIVES

In order to provide NatVent software users with an expected Level of Satisfaction for a design of a naturally ventilated building for any location across Canada, this study will:

1 - perform a Level of Satisfaction survey of agricultural producers and knowledgeable experts for various naturally ventilated buildings located in Ontario or Québec;

2 - calibrate the Natvent software;

3 - discuss the use of the obtained Level of Satisfaction for other types of livestock;

4 - discuss the applicability of the obtained Level of Satisfaction for other climatic regions across Canada.

It should be noted that all the above apply only to insulated buildings where solar gains are not considered as a factor. If solar gain is a factor, such as with an uninsulated building, then required ventilation openings would be larger.

SELECTION OF DESIGN CRITERIA

Choinière *et al.* (1989, 1990) demonstrated that naturally ventilated buildings should be designed based on with wind forces only. To check performance, Choinière (1989) and Zemanchik *et al.* (1991) suggested considering weather conditions where the outside temperature was equal to or greater than a basic temperature of 20°C. This temperature was selected for two reasons. The first was to limit the size of the historical weather data files used in the analysis and the second was to concentrate on warm weather when there is more of a concern for low ventilation rates due to low wind speeds.

Given the preceding, Zemanchik *et al.* (1991), Choinière *et al.* (1992) considered the following specific design criteria to help choose the best building orientation and size of ventilation openings:

1. maximize the average ventilation rate;
2. maximize the average proximal ventilation rate;
3. minimize the frequency of single hour events, the frequency of three consecutive hour events, and the longest continuous event; when ventilation rates are below the minimum recommended for summer;
4. maximize the rate of decay of the frequency distribution curve of consecutive hours below the minimum recommended summer ventilation rate.

Average Ventilation Rates

Using these criteria, both the average ventilation and average proximal ventilation rates are maximized; basically, the larger the number, the better the design.

Average Ventilation Rate

The average ventilation rate is calculated by summing the hourly ventilation rates predicted by NatVent for actual historical weather data, and dividing by the number of values included in the summation (Suchorski-Tremblay *et al.* (1991), Choinière *et al.* (1992)).

Figure 1 presents a schematic of the ventilation rate distribution curve with the average ventilation rate marked. For a successful building design and orientation, the average ventilation rate should be considerably greater than the minimum recommended summer ventilation rate. Zemanchik *et al.* (1991) reported predicted average ventilation rates between 1.8 and 2.0 air changes per minute for a typical finishing hog barn based on Ottawa weather.

Average Proximal Ventilation Rate

Most agricultural producers enjoy the high ventilation rates that coincide with high wind speeds. However, they are concerned about periods of low ventilation rates which occur more often with low wind speeds. The following is a description of the concept of average proximal ventilation rate, which optimizes the ventilation rates that occur below the minimum recommended summer ventilation rate.

When NatVent uses historical weather data, the predicted ventilation rates can be either less than, equal to, or greater than the minimum recommended summer ventilation rate. To calculate the average proximal ventilation rate, all predicted ventilation rates which are greater than the minimum recommended summer ventilation rate are reduced to the minimum recommended summer ventilation rate. This is done since in reality, surplus ventilation cannot be stored and used during periods of low wind speeds. The average of all ventilation rates, including the reduced rates, is now calculated.

By reducing high predicted ventilation rates down to the minimum recommended summer ventilation rate, the resultant average ventilation rate will be weighted downwards. The average proximal ventilation rate can approach, but not be greater than the minimum recommended summer ventilation rate. Figure 2 presents a schematic of a ventilation rate curve with the average proximal and minimum recommended summer ventilation rates shown.

NatVent selects the Preferred Building Orientation (Suchorski-Tremblay *et al.* (1991), Zemanchik *et al.* (1991) and Choinière *et al.* (1992)), giving preference to the highest average proximal ventilation rate. At the present time, it is recommended to use this criteria for design purposes.

Consecutive Hours Below the Minimum Recommended Summer Ventilation Rate Concept

Choinière (1989) introduced the concept of using the frequency of events occurring when the predicted ventilation rate is below the recommended ventilation rate for a given number of consecutive hours. This idea is based on the concern that the animals or plants within the building may possibly suffer from heat stress during periods of low ventilation. The goal is to find the building orientation which provides the least number of these low ventilation rate events during the many years of historical weather data. For a given building design and historical weather data set, NatVent analyzes the predicted hourly ventilation rates, using simple sorting and counting techniques. The frequency distribution of consecutive hours (1, 2, 3, etc.) when the predicted ventilation rates are less than a given minimum recommended summer ventilation rate can then be produced.

In this concept, each predicted ventilation rate below the minimum recommended summer ventilation rate is a single hour event. If the next hour's predicted ventilation rate is also below the recommended summer ventilation rate, it is also counted as a single hour event and the two together comprise a two consecutive hour event (hour1 + hour2). If a following hour's predicted ventilation rate is below the recommended summer ventilation rate, then it is also a single hour event. Together with the two previous hours, there is one three consecutive hour event (hour1 + hour2 + hour3) and two two consecutive hour events (hour1 + hour2, hour2 + hour3). If the fourth hour's predicted ventilation rate is equal to or greater than the recommended summer ventilation rate, the addition ceases. When the frequency of events of low ventilation rates are plotted against the event size (duration of events (single, two, three, etc.)), an exponentially declining type curve results (Choinière, 1989 and Zemanchik *et al.* (1991)). Such a curve is shown in Fig. 3.

From these data, building designers may emphasize the effect of the number of consecutive hours below the minimum recommended summer ventilation rate by selecting any of these design criteria: the frequency of single hour events, the frequency of three consecutive hour events, and the duration of maximum consecutive hours event.

<u>Frequency of Single Hour Events</u>

Consultations with experts and agricultural producers suggested that part of the design criteria should be the frequency of single hour events. Everyone consulted expressed their desire to minimize low ventilation rates.

<u>Frequency of Three Consecutive Hour Events</u>

This criteria provides an estimate of the possible discomfort felt by agricultural workers and animals remaining within the building during three consecutive hours. The three hour duration was suggested by local agricultural producers. They become concerned when the predicted ventilation rate remains low for that length of time. This also depends upon the temperature at which this occurs. However, the cut off value is arbitrary since there is no scientific literature available comparing the period of time of low ventilation and temperature with the growth or production performances of the animals.

