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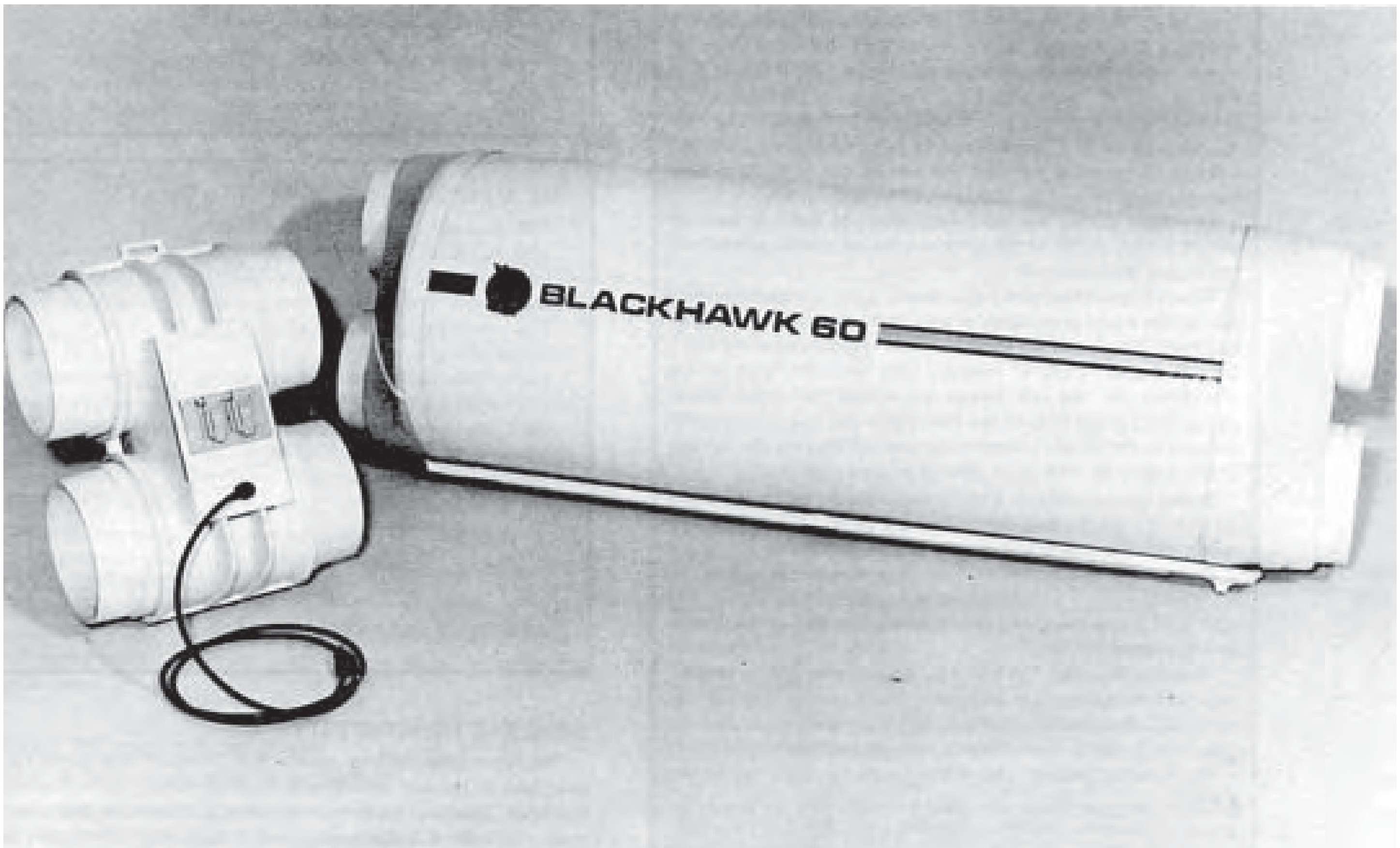

Blackhawk 60 Heat Exchanger

A Co-operative Program Between
ALBERTA FARM MACHINERY RESEARCH CENTRE
PAMI
PRAIRIE AGRICULTURAL MACHINERY INSTITUTE

BLACKHAWK 60 HEAT EXCHANGER

MANUFACTURER AND DISTRIBUTOR:
Blackhawk Industries Inc.
607 Park Street
Regina, Saskatchewan
S4N 5N1

RETAIL PRICE:
$1408.00 (August, 1983, f.o.b. Humboldt). Does not include insulated flexible ducting required for operation.

