Mechanical Ventilation of Animal Housing: A Real-World Application of Physics Concepts?

Grade Level
9-12

Lesson Length
3 periods x 55 minutes

STEM Careers
- Agricultural Engineer
- Architectural Engineer
- Construction Engineer
- Environmental Engineer
- Meteorologist
- Physicist

Next Generation Science Standards
- MS-PS1-4
- MS-PS3-3
- HS-PS3-1
- HS-PS3-4

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These lessons aim to bring the science, skills of inquiry, critical thinking, and problem solving to life through an agricultural context.

Learning Objectives

By the end of this unit, students should be able to:

- Discuss the importance of proper ventilation.
- Describe principles of physics associated with ventilation.
- Diagram air flow in positive and negative pressure systems.
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Materials List

- Cardboard for making a box
- Ruler
- Pencil or Pen
- Scissors
- Packing tape
- Bungee cord
- Small fan (to be shared amongst groups)
- Device with a USB power port
- Air meter (to be shared amongst groups)
- Calculator

Do

Introduction (*Interest Approach that Aligns with the Investigation*)

To introduce students to the importance of ventilation, show the following video titled "Ventilation Basics Series #1 – Why we need ventilation". The video provides a focus on the need for proper ventilation within our homes, but the principles

- https://www.youtube.com/watch?v=FwuR_tRpbGw (5:30)

Facilitate a 1-2 minute discussion with students on how spaces are ventilated, and the importance of ventilation. This does not have to be animal related, in fact, it may be easier to start the conversation on how we ventilate our homes and schools. If the air is not flowing through a room, how do we feel? Then, if desired, one can redirect that conversation to how ventilation can impact animals housed within environmentally controlled housing systems.

Essential Questions

- *Why is good ventilation of animal housing units important?*
- *What is the difference between negative and positive pressure systems?*

Learning Activity 1: [PowerPoint Discussion]

Please use the provided information and/or associated PowerPoint to introduce students to the physics related to ventilation. If teachers prefer to show a recording, that is available.

There are three operating principles related to this learning activity. First, fans represent the driving force to facilitate air movement. Second, targeted airflow rates will be influenced by fan size and operating speed as well as the number of fans. Third, the airflow distribution will be dependent on the inlet or outlet location and size, in addition to the room or building size and shape.

Wording for Key Properties:

- Airflow Rate (Q) is the volume of air moved per unit of time, measured as cubit feet per minute (ft^3/min or cfm).
- Air velocity (v) or speed is the distance that air moves per unit of time, measured as miles per hour (mi/hr or mph) or feet per minute (ft/min).
- Air pressure (P) is the force of air per unit of surface area, measured as pounds per square inch (lb/in^2 or psi) or equivalent water depth (inches of H_20). Measurement of air pressure in inches of water dates to at least the early 20th century when physicists developed and used a water manometer to measure pressure. The simplest design is simply a U-shaped tube filled with fluid (water). As pressure or weight is placed on one side of the tube, the amount of rise of the fluid is measured on the opposite side, hence inches of water (https://hvacrschool.com/in_wc/).

- Energy represents the work that is being or could be done, calculated as P x Q or Air pressure times airflow rate.

Uniform Air Pressure – The pressure of a confined gas is uniform across the airspace.

Air Pressure and Velocity – As air pressure is increased, speed of air through any opening should increase, and vice-versa.

Airflow Rate (Q) = Open Area (A, ft^2) times average air velocity (v, ft/min).

With mechanical ventilation systems, there are positive- and negative-pressure systems. Positive pressure systems use fans to blow air into the building. This slightly increases air pressure inside the building and forces room air outside. Negative-pressure systems use fans to blow air out. These are commonly referred to as exhaust fans. This functions to decrease the room pressure inside. The resulting slight vacuum pulls fresh air in from the outside. Negative-pressure systems are commonly used with animal housing systems.