The goal is to find the building orientation which provides the least number of these three consecutive hour low ventilation rate events during the many years of historical weather data.

Rate of Decay of the Frequency of Consecutive Hours Events

For each combination of building configuration, orientation angle, and weather station, Choinière (1989) and Zemanchik *et al.* (1991) attempted to use the natural logarithm of the consecutive number of hours curve and obtain a tentative "rate of decay" curve (Fig. 4) where the slope of the curve would indicate how fast the number of consecutive hours below the recommended ventilation rate would be reduced. However, subsequent work by Zemanchik *et al.* (1991) demonstrated that there was very little difference between the various tested building orientations. Consequently, this design criteria was eliminated.

Duration of Maximum Event

The work of Zemanchik *et al.* (1991) also demonstrated that there was very little difference among building orientations based on the maximum duration event. Consequently, this design criteria was not considered further.

METHOD AND PROCEDURE

Survey of Producers and Experts

During 1991, a survey was performed among agricultural producers already using naturally ventilated barns, as well as knowledgeable experts in the areas of natural ventilation equipment manufacturing and distributing. Also, Ontario Ministry of Agriculture and Food's extension engineers were consulted. From this survey, it has been possible to obtain a typical building design for new free stall and tie stall dairy barns, finishing hog barns, and broiler and turkey barns (see Table 1).

The producers were asked to give their opinion on their expected Level of Satisfaction of the various possible sidewall, end wall and ridge openings that could be installed on the same typical building. They had to tell if the Level of Satisfaction would be excellent, very good, good, fair or not recommended for the proposed openings. These are the definitions attached to the Level of Satisfaction:

Excellent	The operator is extremely satisfied; there is no need for additional openings, even during the hottest days of the summer.
Very Good	The operator is very satisfied; there are only a few days during the summer when the operator feels he needs additional openings.
Good	The operator is satisfied; however, the operator would like more air movement during the periods of low winds and suggests to use some supplemental circulation fans.
Fair	The operator expresses concerns about the hot summer days accompanied with low speed winds and a shortness of air movement; permanent circulation fans are strongly suggested.
Not Recommended	Most operators and experts dislike these types of barns.

The opinions of these people were averaged to provide the basis for the calibration of the NatVent software.

The proposed typical buildings with the various openings were then entered into NatVent to calculate the percentages associated with the expected Levels of Satisfaction. The weather data from the Ottawa International Airport was used for the simulation. The resultant percentages associated with the Levels of Satisfaction were plotted against the total opening area around the building used for ventilation. Finally, the survey results on the Level of Satisfaction were compared to the resultant percentages. As a result, different percentage ranges were established for each Level of Satisfaction and each typical barn tested.

Recommended Design Criteria Used in NatVent

With the present knowledge, experts recommended to use in NatVent (Choinière *et al.*, 1992) the following criteria:

Weight of proximal average ventilation rate	33⅓
Weight of frequency of single hour events	33⅓
Weight of frequency of three consecutive hour events	33⅓

The relative weights have been established arbitrarily based on the suggestions of the consulted agricultural producers and experts.

Weather data used were for Ottawa for outside temperatures equal to or above 20°C.

Calculation of the Level of Satisfaction for the Selected Design Criteria

The Level of Satisfaction for the three selected design criteria are calculated as follows:

$$\frac{\textit{Average Proximal Ventilation Rate}}{\textit{Recommended Summer Ventilation Rate}} \times 100 = A(\%) \qquad [1]$$

$$100 - \left(\frac{\textit{Number of Single Hour Events}}{\textit{Total Number of Hours}} \times 100\right) = S(\%) \qquad [2]$$

$$100 - \left(\frac{\textit{Number of 3 Consecutive Hour Events}}{\textit{Total number of Hours}} \times 100\right) = T(\%) \qquad [3]$$

The Level of Satisfaction is calculated by

$$\frac{A(\%) + S(\%) + T(\%)}{3} = \textit{LEVEL OF SATISFACTION} \qquad [4]$$

RESULTS AND DISCUSSION

Tables 2 to 6 present the combinations of ridge, sidewall and end wall opening types and sizes tested with the calculated Level of Satisfaction from NatVent and the experts' opinions for each combination. The total opening area around the building is also added. Figures 5 to 9 show the Level of Satisfaction versus the total opening area for each type of livestock investigated.

Generally, the results of Tables 2 to 6 and Figs. 5 to 9 show that an increase in the total opening area results in an increase in the Level of Satisfaction. When small total opening areas are used to begin with, the increase in the Level of Satisfaction is rapid as the opening area is enlarged. However, after the two highest ranges (Excellent and Very Good) are obtained, the curve plateaus, indicating that larger sidewall openings would increase the operators' Level of Satisfaction only slightly.

The selection of the ranges of percentages associated with the Levels of Satisfaction were based on comments from ventilation experts and agricultural producers. For calibrating the dairy free stall, the Excellent range was established to be between 88% and 100%. From Table 2, the RI-900-CL test (66.8 m^2 of openings) obtained 87.9%, while the CH-1050-CL test (71.6 m^2 of openings) obtained 88.2%. Since the former test was classified as Very Good and the latter as Excellent, the 88% value was simply taken as a compromise. All the other ranges were established following this procedure.

Consequently, the proposed ranges for the Levels of Satisfaction for different animal productions are established based on the best knowledge of the natural ventilation experts and agricultural producers today.

The lower limit for the excellent range varies among the different animal production types. The tie stall dairy barn has the highest lower limit at 93%, followed by the free stall dairy barn with 88%, turkey and broiler chicken barns at 84.5% and 84%, respectively, and finally swine barns with 80%. The producers' working time spent in each facility may be the main factor in this phenomenon. For example, dairy producers spend considerably more time in the barn as compared to a hog producer.

Table 7 presents the proposed Level of Satisfaction ranges for various production types. This table presents the five species tested as well as others where natural ventilation is used. Since it was not possible to collect data for all these types of production, some animals were associated with others based on the type of housing, summer ventilation rate requirements and the general perception of the experts. Again, a more precise calibration would be necessary in order to obtain percentage ranges for the Level of Satisfaction for each species.