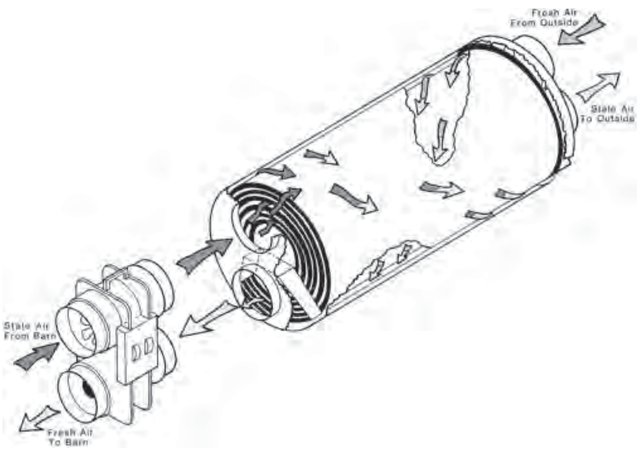

FIGURE 1. Blackhawk 60 Heat Exchanger.

SUMMARY AND CONCLUSIONS

Functional Performance: Overall functional performance of the Blackhawk 60 heat exchanger was good.

Fan Performance: In a typical installation, standard airflow was 280 cfm (132 L/s) exhaust and 230 cfm (109 L/s) supply, with the fans set at high speed. Supply airflow was substantially reduced at colder temperatures by operating the supply fan at low speed and adjusting a damper at the supply air inlet.

Heat Recovery: At Machinery Institute standard test conditions of 65°F (18°C) barn air temperature and 70% relative humidity, the average heat recovered by the Blackhawk 60 varied with outside temperature as follows: 6200 Btu/h (1.8 kW) at -22°F (-30°C), 7000 Btu/h (2.1 kW) at +5°F (-15°C), and 5800 Btu/h (1.7 kW) at +32°F (0°C). The heat recovery ratio[1] (the percentage of heat recovered from the exhaust air removed from the barn) at the above three outside temperatures was 25%, 40% and 59% respectively. Leakage: During the Machinery Institute leakage test, 18 cfm (8.5 L/s), or 6% of the normal exhaust airflow leaked into the supply air passages.

Ease of Operation and Adjustment: Ease of installation was fair. In the moderately dusty environment of a grower/finisher hog barn, the core of the Blackhawk 60 required washing every 5 or 6 weeks. Ease of cleaning was fair. The core of the Blackhawk 60 did not freeze up during the tests. Water condensing in the core of the Blackhawk 60 was conveniently drained inside the barn. Recommended settings for the damper at the supply air inlet were difficult to judge accurately.

Power Requirements: The Blackhawk 60 drew a maximum current of 1.92 A when plugged into a standard 120 V, 3 pin outlet. Average power required was 224 W.

Safety: The Blackhawk 60 was safe to operate as long as the manufacturer's safety instructions were followed. It was not CSA (Canadian Standards Association) certified to the Canadian Electrical Code.

Operator Manual: The operator manual was clearly written very well illustrated and contained much useful information. However, instructions for setting the fan controls to prevent the core from freezing were unclear and incomplete.

Mechanical History: Two minor problems occurred during the test.

[1]The heat recovery ratio is not the same as effectiveness. The Machinery Institute recommends that the heat recovery ratio be used rather than effectiveness to compare the heat recovery performance of different heat exchangers.

RECOMMENDATIONS

It is recommended that the manufacturer consider:

1. Modifying the connections at the heat exchanger ports to prevent the ducts from slipping off.
2. Providing easier access for inspecting and washing the heat exchanger core.
3. Modifying the drain hose connection to the drip tray to prevent the hose from slipping off.
4. Including in the operator manual the conditions in which the core may freeze up and the procedures to be followed if it does.
5. Revising the operator manual to indicate correctly the effect of damping off the supply flow on the heat exchanger's performance.
6. Labelling the fan module to identify the on/off and speed selector switch for each fan.
7. Using decals on the outside of the heat exchanger that will not wash off.
8. Having the heat exchanger CSA (Canadian Standards Association) certified to meet the requirements of the Canadian Electrical Code.