Learning Activity 2:

Students will be placed in small groups who will build a ventilated room (per instructions provided). Then, students will test and calculate the effect of negative- vs. positive-pressure systems, the effect of increasing air speed, and the effect of different openings on total air movement through the facility (see student instructions).

Learning Activity 3: Industry and Career Video – Career Opportunities Applying Physics Concepts to Agriculture

Show the industry and career video that discusses "real world" application of physics concepts, while also introducing students to career possibilities that function to bridge science and agriculture.

Reflection

Using the prompts below to facilitate reflection, allow each student to respond in writing to the prompts and then facilitate a whole class discussion.

1. What is your definition of good ventilation?
2. Why is negative-pressure ventilation more commonly used than positive-pressure?

Apply

Use the prompts below to facilitate small group and whole class discussion.

1. Describe an ideal ventilation system.

References:

- Ventilation Basics Series #1 – Why we need ventilation? https://www.youtube.com/watch?v=ATrSoMIx5PE
- Inches of Water Column (https://hvacrschool.com/in_wc/); accessed 6/11/22.

Mechanical Ventilation of Animal Housing
(Student Instructions)

Learning objectives: Confirm with a hands-on experience how physics concepts apply to air flow and are useful for professionals in animal agriculture

Safety precautions: Do not remove any guards or disassemble fans, as doing so will expose users to hazards from moving blades and electrical shocks.

Basics procedures:

A) Construct 'ventilated room' out of cardboard packaging and small fan
B) Measure air pressure and outlet air speeds for various situations
C) Determine airflow rates delivered through the room for various situations
D) Draw conclusions from your results and share/compare findings

Before starting, confirm that your team has access to the needed supplies (Refer to Figure 1):

- Cardboard for making a box
- Ruler
- Pencil or pen
- Scissors
- Packing tape
- Bungee cord
- Small fan
- Laptop/device with USB power port
- Air meter
- Calculator

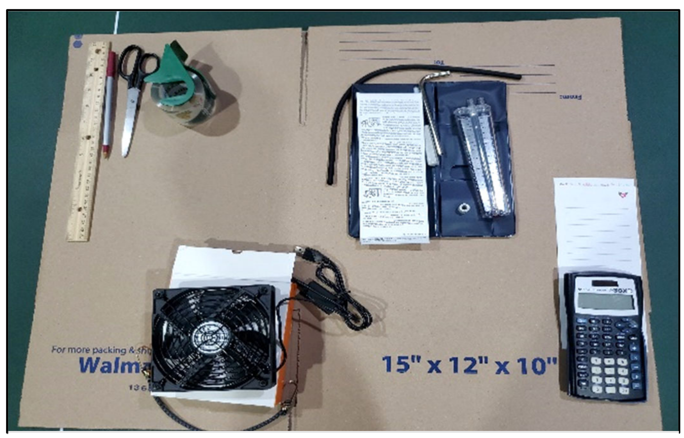

Figure 1. Materials for hands-on experience.

Construct the ventilated room:

The finished box should look like the one shown in Figure 2. One end will have a hole for receiving air from the fan, while the other end and the two sides will each have an air outlet formed with a flap that can be opened and closed. The top and bottom of the box will not have holes and will have edges taped to limit air leaking in or out of the box. It will be easier to mark and cut holes before making the box, so follow these steps:

Figure 2. Finished box.

1) ***Identify the top, bottom, ends, and sides of the box.*** First, open the flattened cardboard and stand it up so that the top is open and most of the wording on the cardboard is readable (not upside down).

   a) The four flaps along the top edge will become the top of the box. Write "Top" on a couple of these flaps.
   b) The flaps at the bottom will become the bottom of the box.
   c) The smaller rectangles in between top and bottom flaps are the ends of the box.
   d) The other two rectangles will be referred to as the sides of the box.