Applicability to Other Climatic Areas across Canada

Levels of Satisfaction were obtained from a survey performed in Eastern and Southwestern Ontario and Western Québec. For these areas, the design dry bulb and wet bulb temperatures are equal to 30°-31°C and 23°-24°C, respectively (National Building Code Supplement, 1990). In order to secure the same Levels of Satisfaction for other locations across Canada, the NatVent user must verify that the local climate is similar or cooler than the one used to calibrate NatVent.

At this time, the proposed Levels of Satisfaction could be used with success for all climatic areas across Canada. Only some regions in Southwestern Ontario are known to have slightly higher temperatures.

SUMMARY AND CONCLUSION

A survey on the relative Levels of Satisfaction of agricultural producers and knowledgeable experts for naturally ventilated dairy tie and free stall barns, turkey and broiler chicken barns, and finishing hog barns was performed in Ontario and Western Québec. They were asked for their opinions regarding the expected performance of these same building designs (Excellent, Very Good, Good, Fair and Not Recommended).

These opinions were correlated with the predicted performance criteria to establish the proposed ranges of Levels of Satisfaction that could be used in the software, NatVent, to evaluate other building designs.

The proposed ranges were also applied to other types of animal production which were not part of the survey and initial calibration.

Finally, with the present state of knowledge, the proposed Levels of Satisfaction could be used with success for all climatic areas across Canada.

The proposed Levels of Satisfaction apply only to insulated barns where solar gain is not a factor.

RÉSUMÉ ET CONCLUSION

Une enquête a été effectuée avec plusieurs producteurs agricoles et experts reconnus en Ontario et au Québec. Les répondants devaient exprimer les niveaux de satisfaction espérés (excellent, très bon, bon, acceptable et non recommandable) pour plusieurs étables types pour la production laitière, porcine, de poulet de chair et dindons.

Les opinions furent correlées avec les performances prédites par le logiciel "NatVent" en fonction d'obtenir un moyen de proposer différents niveaux de satisfaction à espérer pour les bâtiments futurs. Les niveaux de satisfaction ainsi obtenus pour les espèces animales incluses dans l'enquête furent aussi étendus à d'autres espèces animales selon les besoins en ventilation.

Finalement, selon les connaissances actuelles, les présents niveaux de satisfaction proposés par "NatVent", peuvent être utilisés avec confiance au travers du Canada. Cependant, ces recommandations s'appliquent uniquement pour les bâtiments isolés où les gains d'énergie solaire sont négligeables.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge K. Boyd, P.Eng., Education and Research Fund, Ontario Ministry of Agriculture and Food, AgriCentre, Guelph, Ontario; C. Weil, P.Eng., Head of the Agricultural Engineering Department and M. Paulhus, P.Ag., Principal, Collège de technologie agriculture et alimentaire d'Alfred, Alfred Ontario; G. Garland, P.Eng., Head of the Engineering Resources Unit, J. Johnston, P.Eng., Manager, and V. Spencer, Director of the Resources Management Branch, Guelph, Ontario for their support and funding.

Special thanks are addressed to Dan Lambert, Sun-North Systems Ltd., Ontario; Wayne Blenkhorn, Faromor Inc., Ontario; Claude Paquet, C. Paquet Inc. Québec; Camille Moore, D.M.V., Québec; Jean-Pierre Frappier, Acton Construction Ltd., Québec; Gaétan

Gingras, M.A.P.A.Q., Québec; Franklin Kains, O.M.A.F., Ontario; Norm Bird, O.M.A.F., Ontario; and the numerous agricultural producers visited during this study.

The financial support provided by the Ontario Ministry of Agriculture and Food, Agriculture Canada, Ontario Hydro Technical Services and Development for Agriculture, the Canadian Electrical Association, the Ontario Pork Producers' Marketing Board, Sun-North Systems, Ltd., Faromor Inc., and IRAP, National Research Council were greatly appreciated.

REFERENCES

Choinière, Y. 1989. Natural ventilation of low-rise buildings by the wind; development of a model to predict average ventilation rates and the frequencies of consecutive hours below minimum limits of ventilation rate with summer meteorological data. Alfred College of Agriculture and Food Technology, P.O. Box 580, Alfred, Ont. K0B 1A0.

Choinière, Y., J.A. Munroe, O. Ménard and F. Blais. 1990. Thermostat location for a naturally ventilated swine barn. Can. Agric. Eng. **33**:169-177.

Choinière, Y., J.A. Munroe, G. Desmarais, H. Dubois and Y. Renson. 1989. Effect of different ridge opening widths on the thermal performance and ventilation rate of a naturally ventilated swine building during warm summer conditions. Paper No. 89-4065. Can. Soc. of Agric. Eng., Box 306, Sub Post Office #6, Saskatoon, Sask. S7N 0W0.

Choinière, Y., A. Suchorski-Tremblay and S. Tremblay. 1992. NatVent A Natural Ventilation Software Package for Livestock Buildings and Greenhouses. Version 1.01. Alfred College, P.O. Box 580, Alfred, Ontario, K0B 1A0.

Suchorski-Tremblay, A., Y. Choinière, J.A. Munroe, S. Tremblay, N. Zemanchik. 1991. Computer aided design software for naturally ventilated livestock buildings. CSAE Paper 91-228. Can. Soc. of Agric. Eng., Box 306, Sub Post Office #6, Saskatoon, Sask. S7N 0W0.

Zemanchik, N., Y. Choinière, A. Suchorski-Tremblay, J. Munroe and S. Barrington. 1991. Optimum building orientation for natural ventilation. CSAE Paper 91-214. Can. Soc. of Agric. Eng., Box 306, Sub Post Office #6, Saskatoon, Sask. S7N 0W0.

Supplement to the National Building Code of Canada. 1990. National Research Council of Canada. NRCC No. 30629, 259 pp.

Table 1. Typical naturally ventilated buildings used for the Levels of Satisfaction survey.