Senior Engineer: G. E. Frehlich
Project Engineer: J. C. Begin
Project Technologist: M. W. Garrod

THE MANUFACTURER STATES THAT

With regard to recommendation number:

1. This modification is being made for the 1983/84 season. A retrofit kit will be made available for purchase through Blackhawk dealers to former customers who have been inconvenienced by this problem.
2. Same as Reply No. 1.
3. This modification is being made for the 1983/84 season.
4. This recommendation will be followed in the next printing of the Blackhawk Installation Guides in early 1984. Meanwhile, information and corrective inserts will be included in the present guide from now on.
5. Same as Reply No. 4.
6. Same as Reply No. 3.
7. Same as Reply No. 3.
8. CSA certification has been applied for and is expected in early 1984. Meanwhile, all units are being constructed according to CSA criteria.

GENERAL DESCRIPTION

The Blackhawk 60 is a counter flow air-to-air heat exchanger, designed to recover waste heat from ventilation air in livestock buildings. The heat exchanger consists of a moulded ABS plastic shell enclosing a plastic core, and a separate ABS plastic fan module which houses two axial fans and the fan controls. The heat exchanger core consists of a series of alternating supply and exhaust air passages made of plastic (polystyrene) sheets separated by narrow spacers and cemented together at the ends (FIGURE 1).

During normal operation, the exhaust fan draws stale barn air into the exhaust passages of the core, then blows it through a duct to the outside. The supply fan draws fresh outside air into the supply passages of the core and blows it through a duct into the barn. The stale exhaust air does not mix with the fresh supply air in the core. However, heat is transferred from the exhaust air through the passage walls to the supply air.

During defrost operation the supply fan is switched off to allow heat from the exhaust air to melt ice that may have built up in the exhaust passages. The heat exchanger is automatically switched into defrost for 20 minutes, every six hours.

The Blackhawk 60 fans are controlled by an on/off switch and a two-speed selector switch located on the fan module. The heat exchanger is designed to operate on a 120 V AC outlet.
Detailed specifications are given in APPENDIX I.

SCOPE OF TEST

The Blackhawk 60 was operated in a grower/finisher hog barn in the conditions shown in TABLE 1 for 110 days during the winter of 1982-83. During this time, it was evaluated[1] for ease of operation and adjustment, safety, and suitability of the operator manual. In addition, the Blackhawk 60 was tested in the laboratory to determine fan performance, heat recovery, power requirements and leakage.

TABLE 1. Operating Conditions.

Type of barn:	grower/finisher hog barn
Number of animals:	400
Construction:	wood frame
Insulation levels:	walls R20; ceiling R32
Layout:	centre manure pit with outside feed alleys, 32% slatted floor
Feeding system:	overhead auger to self feeders
Feed type:	pelletized
Frequency of feeding:	twice per day
Average barn temperature:	69°F (21°C)
Average barn humidity:	65%
Outside temperature:	°F (°C)

	NOV.	DEC.	JAN.	FEB.	MARCH
Monthly Min:	-24 (-31)	-31 (-35)	-38 (-38)	-39 (-40)	-13 (-25)
Mean:	+12 (-11)	+8 (-13)	+7 (-14)	+9 (-13)	+18 (-8)

RESULTS AND DISCUSSION

EASE OF OPERATION AND ADJUSTMENT

Installation: The Blackhawk 60 was easy to install, requiring two men about 3-1/2 hours. Extra materials needed were 20 ft (6.1 m) of insulated flexible ducting, duct hangers, duct tape, a vent hood and 3 short lengths of 2 x 4 in (50 x 100 mm) wood.

In a typical barn installation, the Blackhawk 60 is suspended from the ceiling, close to an outside wall (FIGURE 2). Insulated flexible ducting directs stale air from the heat exchanger to the outside, and fresh air from outside to the heat exchanger. Fresh air may be drawn either from the attic space through the ceiling, or from the outside, through a wall. Flexible ducting connects the fan module to the heat exchanger, and distributes air throughout the barn.

The flexible ducts were securely connected to the fan module by taping them onto the quick disconnect sleeves provided. However, the ducts, which were connected to the heat exchanger ports and the fan module with large clamps often slipped off. It is recommended that the connections at the heat exchanger ports be modified to prevent the ducts from slipping off.

Tests were conducted as outlined in the Machinery Institute Detailed Test Procedures for Air-to-Air Heat Exchangers.