2) ***Outline the hole for the fan and the outlet flap locations***.

   a) Fold the bottom flaps out so the sides and ends of the box rest on the table/desk. Select one end and mark an X near the bottom (see Figure 3) to note where to cut a hole for the fan. Lay the cardboard down flat again so the mark you made is visible and the top flaps are away from you and the bottom flaps are close to you.

Figure 3. Mark fan location.

   b) Place the fan face-up on the cardboard so the fan covers the mark and the bottom edge of the fan lines up with the crease where the bottom flap meets the end of the box. Since the fan probably is not a perfect square, position it so you can read the company name without turning your head.

   c) Trace a line around the fan (Figure 4). If the bottom crease is clearly visible, you may not need to draw a line along the bottom. Then remove the fan and darken any faint lines using the pencil and ruler.

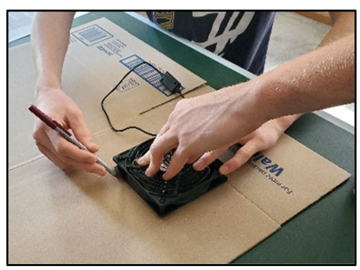

Figure 4. Tracing outline of

   d) Using the pencil, draw lines to chop/round off the corners of the tracing (Figure 5).

Figure 5. Prep for fan hole.

   e) In the central area of the side of the box that is facing toward you, use the ruler and pencil to draw a rectangle (Figure 6) that is 3 inches wide and 2 inches tall.

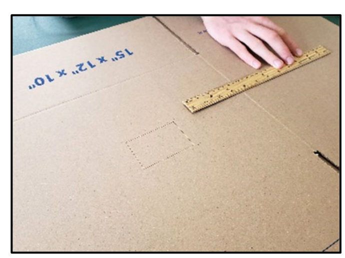

Figure 6. Outline of outlet.

   f) Flip the cardboard over – keeping the bottom edge close to you – and draw out two more 3"x2" rectangles, one near the middle of the side and one in the middle of the end of the box.

3) ***Make the hole for the fan.***

a) Unflatten the cardboard for easier cutting.

b) The hole for the fan should be made a little smaller than the tracing to reduce air leaking out along the sides of the fan, so make the cuts a little on the inside of the trace line (Figure 7).

Caution! When inserting the tip of the scissors through the cardboard to start cuts, make sure no hands or other body parts are on the other side!
Hint: Make the first cut in the bottom crease.

c) Discard cardboard piece(s) produced by making this hole.

Figure 7. Cutting hole for fan.

4) ***Make the outlet flaps.***

a) Select one of the 3”x2” rectangles and cut along the lines forming the bottom, one side, and the top. Leave one side intact (uncut)!

b) Reach inside box and pop the newly cut flap open. Uncut side should act like a hinge.

c) Repeat steps a & b to make the other two outlet flaps.

5) ***Make the top and bottom of the box.*** This may require more than one person.

a) Fold the two smaller bottom cardboard flaps inward – toward each other.

b) Fold the other two bottom cardboard flaps inward (over the other flaps) and hold in place when they align.

c) Apply packing tape to join the two flaps together (Figure 8).

d) Apply packing tape along free edges of the flaps to seal cracks and minimize air leakage.

Figure 8. Taping the bottom flaps.

e) Flip the box over and repeat steps a-d to make and seal the top of the box.

You should now have a room that looks like the box in Figure 1 and is ready to ventilate!

6) ***Attach the fan to the box.*** May require more than one person.

   a) With the box resting on its bottom, stand the fan in front of the fan hole with the company name readable. Then turn it around so the side with the company name is up against the hole, so air will be blown into the box.

   b) Stretch the bungee cord across the front of the fan and secure the clips to the edges on each side where the endwall meets a sidewall (Figure 9). You may need to make a dimple or small hole in the outer sheet of the cardboard to make the clips stay put.

   You're now ready to test out your system!

