Mechanical Ventilation Design Worksheet for Swine Housing

Livestock Industry Facilities & Environment

This worksheet is intended to guide you through a simplified procedure for selecting the components of a ventilation system. It will help you decide on fans and inlets needed and how to set controls to create a prescribed environment. Ventilation design is an important factor in ensuring the health and superior productivity of your animals, as well as the health of workers, and should not be taken lightly. It also is important because of the large potential for wasted energy in a poorly designed facility. For a complete systems design beyond this simplified approach, seek guidance from an agricultural engineer.

Step 1. Determine the minimum ventilation rate (W)

The minimum ventilation rate, represented by **W**, is the rate used during cold weather to maintain air quality and humidity within the building while minimizing the loss of heat. Use the recommended ventilation rates (see Table 1) to determine the amount of air exchange required to maintain good air quality. To calculate the minimum ventilation rate, the number and size of animals in the ventilated space must be known. Multiply the number of animals by the cold weather rate, expressed in cubic feet of air per minute or cfm.

Minimum ventilation rate formula (W):

(W) = ______ No. of animals x ______ cold weather rate (cfm/animal) = ___________ cfm

Example 1.
What is the minimum ventilation rate for a farrowing house (22' by 66') that contains 24 farrowing crates?

(W) = 24 animals x 20 cfm/animal = 480 cfm

Table 1. Recommended Ventilation Rates*

Housing	Weight	Cold Weather Rate cfm/unit	Hot Weather Rate cfm/unit
Sow and Litter	400	20	500
Nursery Pigs	12-30	2	25
	30-75	3	35
Finishing Pigs	75-150	7	75
	150-250	10	120
Gestating Sows	325	12	150
Boars & Breeding Sows	400	14	300

*From MWPS-8 “Swine Housing and Equipment Handbook,” MidWest Plan Service, Ames, Iowa.

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Step 2. Determine the maximum ventilation rate (S)

The maximum ventilation, represented by **S**, is the highest practical rate for hot weather conditions. Once the outdoor temperature exceeds the target indoor temperature, the best that the ventilation system can do is to move enough air to maintain indoor conditions only a few degrees warmer than the outside conditions. This is calculated using a similar procedure as in step 1. Multiple the number of animals by the recommended hot weather rate from Table 1.

Maximum ventilation rate formula (S):

(S) = _____ No. of animals x _____ hot weather rate (cfm/animal) = __________ cfm

Example 2.
What is the maximum ventilation rate for the same farrowing house in Example 1?

(S) = 24 animals x 500 cfm/ animal = 12,000 cfm

Step 3. Determine two intermediate ventilation stages (I1 and I2)

In most mechanical ventilation systems there should be at least 4 ventilation stages: one based on the cold weather rate, one based on the hot weather rate and 2 stages between these stages. In practice, the number of stages will depend on the total span of the ventilation rates and the availability of appropriate fans. It is generally better to start with smaller fans to prevent constant fluctuations in temperature due to large changes in ventilation rate during cold weather. Usage of more than four stages is often used in systems in which many animals are housed in one room. Calculation of these fan stages would be done in a similar manner.

Intermediate ventilation rate formula (I1) :

$$\textbf{(I1)} = \frac{(S) - (W)}{(\_\_\_\_ \text{ no. of stages} + 2)} + (W)$$

Intermediate ventilation rate formula (I2) :

$$\textbf{(I2)} = \frac{2 \times \{(S) - (W)\}}{(\_\_\_\_ \text{ no. of stages} + 2)} + (I1)$$

Example 3
What would be two intermediate stage ventilation rate based on the information in examples 1 and 2?

$$\textbf{(I1)} = \frac{(12{,}000 \text{ cfm} - 480 \text{ cfm})}{(4 \text{ stages} + 2)} + 480 \text{ cfm} = 2400 \text{ cfm}$$

Intermediate ventilation rate formula (I2) :

$$\textbf{(I2)} = \frac{2 \times (12{,}000 \text{ cfm} - 480 \text{ cfm})}{(4 \text{ stages} + 2)} + 2400 \text{ cfm} = 6240 \text{ cfm}$$

Step 4. Determine the fan capacity needed for each ventilation stage

Once the ventilation stages are determined, the fans that provide the proper rate at each stage should be selected. Fans that are available from manufacturers will likely not deliver the exact rate needed so stages may need to be adjusted. Calculate the fan size needed at each stage (see below). The first stage (W) will be provided with a continuously running fan. Using static pressure ratings of 0.125 or 0.1 inches of water is recommended for selecting winter fans (stages W and I1). Static pressure ratings of 0.05 to 0.08 inches of water may be used for summer fans (stages I2 and S). In some applications the minimum ventilation rate is less than the smallest fan that is available and may be attained using a variable speed controller.