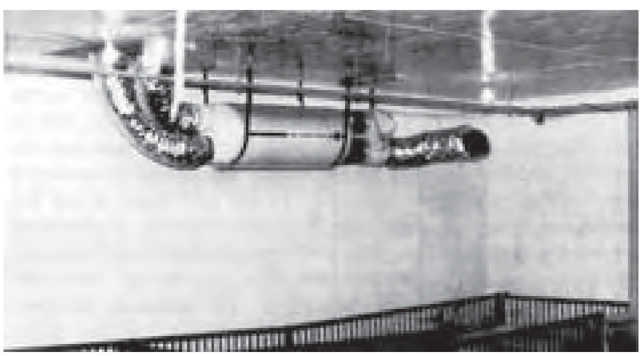

FIGURE 2. The Blackhawk 60 Installed.

Cleaning: In the moderately dusty environment of a grower/ finisher hog barn, the Blackhawk 60 had to be washed every 5 or 6 weeks, to remove dirt, which had built up in the exhaust passages. To gain access to the core for inspection and for washing, the large clamps and the exhaust inlet and outlet ducts at the heat exchanger had to be removed (FIGURE 3). This was inconvenient and it is recommended that the manufacturer provide easier access to the core for inspection and washing.

The core of the Blackhawk 60 could only be washed with a low pressure (50 psi maximum) washer (FIGURE 4). Water was sprayed into the core from the exhaust inlet and outlet ports to rinse away dirt, which had built up. Occasionally, the drain hose plugged with dirt, causing the rinse water to spill over the edges of the drip tray.

Washing the core as indicated in the operator manual was not completely effective. When the heat exchanger was removed at the end of the season, a thorough washing showed that a considerable amount of dirt had remained in the core in spite of regular washings.

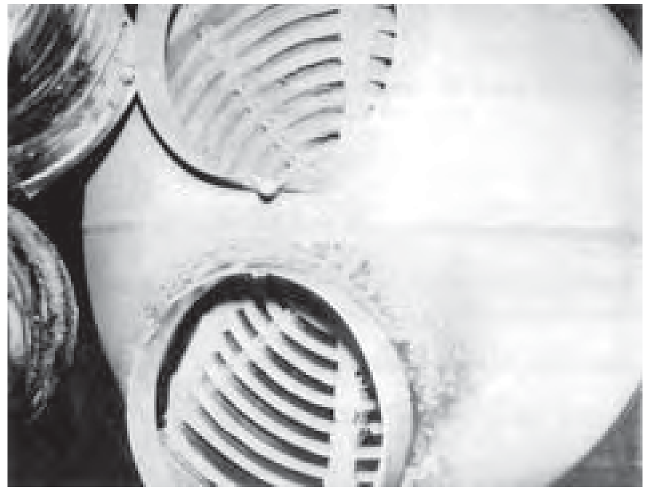

FIGURE 3. Access to the Core.

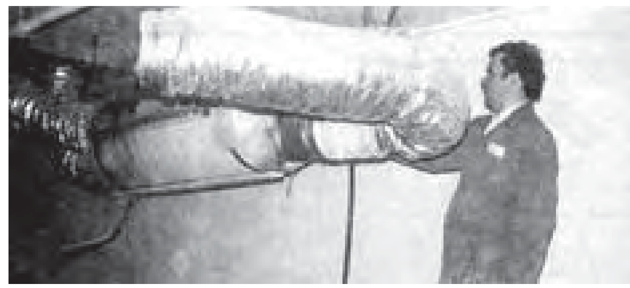

FIGURE 4. Washing with a Garden Hose.

Condensation and Freeze-Up: Water condensing in the exhaust passages of the Blackhawk 60 was drained from the drip tray by a plastic hose to the desired place in the barn (e.g. manure pit). The drainage hose often slipped off the smooth tapered nipples on the bottom of the drip tray (FIGURE 5), even when a hose clamp was used. It is recommended that the manufacturer modify the drain hose connection to the drip tray to prevent the hose from slipping off.

FIGURE 5. Drip Tray Nipple.

Draining the core inside the barn was convenient. Some ice built up below the exhaust air outlet outside the barn, but never had to be removed.