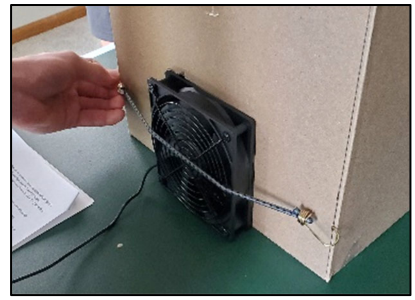

Figure 9. Attaching the fan.

7) ***Make sure the setup works.***

   a) Fold outward each of the three outlet flaps, so the outlets are fully open.

   b) With the fan switch set in the Off position ("O"), plug the power cord into a USB port on a nearby laptop or other power supply device with USB ports.

   c) Set the switch to run at Low speed ("L"). The fan blades should start spinning, blowing air into the box. You should feel some air coming out of the outlets.
   If the fan does not come on, you may need to turn the device on or find a different power source. If the fan is blowing air out of the box instead of into it, shut the fan off, remove it, turn it around, and secure it back into position.

   Congratulations!! You've successfully constructed a ventilated room!

<u>Measure air speed and pressure:</u>

Now you are ready to take some measurements to see how the ventilation system is performing. An 'air meter' (Figure 10) is a simple sensor that can measure both air velocity (speed) and pressure.

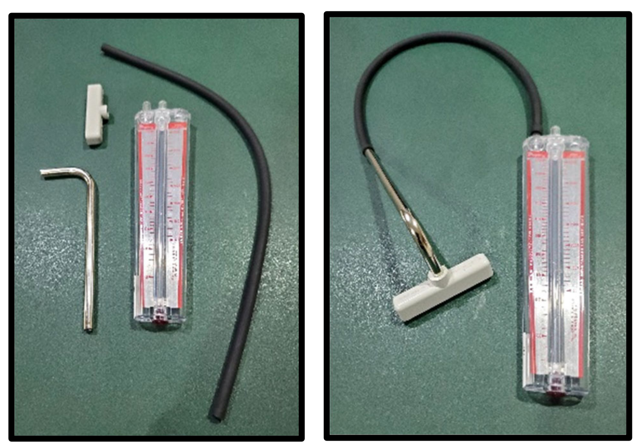

Figure 10. Air meter before and after assembly.

To measure air speed from an outlet:

1) With one hand, hold the gauge so it's vertical with the tubing ports on top. You'll notice a little ball that will rest at the bottom of the gauge when there is no air flowing through the air meter.

2) With the other hand, grasp the metal tubing and position the [gray, rectangular] flange within an outlet opening so air flows directly into the open side. The metal tubing does not have to be held in a vertical position, but that may often be the most convenient and comfortable.

   Make sure that the rubber tubing is not kinked or twisted – as this will restrict airflow and lead to inaccurate measurements. Usually, lowering the gauge so it is below the other hand – while keeping it vertical – will reduce the tendency for the tubing to kink. Refer to Figure 11. Placing the box near the edge of the table or desk may help.

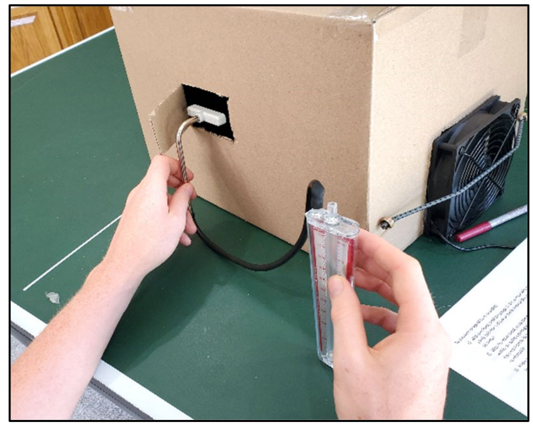

Figure 11. Flange of air meter is positioned well, but the gauge being too high may make the hose kink.