Production	Building			
	Length (m)	Width (m)	Sidewall (m)	Ridge, End Wall Openings
Dairy Free Stall, 100 cows	36.5	24.4	3	1. Chimney, 600 mm x 600 mm every 6 m 2. Continuous ridge, 200 mm wide 3. One 3.7 m x 3.7 m end door at each end
Dairy Tie Stall, 50 cows	36.5	12.2	3	1. Chimney, 600 mm x 600 mm every 6 m 2. Continuous ridge, 150 mm wide 3. One 2.1 m x 2.4 m end door at each end
Finishing Swine, 580 hogs	36.5	12.2	2.4	1. Chimney, 600 mm x 600 mm every 6 m 2. Continuous ridge, 200 mm wide 3. Two .9 m x 1.8 m end windows at each end
Broiler Chicken, single storey, 40,000 birds	122	21	2.7	1. Chimney, 600 mm x 600 mm every 4 m 2. Continuous ridge, 250 mm wide 3. One 3.6 m x 3.6 m end door at each end
Turkey, 8700 birds	122	23	2.7	1. Chimney, 600 mm x 600 mm every 4 m 2. Continuous ridge, 300 mm wide 3. One 3.6 m x 3.6 m end door at each end

Important Notice: All these buildings have wall and roof insulation of RSI 2.5 to 3.5.

Nomenclature and Abbreviations

Code	Description
CH	Chimney
RI	Continuous Ridge Opening
.6 x 2.1	Intermittent Sidewall Opening, 0.6 x 2.1 m, every 4 m
.9 x 2.1	Intermittent Sidewall Opening, 0.9 x 2.1 m, every 4 m
600	600 mm Continuous Sidewall Opening
675	675 mm Continuous Sidewall Opening
750	750 mm Continuous Sidewall Opening
900	900 mm Continuous Sidewall Opening
1050	1050 mm Continuous Sidewall Opening
1200	1200 mm Continuous Sidewall Opening
1350	1350 mm Continuous Sidewall Opening
1500	1500 mm Continuous Sidewall Opening
OP	Open End Wall
CL	Closed End Wall

Table 2. Dairy free stall calibration for Level of Satisfaction.

Description	Calculated Level of Satisfaction	Experts' Opinions	Total Area m²
CH-.9x2.1-CL	74.3	Not Recommended	41.3
CH-600-CL	75.1	Fair	41.9
RI-.9x2.1-CL	78.6	Good	46.3
RI-600-CL	78.7	Good	47.0
CH-750-CL	81.3	Good	51.8
RI-750-CL	83.9	Very Good	56.9
CH-900-CL	85.7	Very Good	61.7
RI-900-CL	87.9	Very Good	66.8
CH-.9x2.1-OP	86.5	Very Good	68.0
CH-600-OP	87.4	Very Good	68.6
CH-1050-CL	88.2	Excellent	71.6
RI-.9x2.1-OP	89.4	Excellent	73.1
RI-600-OP	89.4	Excellent	73.7
RI-1050-CL	90.1	Excellent	76.7
CH-750-OP	90.4	Excellent	78.5
RI-750-OP	91.6	Excellent	83.6
CH-900-OP	92.2	Excellent	88.4
RI-900-OP	92.4	Excellent	93.5
CH-1050-OP	92.5	Excellent	98.3
RI-1050-OP	93.7	Excellent	103.4

Grades	Proposed Ranges for Levels of Satisfaction
Excellent	88 to 100
Very Good	82 to 87.9
Good	78 to 81.9
Fair	75 to 77.9
Not Recommended	less than 75

Table 3. Dairy tie stall calibration for Level of Satisfaction.

Description	Calculated Level of Satisfaction	Experts' Opinions	Total Area m²
CH-.6x2.1-CL	83.7	Fair	28.3
RI-.6x2.1-CL	87.4	Good	33.4
CH-.6x2.1-OP	90.3	Very Good	38.7
CH-.9x2.1-CL	91.1	Very Good	41.3
CH-600-CL	91.0	Very Good	41.9
RI-.6x2.1-OP	91.7	Very Good	43.8
RI-.9x2.1-CL	92.6	Very Good	46.4
CH-675-CL	92.6	Very Good	46.8
RI-600-CL	92.7	Very Good	47.0
CH-.9x2.1-OP	93.5	Excellent	51.7
CH-750-CL	93.2	Excellent	51.8
RI-675-CL	93.3	Excellent	51.9
CH-600-OP	93.5	Excellent	52.3
RI-.9x2.1-OP	94.0	Excellent	56.8
RI-750-CL	93.8	Excellent	56.9
CH-675-OP	94.1	Excellent	57.2
RI-600-OP	94.1	Excellent	57.4
CH-900-CL	94.5	Excellent	61.7
CH-750-OP	94.3	Excellent	62.2
RI-675-OP	94.3	Excellent	62.3
RI-900-CL	95.1	Excellent	66.8
RI-750-OP	95.3	Excellent	67.3
CH-900-OP	95.3	Excellent	72.1
RI-900-OP	95.5	Excellent	77.2

Grades	Proposed Ranges for Levels of Satisfaction
Excellent	93 to 100
Very Good	90 to 92.9
Good	85 to 89.9
Fair	80 to 84.9
Not Recommended	less than 80

Table 4. Finishing hog calibration for Level of Satisfaction.

Description	Calculated Level of Satisfaction	Experts' Opinions	Total Area m^2
CH-600-CL	68.9	Fair	38.3
CH-.9x2.1-CL	71.3	Good	41.3
RI-600-CL	72.5	Good	42.1
CH-600-OP	75.2	Very Good	45.0
RI-.9x2.1-CL	75.3	Very Good	45.0
CH-750-CL	76.6	Very Good	47.3
CH-.9x2.1-OP	76.9	Very Good	47.9
RI-600-OP	77.7	Very Good	48.8
RI-750-CL	79.0	Very Good	51.1
RI-.9x2.1-OP	79.8	Very Good	51.7
CH-750-OP	80.2	Excellent	54.0
CH-900-CL	81.3	Excellent	56.3
RI-750-OP	83.1	Excellent	57.8
RI-900-CL	83.2	Excellent	60.1
CH-900-OP	83.9	Excellent	63.0
CH-1050-CL	84.8	Excellent	65.3
RI-900-OP	86.6	Excellent	66.8
RI-1050-CL	86.5	Excellent	69.1
CH-1050-OP	87.3	Excellent	72.0
RI-1050-OP	88.0	Excellent	75.8

Grades	Proposed Ranges for Levels of Satisfaction
Excellent	80 to 100
Very Good	75 to 79.9
Good	70 to 74.9
Fair	65 to 69.9
Not Recommended	less than 65

Table 5. Broiler chicken calibration for Level of Satisfaction.