Fan test data is examined to find fans that are available that meet the calculated size requirement. Fan test data is available from the Air Movement and Conditioning Association (AMCA) or from the Bioenvironmental and Structural Systems Laboratory (BESS) at the University of Illinois (IL-99).

For more information on fans, see "Choosing Fans for Livestock and Poultry Ventilation," Pm-1587.

Minimum Ventilation Fan = **(W)** cfm

2nd Fan = **(I1)** - **(W)** = ________ cfm

3rd Fan = **(I2)** - **(I1)** = ________ cfm

4th Fan = **(S)** - **(I2)** = ________ cfm

Example 4.
Using the calculated ventilation stages from the previous example, what are the approximate fan sizes needed for each stage?

Minimum Ventilation Fan = 480 cfm

2nd Fan = 2400 cfm - 480 cfm = 1920 cfm

3rd Fan = 6240 cfm - 2400 cfm = 3840 cfm

4th Fan = 12,000 cfm - 6240 cfm = 5760 cfm

An 8" fan was found to deliver 521 cfm at 0.1 inches of water. This will be selected as our continuously running minimum ventilation fan. Likewise, a 16" fan was found to deliver

1950 cfm at 0.1 inches of water. An 18" fan had a rating of 3720 cfm at 0.05 inches of water. A lower pressure rating is used here because it will be a summer fan. This means with three stages, 6191 cfm will be provided. To complete our system we will look for a fan to deliver approximately 5809 cfm (12,000 minus 6191). A 24" fan is found that will provide 5900 cfm at 0.05 inches of water. To summarize, the actual fan stages appear below.

Table 2. Actual fan stages for the example.[1]

Stage	Model	Rated CFM[2]	Stage CFM
Continuous	8" fan Model V	521	521
2nd	16" fan Model X	1950	2471
3rd	18" fan Model Y	3720	6191
4th	24" fan Model Z	5900	12,091

[1] Actual fan test data with model number removed comes from Agricultural Ventilation Fans, Perfomance and Efficiencies. 1997 University of Illinois. Available through MidWest Plan Service.
[2] The continuous and 2nd stage fan are chosen using 0.10 inches of water and the 3rd and 4th stages use 0.05 inches of water.

Step 5. Determine the size and type of inlet

Inlets can be made with continuous slot inlets or commercially available, self-adjusting inlets. These two cases will be handled separately.

Continuous Slot Inlets

Continuous slot inlets, Figure 1, are used to bring fresh air into the room through inlets that are mounted in the ceiling next to the sidewall. Generally these types of buildings will have hinged flap doors over the eave openings that are closed during the winter in order to bring tempered air in through the attic. During summer, these same doors are opened to allow cooler air to enter the room rather than hot attic air. Inlets are adjusted by hand to different season conditions and are used on one side for buildings 25' wide or narrower and on both sides for buildings 25 to 40' wide. Wider buildings use additional center-ceiling inlets. The inlet baffle adjustment is sized such that air will enter at a speed of 800 feet per minute. This will cause the air to be thrown further into the building and cause proper air mixing. The throat of the inlet should be sized at least big enough to accommodate the hot weather ventilation rate. Continuous inlets should be discontinued within 5 feet of sidewall fans. The formulas below are used to size the inlets based on the desired air velocity of 800 feet per minute (fpm).