3) Now you are ready to take readings. As air flows through the meter faster, the ball will be blown higher within the gauge. For measurements you will make in these exercises, readings will be on the 'low scale', which means you'll read off the scale on the left side (Figure 12).
   a. ***Air velocity*** can be read, in feet per minute (FPM), off the red side of the gauge. You should be able to make readings to the nearest 20 FPM.

   b. ***Air pressure*** within the room can be read, in inches of water, off the black side of the gauge. You should be able to make readings to the nearest 0.002 inch H_2O.

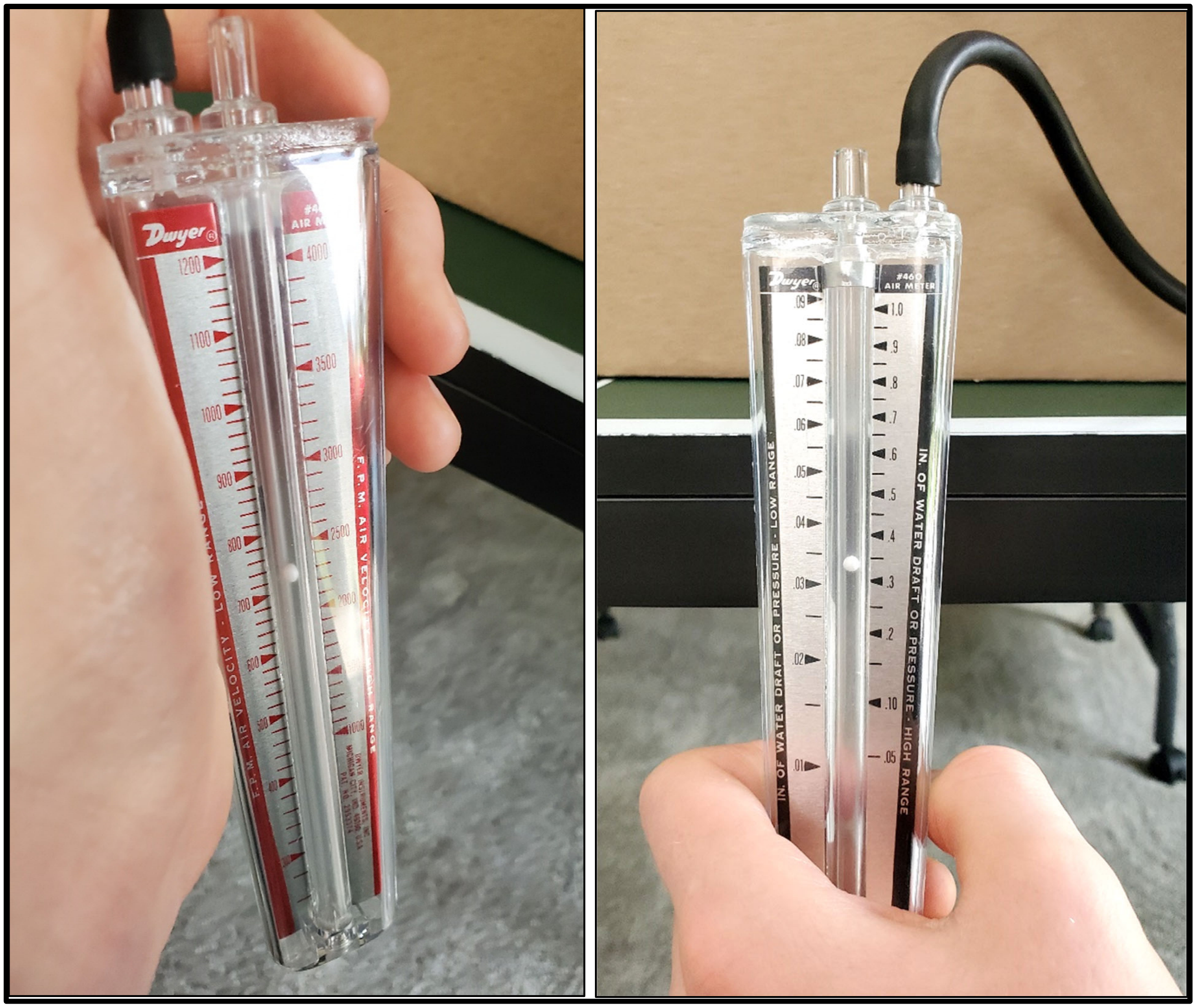

Figure 12. Air velocity side (left photo) and pressure side (right photo) of air meter gauge.

To switch between readings, simply rotate your hand, while keeping the gauge vertical, to view the other side of the gauge.

Note that in real life some variability can be expected, so if the ball bobs up and down slightly, this is normal. Just take a mid-point reading.

EXERCISE I – EFFECT OF FAN SPEED

In this exercise, you will change the speed of the fan and see what happens to the measured air velocity and air pressure, as well as the calculated airflow rate, with all three outlets fully open. You may use Table 1 to record your readings. {Numbering of the outlets is up to you.}

1) Beginning with the fan set to low speed ("L"), measure the air velocity and pressure at each of the three openings. At low fan speed, air is not moving very fast and the airflow might not be enough to lift the ball off the bottom of the gauge. If this is the case, just note that readings were "Low" and use the minimum scale value of 260 FPM as the average speed for your airflow calculations.

2) Set the fan to medium speed ("M"), measure and record the air velocity and pressure with the sensor positioned at each of the three openings as before.

   If the ball still stays in the bottom of the gauge at medium speed, your room may be too leaky – meaning air is leaving through cracks, gaps and/or unwanted holes instead of through the outlets like it's supposed to do. This can be a problem in real buildings also. Examine your box to see if air is flowing out of other places – such as an un-taped box flap or around the side of the fan – and see if this leakage can be reduced using packing tape.

3) Set the fan to high speed ("H"), measure and record the air velocity and pressure with the sensor positioned at each of the three openings as before.