Description	Calculated Level of Satisfaction	Experts' Opinions	Total Area m^2
CH-600-OP	64.5	Not Recommended	172.6
RI-600-OP	68.8	Not Recommended	188.9
CH-750-OP	72.6	Fair	206.0
RI-750-OP	75.2	Fair	222.3
CH-900-OP	78.0	Good	239.4
RI-900-OP	79.9	Good	255.7
CH-1050-OP	81.4	Very Good	272.8
RI-1050-OP	83.6	Very Good	289.1
CH-1200-OP	83.6	Very Good	306.2
RI-1200-OP	86.2	Excellent	322.5
CH-1350-OP	86.6	Excellent	339.6
RI-1350-OP	87.9	Excellent	355.8
CH-1500-OP	88.3	Excellent	373.0
RI-1500-OP	89.9	Excellent	389.2

Grades	Proposed Ranges for Levels of Satisfaction
Excellent	84 to 100
Very Good	80 to 83.9
Good	76 to 79.9
Fair	70 to 75.9
Not Recommended	less than 70

Table 6. Turkey calibration for Level of Satisfaction.

Description	Calculated Level of Satisfaction	Experts' Opinions	Total Area m²
CH-600-OP	61.7	Not Recommended	172.6
RI-600-OP	64.6	Not Recommended	194.6
CH-750-OP	69.7	Fair	206.0
RI-750-OP	73.6	Fair	228.0
CH-900-OP	75.4	Good	239.4
RI-900-OP	77.7	Good	261.4
CH-1050-OP	79.1	Good	272.8
RI-1050-OP	81.9	Very Good	294.8
CH-1200-OP	82.2	Very Good	306.2
RI-1200-OP	84.0	Very Good	328.2
CH-1350-OP	84.5	Excellent	339.6
CH-1500-CL	84.5	Excellent	346.3
RI-1350-OP	86.3	Excellent	361.5
RI-1500-CL	86.9	Excellent	368.2
CH-1500-OP	86.6	Excellent	373.0
RI-1500-OP	87.9	Excellent	394.9

Grades	Proposed Ranges for Levels of Satisfaction
Excellent	84.5 to 100
Very Good	80 to 84.4
Good	75 to 79.9
Fair	65 to 74.9
Not Recommended	less than 65

Table 7. Level of Satisfaction ranges for various production types.

Production Type	Excellent	Very Good	Good	Fair	Not Recommended
Dairy free stall Heifers Calves Beef Cattle Sheep or Goats	88.0	82.0	78.0	75.0	<75.0
Dairy tie stall Horses Single arch greenhouse	93.0	90.0	85.0	80.0	<80.0
Grower-finisher hogs Gestating sows	80.0	75.0	70.0	65.0	<65.0
Turkeys	84.5	80.0	75.0	65.0	<65.0
Broiler chickens	84.0	80.0	76.0	70.0	<70.0

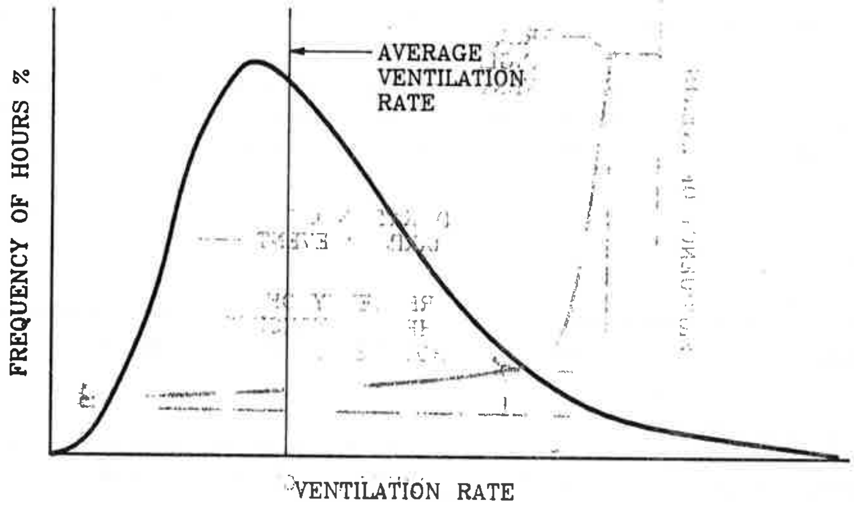

Figure 1. Schematic of a ventilation rate frequency distribution curve and the average ventilation rate.

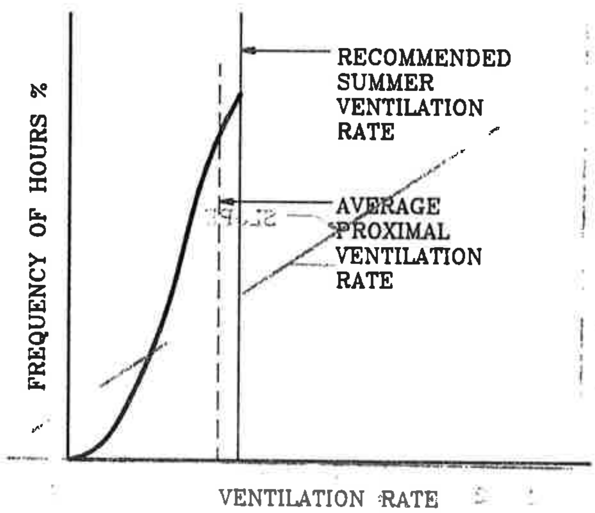

Figure 2. Schematic of an average proximal ventilation rate frequency distribution curve.