Inlet area openings at each ventilation stage **(A_x)**

Ventilation rate at stage X / 800 fpm =______ sq feet

Width of the inlet opening **(I_x)**:

$$\frac{A_x \text{ (sq feet)}}{\text{Total Length of Continuous Inlet (ft)}} \times 12 \text{ in/ft} = \text{width of continuous inlet (in)}$$

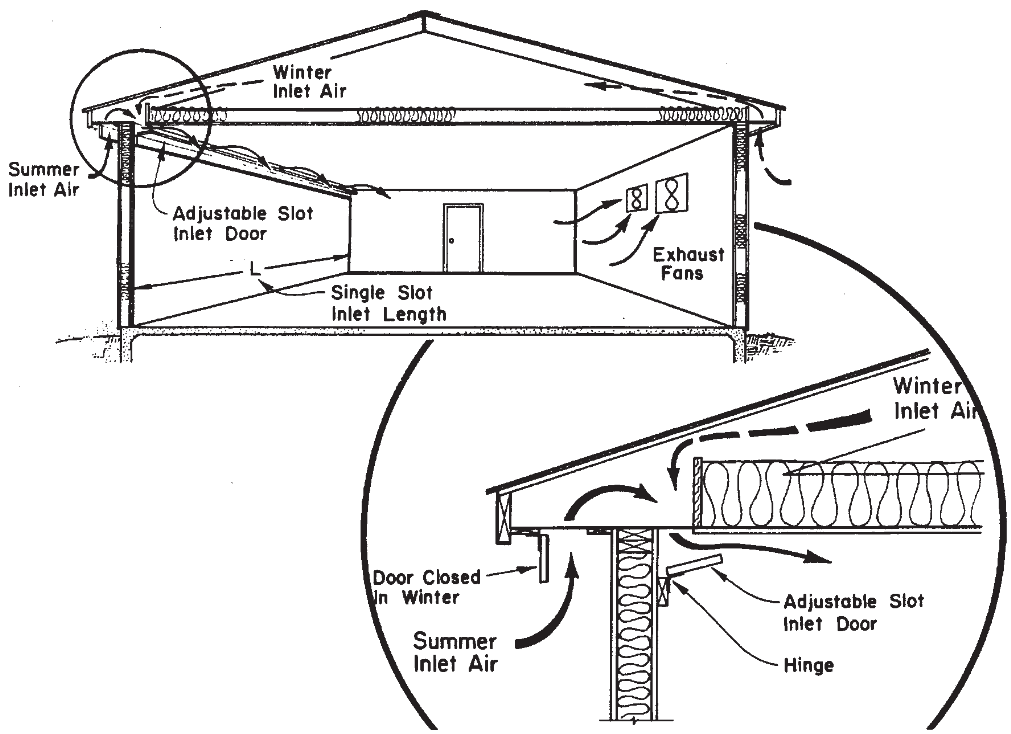


Figure 1. A Continuous Slot Eave Inlet.

Example 5A.
In the farrowing house example, the building was 66 feet long. Because it is a relatively narrow building (narrower than 25 feet), only one eave will have a continuous slotted eave inlet and the opposite sidewall will have the fans mounted in it. For this example, there is 66 feet of sidewall inlet. Use ventilation stage rates found in Example 4 to calculate inlet opening size.

Minimum ventilation opening

(A_1) = 521cfm / 800 fpm = <u>0.65</u> sq feet

(I_1) = 0.65 sq feet / 66 ft x 12 in/ft = <u>0.12 in</u> opening

Stage 2

(A_2) = 2471 cfm / 800 fpm = <u>3.1</u> sq feet

(I_2) = 3.1 sq feet / 66 ft x 12 in/ft = <u>0.56 in</u> opening

Stage 3

(A_3) = 6191 cfm/ 800 fpm = <u>7.7</u> sq feet

(I_3) = 7.7 sq feet / 66 ft x 12 in/ft = <u>1.4 in</u> opening

Stage 4

(A_4) = 12,091 cfm / 800 fpm = <u>15.1</u> sq feet

(I_4) = 15.1 sq feet / 66 ft x 12 in/ft = <u>2.8 in</u> opening

The opening in the ceiling for this inlet should be larger than the largest opening (2.8 inches). This opening in the ceiling would probably be at least 4 inches wide (see Figure 1) and the hinged baffle door would be used to set the actual opening.

As can be seen in Example 5A, winter ventilation rates require a small opening to create the proper air velocity. When using a continuous slot inlet this is hard to manage because the hinged baffle boards tend to warp, creating gaps that are bigger and smaller than desired. This will cause drafts in some places and stagnant air in others. An alternative is the use of commercially available, self-adjusting inlets.