   When the fan is running at high speed, there definitely should be measurable air velocity.

For given fan speeds, were the readings from different outlets similar or did they differ a lot? What conclusion can you draw about air pressure at different locations within a room?

Did the air speed and pressure both behave the same when the fan speed was increased? What conclusion can you draw from the fact that the velocity of the air leaving the box and the air pressure inside the box can be measured using the same sensor?

4) For each fan speed, calculate the airflow rate, Q, in cubic feet per minute (CFM) being moved through the outlets using the equation Q = Area x velocity.

   You may want to recheck your cutting job by measuring the size of your outlet openings, but they should each be about 3 inches wide x 2 inches tall. Assuming this size, knowing that there are 144 sq. inches in a sq. foot, and assuming the air speeds were similar, this equation looks like:

   Q = (3 outlets open x (3 in x 2 in) ÷ 144) x _____ FPM for average velocity

   Confirm that this simplifies to = 1/8 of the numerical value for FPM.

Table 1. Table for entering measurement readings and calculated airflow rates for Exercise I.

Fan Speed	Outlet 1		Outlet 2		Outlet 3		Rough average		Calculated Airflow rate
	Velocity	Pressure	Velocity	Pressure	Velocity	Pressure	Velocity	Pressure	
Low									
Medium									
High									

As fan speed increased, what happened to air pressure inside the box? What happened to air speed exiting the outlets? What happened to airflow rate delivered through the box?

Do you think the fan requires more, less or the same electrical power as it runs faster? Given that the output power of a fan is based upon air pressure and flow rate produced, what conclusion can you draw about input and output power?

EXERCISE II – EFFECT OF OUTLET OPENING AREA

In this exercise, you will change the amount of outlet area that is open and see what happens to the measured air velocity and air pressure, as well as the calculated airflow rate. Keep the fan set to high speed ("H") throughout the exercise. Table 2 may be used to record your measurements and calculated airflow rates. Note that the air speed exiting open outlets should be very similar so taking measurements from each outlet is not required and the sizes of the fully open outlets should be the same so it shouldn't matter which outlets you choose to close.