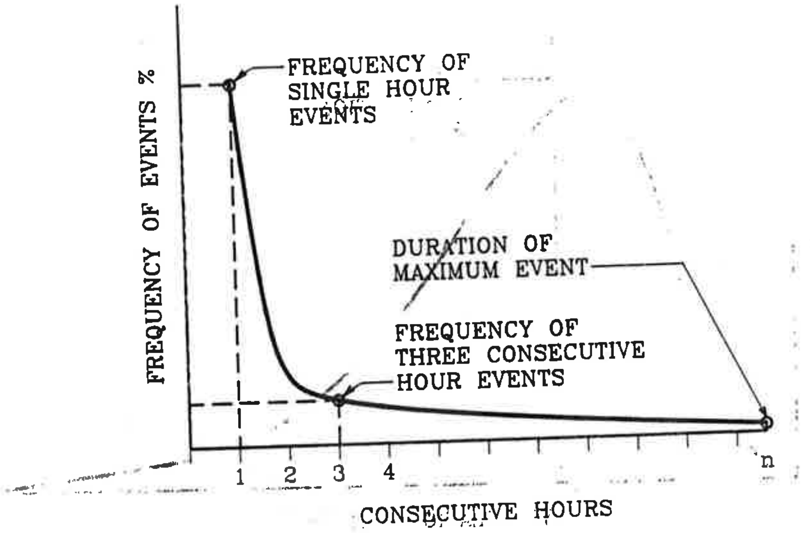

Figure 3. Schematic of the frequency of single hour events and the frequency of three consecutive hour events below the recommended summer ventilation rate and the duration of maximum event.

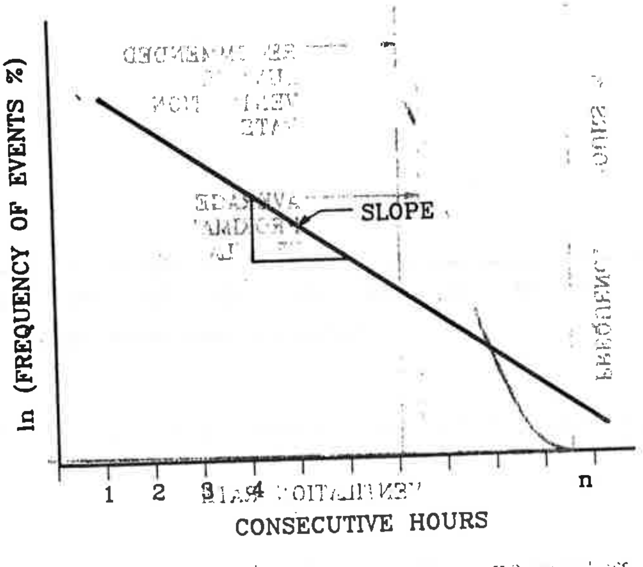

Figure 4. Schematic of the natural logarithm of the number of consecutive hours below the recommended ventilation rate.