Commercial Self-Adjusting Inlets
Commercially available inlets, Figures 2 & 3, generally come with a rating of maximum airflow delivery. Typical maximum ratings for inlets are 600 cfm, 800 cfm, and 1200 cfm but others are available. Models are constructed that send air in one direction, two directions, or four directions. Unlike fan ratings, they do not come from an independent laboratory but are set by the company that manufactures them. These inlets are usually spaced out in order to provide a good distribution of air. At the winter ventilation rate there are generally too many inlets to maintain proper air velocity and, therefore, good air mixing. Most inlets are capable of being closed so a typical strategy is to close off every other inlet until higher ventilation rates are needed. Inlets will adjust to changing static pressure, i.e. more fans being used, but they should be seasonally adjusted to maintain proper air velocity.

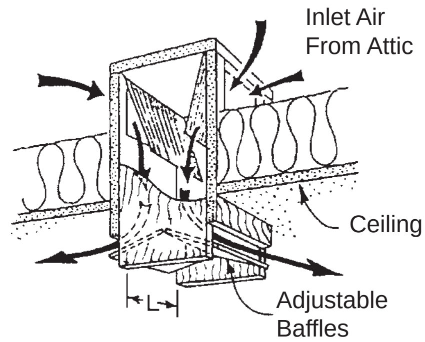


Figure 2. Two Sided Ceiling Inlet.

In some cases the number of inlets should be chosen based on distribution needs rather than rate. Locate inlets so they are no more than 10 to 12 feet apart in the direction that they do not deliver air. Locate inlets so they are no more than 25 to 30 feet apart in the direction that they deliver air.

Example 5B.
In the farrowing house example, the building was 66 feet long and had 2 rows of 12 crates of sows. Using two sided commercial ceiling inlets, determine the size, number and placement of the inlets. Use ventilation stage rates found in Example 4.

In the case of our example, 12,091 cfm is the designed maximum fan capacity. This means that 10-1200 cfm inlets are required (one every 6 feet). However, because there are 12 crates in a row, it will distribute the air better if each pair of crates that are across that alley from one another have one inlet. Therefore, we would chose to use 12-1200 cfm bi-directional inlets over the center alley, one every five feet. In winter, every other inlet would be closed to force more air through the open inlets. This would promote a better air jet across the ceiling and, therefore, better mixing. Inlets should be adjusted so that they deliver a jet of air at 800 cfm during any conditions. During summer conditions, the mixing of air is not as important as it is in winter. Inlets may be adjusted so that they channel air at an angle that may strike sows on the back. This is a good method to promote sow cooling as long as it does not chill the piglets in a draft.

Step 6. Determine the required attic opening

When using ceiling inlets, openings that allow air from the outside into the attic often are overlooked. If these openings are too small, they will restrict the entrance of air into the attic and not allow inlets to properly regulate airflow. To prevent restricted airflow, one square foot of opening should be allowed for every 400 cfm. This opening should be big enough to accommodate hot weather ventilation rates. A portion of the openings may be closed during winter.

Attic Opening Formula (AO):

$$\textbf{(AO)} = \frac{\text{Air flow rate (cfm)}}{\text{400 cfm per square feet}} = \_\_\_\_\_\_ \text{ square feet of attic opening}$$

Example 6.

For the farrowing house in the previous examples, how large should the attic opening be to prevent constricting airflow to the ceiling inlets during winter and summer?

The opening to the attic should be calculated using the maximum ventilation rate for summer, the 4th stage in this case, and the 2nd stage for winter ventilation. The minimum rate should not be used to size the attic openings because during the winter the 2nd stage will run on occasion. Sizing the attic openings using the 2nd stage will prevent restricting air flow when the 2nd stage fans run during winter.

Winter

$(\mathbf{AO})_{\mathbf{w}}$ =2471 cfm / 400 cfm = 6.2 square feet of attic opening

Summer

$(\mathbf{AO})_{\mathbf{s}}$ =12,091 cfm/ 400 cfm = 30.2 square feet of attic opening

The opening into the attic should be more than 30 square feet during the summer. This area may be provided through gable louvers, eave vents, or ridge vents. Square footage should be based on the areas of the actual openings and not the overall louver size. If small openings are used, the actual useable opening is only 66 percent of the openings. During winter, only 6.2 square feet should be provided so the north-side openings may be closed to prevent snow from drifting into the attic. This is based on the needs for the 2nd stage to prevent choking of the system during intermittent weather.