During Machinery Institute standard tests, the Blackhawk 60 did not freeze up when operated continuously at an outside temperature of -22°F (-30°C). However, the tendency for the core to freeze up was reduced by following the manufacturer's recommendation to decrease the supply airflow at colder temperatures. Under less favourable conditions such as lower exhaust or outside air temperatures, or lower exhaust air humidity, the heat exchanger core may freeze up.

The operator manual did not list operating conditions in which core freeze up is likely to occur, nor did it describe the procedure to be followed if the core did freeze up. It is recommended that the

[2]Tests were conducted as outlined in the Machinery Institute Detailed Test Procedures for Air-to-Air Heat Exchangers.

manufacturer include sections that deal with these problems in the operator manual.

FAN PERFORMANCE

The performance[3] of the Blackhawk 60 exhaust and supply fans for a typical installation[4] is shown in FIGURE 6. The flow of standard air at the manufacturer's recommended operating static pressure of 0.00 in-wg (inches-water gage) (0 Pa) was 280 cfm (132 L/s) exhaust and 230 and 165 cfm (109 and 78 L/s) supply, with the fan on high and low respectively. These flow rates are for a typical installation. Less flow will be obtained for installations with longer ducts and more bends. Detailed fan curves are given in APPENDIX II to assist in calculating flows for different installations.

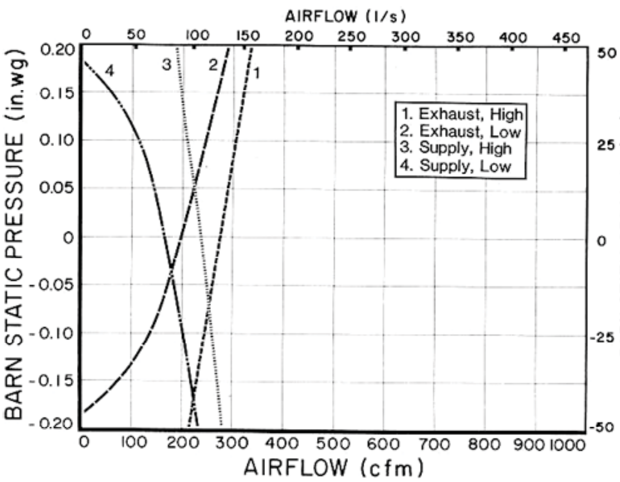

FIGURE 6. Heat Exchanger Airflow.

The operator manual indicated that a damper should be installed at the supply air inlet, and closed progressively as the outside air temperature fell below 32°F (0°C). The manual claimed that fresh air coming into the barn was much more dense than the barn air, and that damping off the supply airflow was necessary to balance the mass flow (weight of air per unit time) of the two airstreams. However, during the heat recovery tests, the fresh air leaving the heat exchanger was warmed sufficiently that its density was only slightly greater than the barn air density. Therefore, setting the damper as recommended for cold outside air temperatures resulted in the supply air mass flow being much less than the exhaust air mass flow. This greatly reduced the amount of heat recovered from the exhaust air, but also reduced the tendency for the core to freeze up. It is recommended that the operator manual be revised to correctly indicate the effect of damping off the supply flow.

Each fan was controlled by two switches on the fan module. The switches were not labelled, which made setting the fans confusing. It is recommended that the fan module be labelled to identify the on/off and speed selector switch for each fan.

HEAT RECOVERY

Standard Test Conditions: The amount of heat recovered by a heat exchanger depends on many factors, including the design of the heat exchanger; the supply and exhaust air temperatures; the barn relative humidity; the method of defrost used; and the amount of dirt, water and ice in the heat exchanger core. Therefore, to compare the performance of different heat exchangers, they must be tested under the same operating conditions. The Machinery Institute has selected the nine operating conditions listed in TABLE 2 as standard test conditions for heat exchangers.

Average Heat Recovery: This is the average rate at which sensible heat is recovered from the exhaust air at each standard test condition. It takes into consideration the defrost operation, during which no heat is recovered because the supply fan is switched off.

The average heat recovery gives a true indication of how much heat can be recovered by a heat exchanger at each standard test condition. It should not be used to compare the performance of different heat exchangers unless they have the same exhaust airflow.

The average heat recovery of the Blackhawk 60 at the manufacturer's recommended airflow settings[5] varied from 3800 Btu/h (1.1 kW) to 8000 Btu/h (2.3 kW) as shown in TABLE 2 and in FIGURE 7.