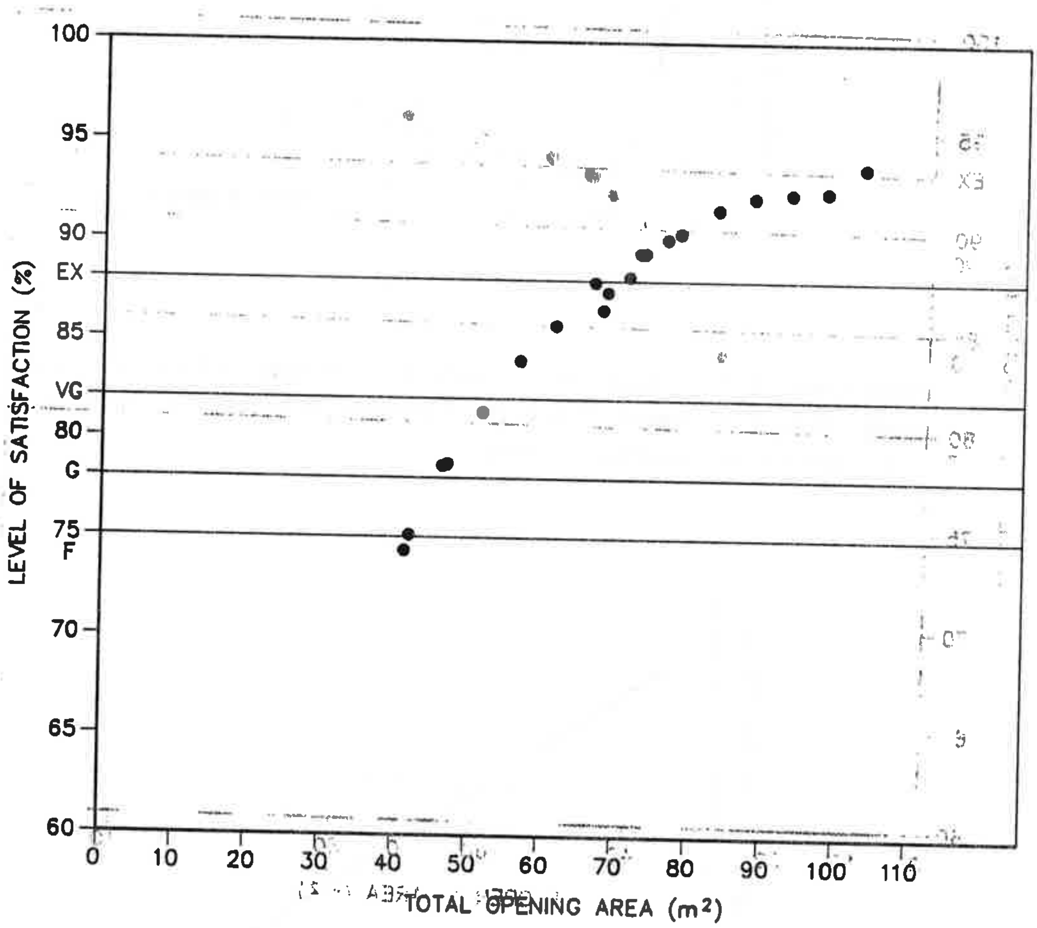

Figure 5. Dairy free stall: Levels of Satisfaction versus the Total Opening Area

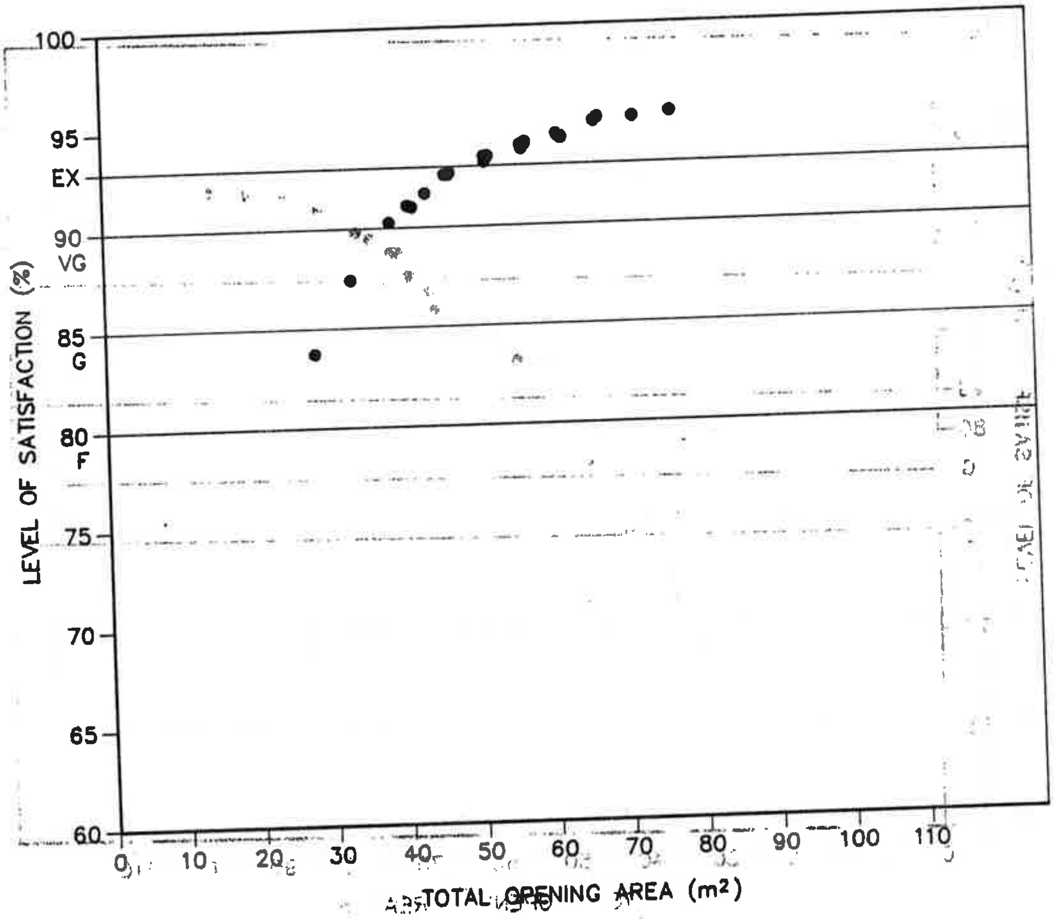

Figure 6. Dairy tie stall: Levels of Satisfaction versus the Total Opening Area.

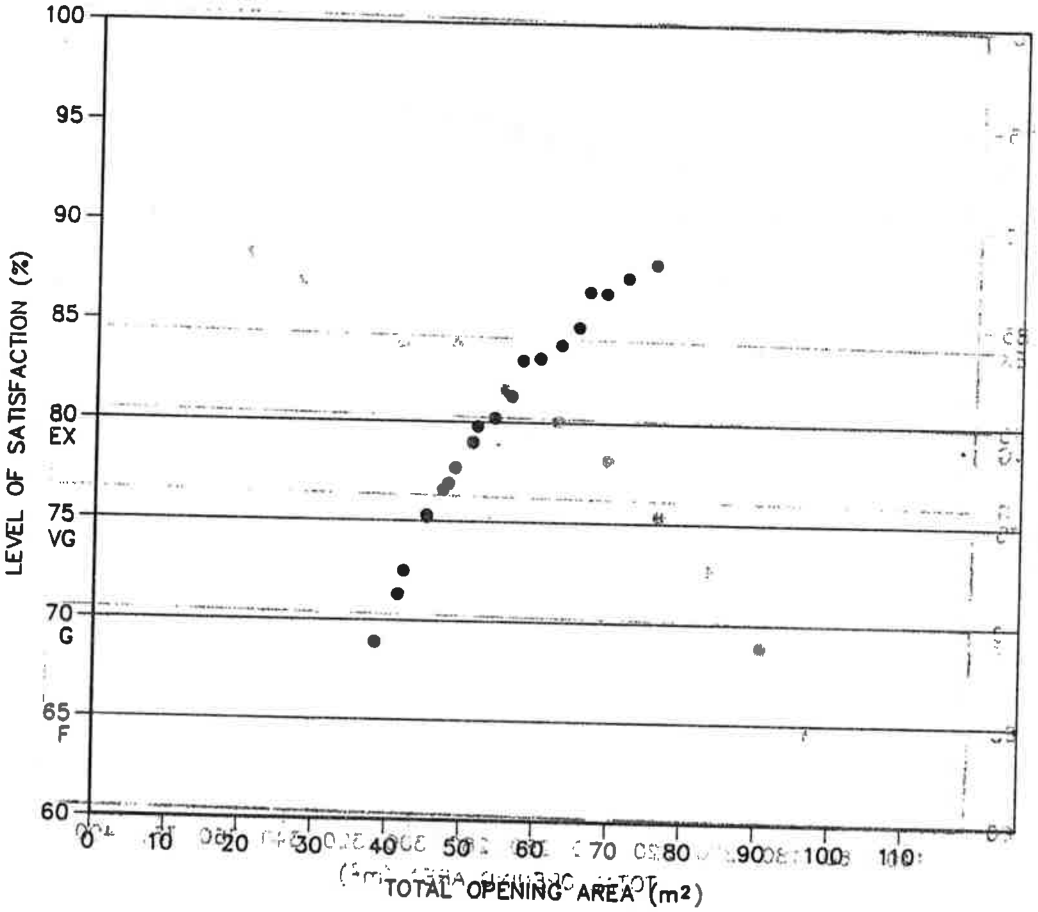

Figure 7. Finishing hogs' Levels of Satisfaction versus the Total Opening Area.