Step 7. Determine thermostat settings

Thermostats should be set so that no fan stage operates except the minimum ventilation rate while the furnace is on. Temperatures should be set at a comfortable level for pigs. Use "Thermal Environmental Guidelines for Swine," ISU Extension publication Pm-1586 for the initial settings. Watch pigs to determine their comfort level and make appropriate adjustments as needed. Other stages should be set 3 to 5 degrees apart, depending on the precision of the controller.

Example 7.

Assume that we are trying to maintain 68°F in the farrowing house while using heat lamps to maintain the microenvironment for the piglets. What should the thermostat settings be for the ventilation and heating stages?

The ventilation stages would be as follows:

Stage	Capacity	Total Capacity	Thermostat Setting
Continuous Fan	521 cfm	521 cfm	on continuously
Heaters	3000 Btu/hr-sow*	72,000 Btu/hr	on at 65 °F
2nd Stage	1950 cfm	2471 cfm	on at 71 °F
3rd Stage	3720 cfm	6191 cfm	on at 74 °F
4th Stage	5900 cfm	12,091 cfm	on at 77 °F

* Heating capacity needed may be found in MWPS-8, "Swine Housing Handbook." Recommendations are 3000 Btu/hr-sow for farrowing, 350 Btu/hr-pig for nursery, 600 Btu/hr-pig for finishing, 1000 Btu/hr-animal for breeding/gestation.

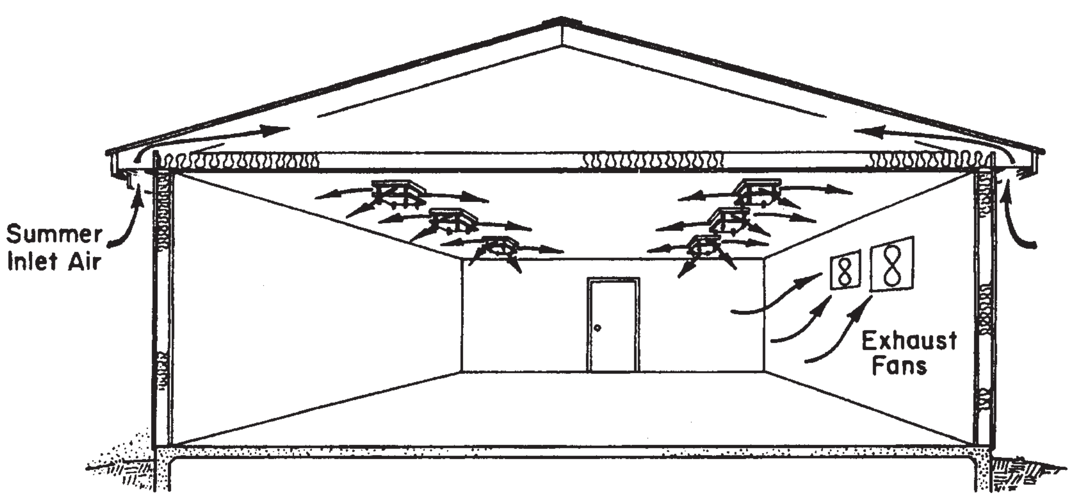
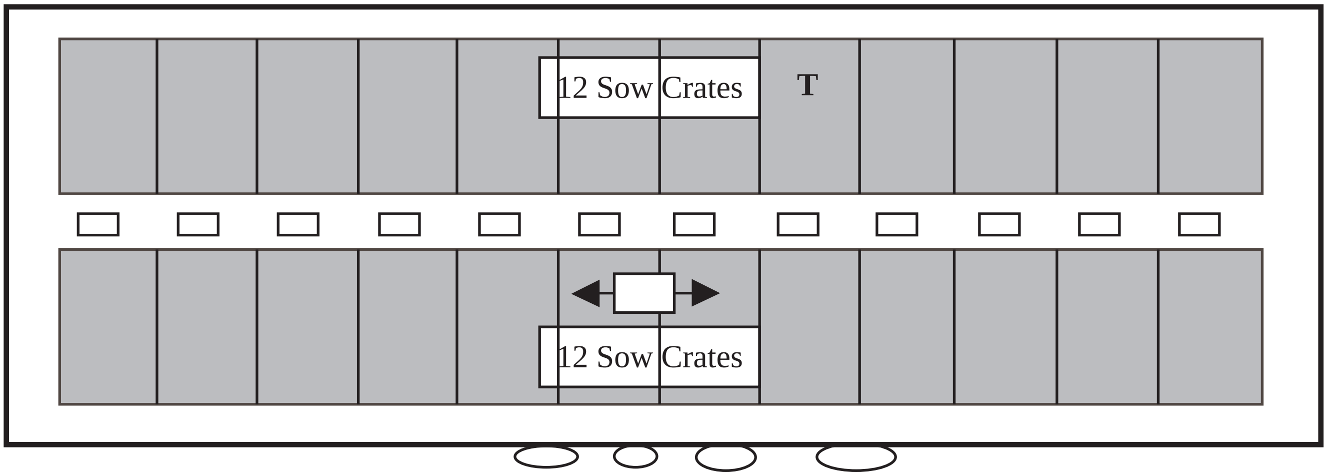