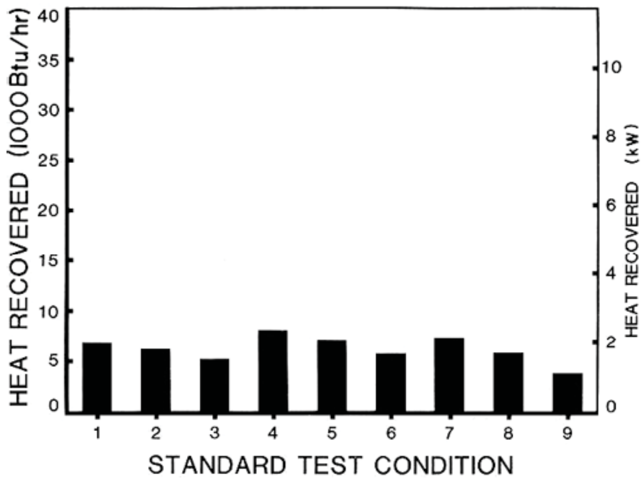

FIGURE 7. Average Heat Recovery.

Heat Recovery Ratio: When air is exhausted from a barn, it is cooled to the outside air temperature. The sensible heat lost by this air as it is cooled, is referred to as the exhaust heat loss. When the exhausted air passes through a heat exchanger, part of this heat is recovered and returned to the barn. It is impossible for a heat exchanger to recover 100% of the exhaust heat loss. However, expressing the average heat recovered as a percentage of the exhaust heat loss gives a good indication of heat exchanger performance. This expression is called the heat recovery ratio. The higher the heat recovery ratio, the better is the performance of the heat exchanger.

The heat recovery ratio of the Blackhawk 60 varied from 24% to 72% as shown in TABLE 2.

Effectiveness: Effectiveness is one measure of heat exchanger performance often stated in manufacturers literature. Although useful for design purposes, effectiveness can often be misleading as an indicator of heat exchanger performance. In particular, when the supply airflow is less than the exhaust airflow, a heat exchanger may have a high effectiveness, but may recover only a small amount of the exhaust heat loss.

In addition, effectiveness is not an average value and does not account for the defrost operation which can vary considerably among heat exchangers. The Machinery Institute therefore recommends that the heat recovery ratio be used, rather than effectiveness, to compare the heat recovery performance of heat exchangers.

LEAKAGE

The amount of air that leaked from the exhaust to the supply airstream during the Machinery Institute leakage test[6] was 18 cfm (12 L/s). This was 6% of the normal exhaust airflow. The test gives a relative indication of the amount of leakage occurring and may not equal the leakage across the core during normal operation.

POWER REQUIREMENTS

The Blackhawk 60 drew a maximum current of 1.92 A when plugged into a standard 120 V, 3 pin outlet. Average power required with both fans on high was 224 W.

SAFETY

The Blackhawk 60 was safe to operate if the manufacturer's instructions for servicing were followed.

The heat exchanger is not CSA (Canadian Standards Association) certified to meet the requirements of the Canadian

[3]Fan performance is given for standard air at a temperature of 59°F (15°C) and a barometric pressure of 29.9 in Hg (101.3 kPa) at sea level.

[4]Typical installation refers to the minimum length of ducting and number of bends required to install the Blackhawk 60 in a barn as outlined in the installation guide.

[5]The manufacturers recommended airflow settings for Machinery Institute standard test conditions were as follows: Close the supply inlet damper 20% for every 18°F (10°C) outside air temperature below 32°F (0°C). Run the exhaust fan on high speed for all tests. Run the supply fan on low speed for conditions 1 to 6 and high speed for conditions 7 to 9.

[6]See Machinery Institute Detailed Test Procedures for Air-to-Air Heat Exchangers.

Electrical Code. It is recommended that CSA certification be obtained for the heat exchanger.