Table 2. Table for entering measurement readings and calculated airflow rates for Exercise 2.

Status of openings	Outlets open	Opening size (W x H)	Total area (sq. inches)	Velocity (FPM)	Pressure (in. H2O)	Airflow rate (CFM)
All outlets open	3					
One outlet closed; other two open	2					
Two outlets closed; only one open	1					
Two outlets closed; one half-open	1					
Two outlets closed; one ~¼ open	1					

1) <u>All outlets open:</u> This situation – with the fan at high speed and all outlets open – is the same as the last part of Exercise 1, so you may pull over some of the values for the first empty row of Table 2 if you like.

   Recall that for your room and measured units:

   Total area = # outlets open x outlet opening size

   Airflow rate = (total area ÷ 144) x air velocity

2) <u>One outlet closed; other two open:</u> Select one outlet and close the flap by pushing the cardboard back in place just enough to stop air from flowing out of the outlet. Then retake air velocity and pressure readings and re-calculate the total open area and airflow rate.

   {If you push a flap into the box, try using your finger to retrieve it. If this doesn't work or there's a lot of leakage, you may have to apply packing tape over the outlet.}

3) Two outlets closed; only one open: Select another outlet and close the flap. Then retake air velocity and pressure readings and recalculate the total open area and airflow rate.

Figure 13. Closing an outlet halfway.

4) Two outlets closed; one half-open: Fold the open flap in half and then push it in to close off about half of the outlet's open area (Figure 13). Then retake air velocity and pressure readings and recalculate the open area and airflow rate.

5) Two outlets closed; one ~¼ open: Fold the open half of the flap in half again and then push in all but the outer portion to close off about 3/4 of the outlet opening (Figure 14). Then retake air velocity and pressure readings and recalculate the open area and airflow rate.

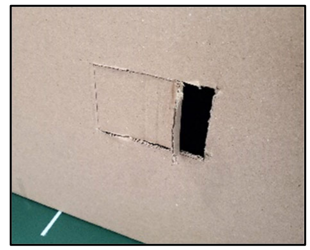

Figure 14. Outlet 1/4

As the outlet area was reduced, what happened to the measured air velocity? What happened to air pressure? What happened to airflow rate?

What relationships were different from what you observed in Exercise I?
Develop an explanation for what caused the difference.
{Hint: consider energy and the open area.}

EXERCISE III – EFFECT OF FAN DIRECTION

In this exercise, you will turn the fan around, so it draws air out of the box, and see what happens to the airflow.

1) Shut off the fan.
2) Remove the fan, turn it around, and secure it back in front of the hole so it will blow air away from the box.
3) Open the flaps.
4) Turn the fan on and set to high speed.
5) Note how the air flows through the box. No measurements needed.

With the fan at high speed and all the flaps open, what changed, if anything, when the fan was turned to blow air in the opposite direction?

If a mouse-sized version of you was resting on the floor in this 'room' during the winter, when the outside air is cold, in which situation would you be more chilled: fan blowing into the room or fan blowing out of the room? Explain your reasoning.

Name:

Lab Report

Please complete the following report during the design and implementation of your experiment.

Research Problem
- Describe what you are investigating and justify why you are investigating the problem.

Hypothesis
- Formulate one or more hypotheses for your experiment.

Procedures
- Create the steps you will follow for your experiment.

Data Collection
- Describe the data that you will collect during your experiment.
- Provide graphs, tables, charts, and raw data as necessary.

Results
- Explain your results.

Conclusion
- Based on your data:
    - What can you conclude?
    - Were your hypotheses supported?
    - Were their limitations to your experiment?
    - What are new research questions that derived from this study?