Figure 3. A system using commercial ceiling inlets.

Step 8. Sketch the System

Sketch the ventilation system including fans, inlets, heaters, and thermostat locations.



1200 cfm inlets (12)

Fans 1 through 4

T Thermostat

Heater

Summary

This method of designing a mechanical ventilation system uses general rules to design a simple system. It summarizes some of the critical aspects of good ventilation design in order to help you improve your knowledge of ventilation systems. This should be helpful in working with building and equipment contractors, in operating the ventilation system, and in troubleshooting the ventilation system.

Design is critical to a well-functioning system. Without proper matching of fans, inlets, and controllers the ventilation system will not create a proper environment, which can affect pig health and productivity, worker health, and energy costs. Proper design is critical and should not be taken lightly. Do not hesitate to seek guidance from agricultural engineers to make sure your system operates properly for years to come.

Figures 1, 2, and 3 are from “Ventilation Worksheet for Dairy and Swine Buildings” by Brian J. Holmes, University of Wisconsin Extension, Madison, WI.

Other resources available from Iowa State University Extension include Pm-1587, “Choosing Fans for Livestock and Poultry Ventilation,” Pm-1586, “Thermal Environmental Guidelines for Swine Housing,” and IL-99, “Agricultural Ventilation Fans Perfomance and Efficiencies” ($8).

Mechanical Ventilation Worksheet

Project Title Example Farrowing House
Date December 1998

Stage Rates

Min.Vent. Rate **(W)**: 24 Animals x 20 cfm/animal = 480 cfm
Max. Vent.Rate **(S)**: 24 Animals x 500 cfm/animal = 12,000 cfm

Intermediate Stage 1 **(I1)** = $\frac{\{12{,}000 - 480\}}{(4 \text{ stages} + 2)} + 480 = 2{,}400$ cfm

Intermediate Stage 2 **(I2)** = $\frac{2 \times \{12{,}000 - 480\}}{(4 \text{ stages} + 2)} + 2{,}400 = 6{,}240$ cfm

Ideal Fan Capacities				**Actual Fan Capacities**
Continuous Fan	= 480	= 480	cfm	521 cfm
2nd Fan	= 2400 - 480	= 1,920	cfm	1,950 cfm
3rd Fan	= 6240 - 2400	= 3,840	cfm	3,720 cfm
4th Fan	= 12,000 - 6240	= 5,760	cfm	5,900 cfm

Actual Fan Stages

Continuous Fan = 521 cfm

Stage 2 = Continuous + 2nd Fan = 521 + 1950 = 2,471 cfm

Stage 3 = Stage 2 + 3rd Fan = 2,471 + 3720 = 6,191 cfm

Stage 4 = Stage 3 + 4th Fan = 6191 + 5900 = 12,091 cfm

Needed Continuous Eave Inlet Area

	Continuous Fan	Stage 2	Stage 3	Stage 4
Actual Fan Stage (cfm)	521	2,471	6,191	12,091
	Divided by 800	Divided by 800	Divided by 800	Divided by 800
Opening (ft^2)	0.65	3.1	7.7	15.1
	Divided by inlet length (66 ft)	Divided by inlet length (66 ft)	Divided by inlet length (66 ft)	Divided by inlet length (66 ft)
	times 12	times 12	times 12	times 12
Inlet Opening (in)	0.12 in	0.56 in	1.4 in	2.8 in

or **Commercial inlets** = Maximum Rate ÷ Rated Capacity = 12,091 cfm ÷ 1200 cfm/inlet = 10 inlets