TABLE 2. Heat Recovery Test Results at Standard Conditions.**

		STANDARD TEST CONDITIONS								
	Units	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Barn Air Temperature (70% Relative Humidity)	°F °C	75 24	65 18	50 10	75 24	65 18	50 10	75 24	65 18	50 10
Outside Air Temperature	°F °C	-22 -30	-22 -30	-22 -30	+5 -15	+5 -15	+5 -15	+32 0	+32 0	+32 0
Temperature of Air Entering Barn	°F °C	70 21	64 18	48 9	68 19	59 14	49 10	63 17	56 14	48 9
Exhaust Airflow	cfm L/s	284 134	284 134	284 134	284 134	284 134	284 134	284 134	284 134	284 134
Supply Airflow	cfm L/s	77 36	77 36	77 36	132 62	132 62	132 62	240 114	240 114	240 114
Exhaust Heat Loss	Btu/h kW	26500 7.8	24600 7.2	21100 6.2	19600 5.8	17400 5.1	13500 4.0	12700 3.7	9700 2.9	5300 1.83
Average Heat Recovery	Btu/h kW	6800 2.0	6200 1.8	5100 1.5	8000 2.3	7000 2.1	5700 1.7	7300 2.1	5800 1.7	3800 1.1
Heat Recovery Ratio*	%	26	25	24	41	40	42	57	59	72

**The heat recovery ratio is not the same as effectiveness, The Machinery Institute recommends that the heat recovery ratio be used rather than effectiveness to compare the heat recovery performance of different heat exchangers.*
***Barometric Pressure during the tests was: mean = 27.9 in-Hg (94.2 kPa); CV = 0.8%.*

OPERATOR MANUAL

The operator manual was clearly written and very well illustrated. It contained useful information on placement, installation, and maintenance of the heat exchanger. However, the manual did not give enough information on setting the fan controls, the conditions under which the core may freeze up, or the procedures to follow should the core freeze up. It is recommended that the operator manual be revised to include more information on these items.

DURABILITY RESULTS

Two minor problems occurred during the 110 days of operation. Two wires, which had been incorrectly connected in the factory, prevented the supply fan from running. Also, during end of season cleanup, the decals on the heat exchanger case washed off. It is recommended that the manufacturer use decals that will not wash off.

The intent of the test was to evaluate the functional performance of the machine. An extended durability test was not conducted.

APPENDIX I
SPECIFICATIONS

MAKE:	Blackhawk	
MODEL:	60	
OVERALL DIMENSIONS:		
-- heat exchanger body		
-length	60.38 in (1534 mm)	
-diameter	19.88 in (505 mm)	
-height (including drip tray)	21.25 in (540 mm)	
-- fan module		
-length	15.13 in (384 mm)	
-width	15.38 in (390 mm)	
-height	20.50 in (521 mm)	
OVERALL WEIGHT:		
-- fan module	27.0 lb (12.24 kg)	
-- heat exchanger body	54.5 lb (24.74 kg)	
CONSTRUCTION MATERIAL:		
-- external shell	ABS plastic	
-- internal core	polystyrene	
-- bonding	unknown	
DEFROST SYSTEM:		
-- method	supply fan automatically switched off for 20 minutes every 6 hours	
-- controls	no adjustments	

INLET AND OUTLET PORT DIAMETER:	**Exhaust**	**Supply**
	7.69 in (195 mm)	7.69 in (195 mm)
FLOW AREA OF CORE:		
-- inlet	73.6 in² (47500 mm²)	73.6 in² (47500 mm²)
-- outlet	16.5 in² (10600 mm²)	16.5 in² (10600 mm²)
PASSAGE SIZE:		
-- width	0.31 in (7.9 mm)	0.31 in (7.9 mm)
-- length	48.13 in (1222 mm)	48.13 in (1222 mm)
FANS:		
-- type	**propeller**	**propeller**
-fan size	8 in (202 mm)	8 in (202 mm)
-no. of blades	5	5
-blade pitch	30°	30°
-controls	2 speeds	2 speeds
-motor voltage	120 V	120 V

APPENDIX II

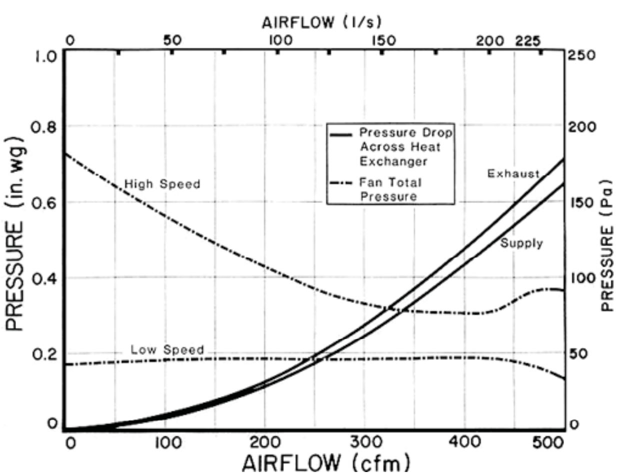

FIGURE 8. Fan Curves and Heat Exchanger Pressure Drop.