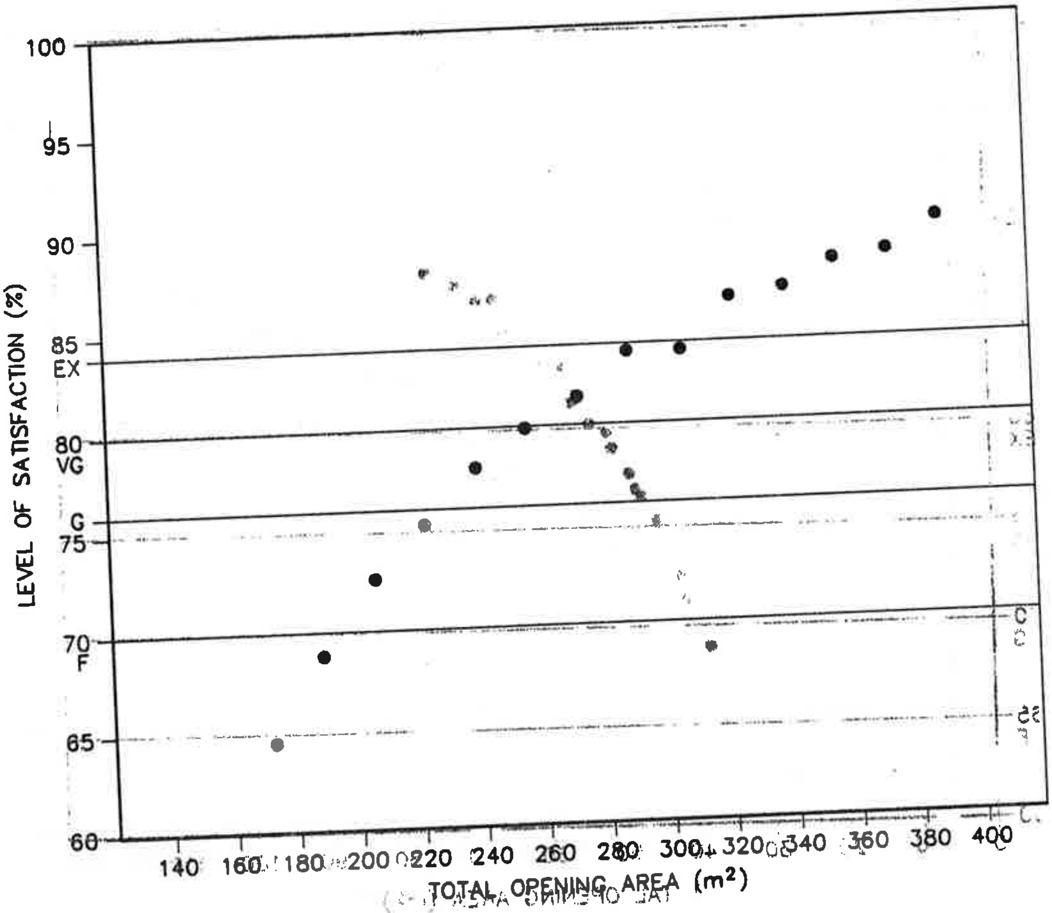

Figure 8. Broiler chickens Levels of Satisfaction versus the Total Opening Area.

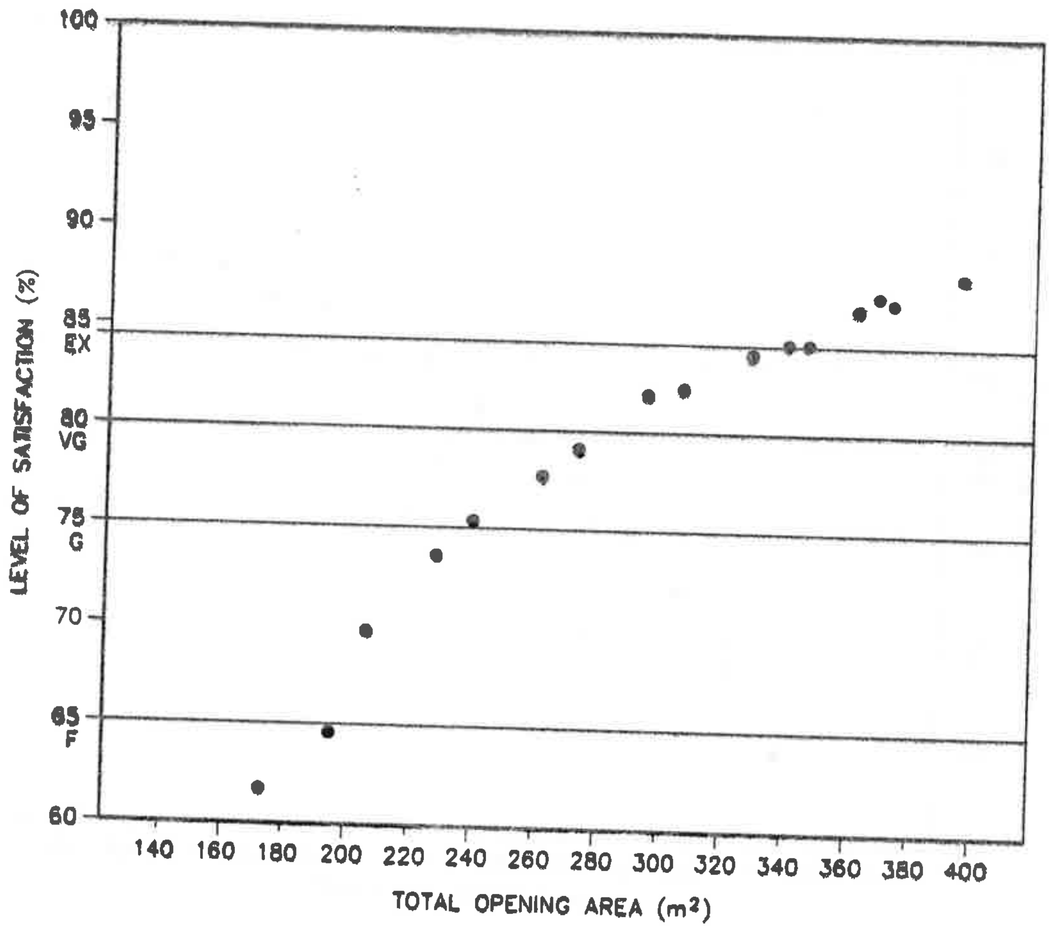

Figure 9. Turkeys: Levels of Satisfaction versus the Total Opening Area.