Needed Attic Opening

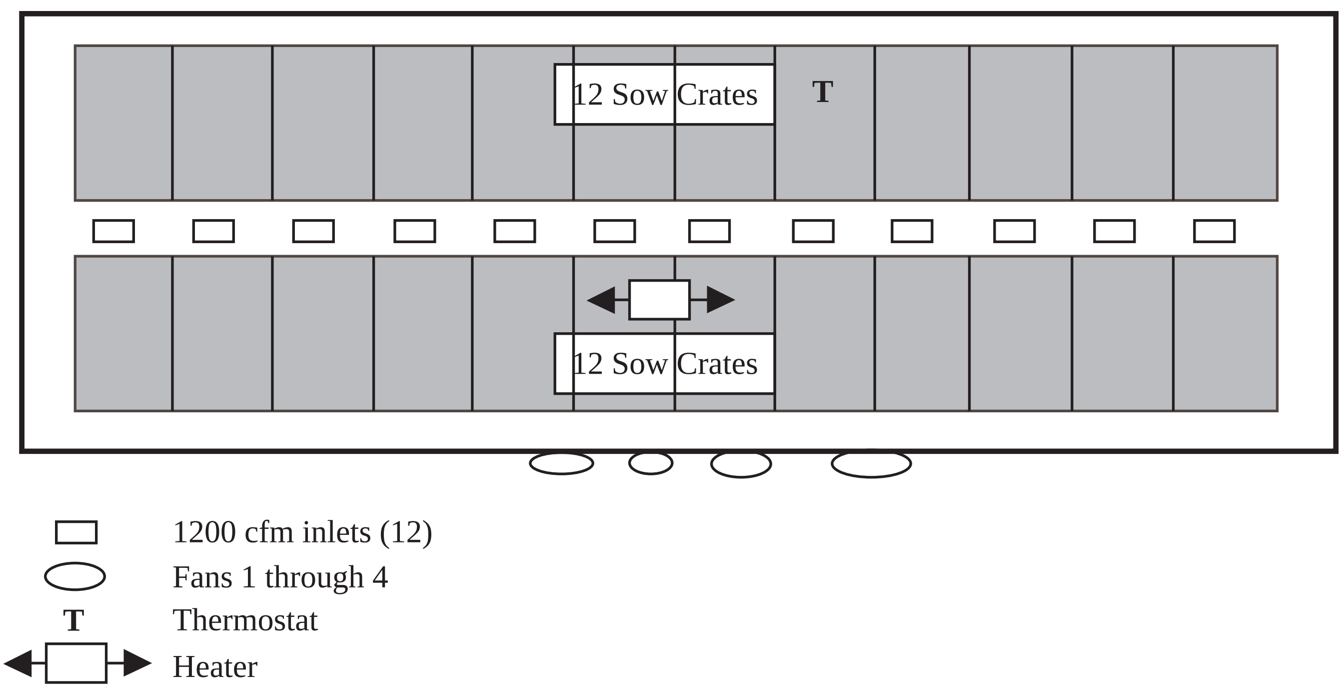
	Winter (Stage 2)	Summer (Stage 4)
Actual Fan Stage (cfm)	2,471	12,091
	Divided by 400	Divided by 400
Opening (ft^2)	6.2 ft^2	30.2 ft^2

Target Temperature = 68 °F

Thermostat Settings

Stage	Stage Capacity	Total Capacity	Thermostat Setting
Continuous	521 cfm	521 cfm	on continuously
Heaters	3,000 Btu/hr-sow	72,000 btu/hr-sow	65°
2nd Stage	1,950 cfm	2,471 cfm	71°
3rd Stage	3,720 cfm	6,191 cfm	74°
4th Stage	5,900 cfm	12,091 cfm	77°

Sketch the Facility



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Prepared by Jay D. Harmon, Ph.D.,P.E.,associate professor and extension agricultural engineer, agricultural & biosystems engineering department.