APPENDIX III
MACHINE RATINGS

The following rating scale is used in Machinery Institute Evaluation Reports:

excellent	fair
very good	poor
good	unsatisfactory

APPENDIX IV
CONVERSION TABLE

IMPERIAL UNITS	MULTIPLY BY	SI UNITS
Inches (in)	25.4	Millimetres (mm)
Feet (ft)	0.305	Metres (m)
Pounds Mass (lb)	0.454	Kilograms (kg)
Cubic Feet/Minute (cfm)	0.472	Litres/Second (L/s)
Pounds/Square Inch (psi)	6.89	Kilopascals (kPa)
Inches Mercury (in Hg)	3.39	Kilopascals (kPa)
Inches of Water Gage (in-wg)	0.25	Kilopascals (kPa)
1000 Btu/hour (Btu/h)	0.293	Kilowatts (kW)

APPENDIX V

HEAT RECOVERY EQUATIONS

Average Heat Recovery: $q_r = W_s C_p (t_2 - t_1) f$

Exhaust Heat Loss: $q_e = W_e C_p (t_3 - t_1)$

Heat Recovery Ratio: $R_q = 100\,(q_r/q_e)$

DEFINITION OF SYMBOLS USED

Symbol	Description	UNITS Imperial	UNITS S.I.
C_p	specific heat of air	Btu/lb°F	kJ/kg°C
f	fraction of time during which heat is recovered	—	—
W_s	mass flow rate of supply air	lb/h	kg/s
W_e	average mass flow rate of exhaust air	lb/h	kg/s
t_1	outside air temperature	°F	°C
t_2	average temperature of fresh air entering barn	°F	°C
t_3	barn air temperature	°F	°C
q_e	exhaust heat loss	Btu/h	kW
q_r	average heat recovery	Btu/h	kW
R_q	heat recovery ratio	%	%

SUMMARY CHART
BLACKHAWK 60 HEAT EXCHANGER

RETAIL PRICE: $1408.00 (August, 1983, f.o.b. Humboldt) Does not include insulated flexible ducting required for operation

	Evaluation	Comments
FAN PERFORMANCE		
Airflow in a Typical Installation	-- standard air	
Exhaust	280 cfm (132 L/s)	-- at high fan speed
Supply	230 cfm (109 L/s)	-- at high fan speed
	165 cfm (78 L/s)	-- at low fan speed
HEAT RECOVERY		
Average Heat Recovered at Outside Temperature of:		
	-22°F (-30°C) 6200 Btu/h (1.8 kW)	-- at exhaust air condition of +65°F (18°C) and 70% relative humidity
+5°F (-15°C)	7000 Btu/h (2.1 kW)	
+32°F (0°C)	5000 Btu/h (1.7 kW)	
Heat Recovery Ratio at Outside Temperature of:		-- The heat recovery ratio is not the same as effectiveness. The Machinery Institute recommends that the heat recovery ratio be used rather than effectiveness to compare the heat recovery performance of different heat exchangers.
-22°F (-30°C)	25%	
+5°F (-15°C)	40%	
+32°F (0°C)	59%	
LEAKAGE	12 cfm (6 L/s) 6% exhaust airflow	
EASE OF OPERATION AND ADJUSTMENT		
Installation	fair	-- about 3-1/2 hours for 2 men
Cleaning	fair	-- access to core inconvenient -- washing with low pressure water not completely effective
Adjustment		-- supply inlet damper settings difficult to judge
POWER REQUIREMENTS		
Voltage	120 V	
Average Power Consumption	224 W	
OPERATOR SAFETY	Good	-- Not CSA approved to Canadian Electrical Code
OPERATOR MANUAL	Fair	-- well written and illustrated -- incomplete information on setting fans and troubleshooting for core freeze-up

CAUTION:
This summary chart is not intended to represent the final conclusions of the evaluation reports. The relevance of the ratings is secondary to the information provided in the full text of the report. It is not recommended that a purchase decision be based only on the summary chart.

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