File: Engineering 1-8

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MECHANICAL VENTILATION WORKSHEET

Project Title ________________________________

Date ____________________

Stage Rates

Min.Vent. Rate **(W)**: ______ Animals x ________ cfm/animal = _____________ cfm

Max. Vent.Rate **(S)**: ______ Animals x ________ cfm/animal = _____________ cfm

Intermediate Stage 1 **(I1)** = {**(S)**____ - **(W)**____} / (____ No. stages +2) + **(W)**____ **=** ________ cfm

Intermediate Stage 2 **(I2)** = 2 x {**(S)** _____ - **(W)**____} / (_____ No. stages +2) + **(I1)**_____ **=**_______ cfm

Ideal Fan Capacities				**Actual Fan Capacities**
Continuous Fan	= **(W)**_____		=_______ cfm	________ cfm
2nd Fan	= **(I1)** _____	- **(W)**______	=_______ cfm	________ cfm
3rd Fan	= **(I2)** _____	- **(I1)**______	=_______ cfm	________ cfm
4th Fan	= **(S)** _____	- **(I2)**______	=_______ cfm	________ cfm

Actual Fan Stages

Continuous Fan = _____________ cfm

Stage 2 = Continuous _______ + 2nd Fan ________ = ________ cfm

Stage 3 = Stage 2 __________ + 3rd Fan ________ = ________ cfm

Stage 4 = Stage 3 __________ + 4th Fan ________ = ________ cfm

Needed Continuous Eave Inlet Area

	Continuous Fan	Stage 2	Stage 3	Stage 4
Actual Fan Stage (cfm)				
	Divided by 800	Divided by 800	Divided by 800	Divided by 800
Opening (ft^2)				
	Divided by inlet length (ft)	Divided by inlet length (ft)	Divided by inlet length (ft)	Divided by inlet length (ft)
	times 12	times 12	times 12	times 12
Inlet Opening (in)				

or **Commercial inlets** = Maximum Rate ______ ÷ Rated Capacity ______ = ______ inlets

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Needed Attic Opening

	Winter (Stage 2)	Summer (Stage 4)
Actual Fan Stage (cfm)		
	Divided by 400	Divided by 400
Opening (ft^2)		

Target Temperature = ____________________ ^oF

Thermostat Settings

Stage	Stage Capacity	Total Capacity	Thermostat Setting
Continuous			on continuously
Heaters			
2nd Stage			
3rd Stage			
4th Stage			

Sketch the Facility

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MECHANICAL VENTILATION WORKSHEET

Project Title ___________________________________
Date ______________________

Stage Rates

Min.Vent. Rate **(W)**: ______ Animals x _________ cfm/animal = ______________ cfm
Max. Vent.Rate **(S)**: _____ Animals x _________ cfm/animal = ______________ cfm

Intermediate Stage 1 **(I1)** = {**(S)**______- **(W)**____} + **(W)**_____ **=** __________ cfm
(_____No. stages +2)

Intermediate Stage 2 **(I2)** = 2 x {**(S)**_____ - **(W)**____} + **(I1)**_____ **=** _______ cfm
(_____ No. stages +2)

Ideal Fan Capacities **Actual Fan Capacities**

Continuous Fan	= **(W)**______		=_______	cfm	________	cfm
2nd Fan	= **(I1)**______	**-** **(W)**______	=_______	cfm	________	cfm
3rd Fan	= **(I2)**______	- **(I1)** ______	=_______	cfm	________	cfm
4th Fan	= **(S)** ______	- **(I2)** ______	=_______	cfm	________	cfm

Actual Fan Stages

Continuous Fan = ______________ cfm

Stage 2 = Continuous ________ + 2nd Fan ________ = ________ cfm

Stage 3 = Stage 2 ___________ + 3rd Fan _______ = ________ cfm

Stage 4 = Stage 3 ___________ + 4th Fan ________ = ________ cfm

Needed Continuous Eave Inlet Area

	Continuous Fan	Stage 2	Stage 3	Stage 4
Actual Fan Stage (cfm)				
	Divided by 800	Divided by 800	Divided by 800	Divided by 800
Opening (ft^2)				
	Divided by inlet length (ft)	Divided by inlet length (ft)	Divided by inlet length (ft)	Divided by inlet length (ft)
	times 12	times 12	times 12	times 12
Inlet Opening (in)				

or **Commercial inlets** = Maximum Rate _____ ÷ Rated Capacity ______ = _______ inlets

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Needed Attic Opening

	Winter (Stage 2)	Summer (Stage 4)
Actual Fan Stage (cfm)		
	Divided by 400	Divided by 400
Opening (ft^2)		

Target Temperature = ____________________ °F

Thermostat Settings

Stage	Stage Capacity	Total Capacity	Thermostat Setting
Continuous			on continuously
Heaters			
2nd Stage			
3rd Stage			
4th Stage			

Sketch the Facility

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