A HEAT EXCHANGER FOR LIVESTOCK SHELTERS

by

John R. Ogilvie
Member C.S.A.E.

Department of Agricultural Engineering
Macdonald College of McGill University
Macdonald College, P.Q.

INTRODUCTION

Sufficient animal heat is produced in most animal shelters at normal stocking rates to maintain desired temperatures within the shelter. The heat production, however, is in the form of both sensible and latent heat. The moisture associated with the latent heat and that evaporated from floor surfaces must be removed from the shelter. Normal practice has been to draw out quantities of the humid shelter air and allow equal amounts of outdoor air to enter the shelter. If the desired shelter temperature and humidity are to be maintained, sufficient heat must be available to warm the incoming air. In this climate continuous low temperatures exist often enough that the requirements of heat for loss through the building components and for warming incoming air exceed the sensible heat available from animals, lights and motors.

Since the heat available within the shelter has been transferred to the shelter air, it is hoped that an air to air heat exchanger might recover much of the available heat from any exhaust air and transfer this heat to the incoming fresh air. Condensation of the moisture in the exhaust air might release heat to the incoming air through the walls of the heat exchanger without allowing the moisture to enter the incoming air. This investigation considers the heat transfer, air flow and flow resistance characteristics of one type of air to air heat exchanger.

Equipment developed as a result of this and subsequent investigations in the same area may allow for maintenance of optimum temperature and humidity conditions within the animal shelter without the use of supplemental heat from hydrocarbon fuel or electricity.

LITERATURE REVIEW

Giese and Downing (3) used a multitube, forced air, parallel flow heat exchanger installed in a dairy cattle stable to transfer heat from the exhaust air to the intake air. This type of exchanger in this installation recovered 41-48.5 per cent of the heat in the exhaust air. Giese and Ibrahim (4) used a counterflow, multitube, forced air heat exchanger of the same design as that used by Giese and Downing and installed this unit in a dairy cattle shelter and in a poultry shelter. Giese and Bond (5) developed a plate type counterflow heat exchanger and in a laboratory study used the unit with humidified air to determine heat exchange characteristics. The efficiency of the unit was such that 50-70 per cent of the total heat in the exhaust air between the incoming and outgoing air temperatures was recovered. Turnbull (7) tested a commercial perpendicular flow plate type heat exhanger and determined its efficiency of heat reclamation to be 20 per cent.

THE INVESTIGATION

The study reported here was initiated to develop an efficient heat exchanger that might cope with some of the problems encountered in earlier studies such as condensation, dust and icing. It was considered that external mounting would be desirable to avoid reconstruction problems internally in an animal shelter. The unit might also fit over existing ventilation systems and hence reduce the cost. A plate type counterflow unit (figure 1) similar to that developed by Giese and Bond (5) was constructed using corrugated aluminum sheets 0.0457 centimeters (0.018 inches) thick. There were 40 sheets of this material approximately 38 centimeters (15 inches) wide by 183 centimeters (72) nches long and spaced 0.635 centimeters (0.25 inches) apart. The sheets were stacked flat-side to flat-side and held apart with leather spacers mounted on a rod which pierced the sheets. The resultant area of heat exchange surface was 30.45 square meters (327 square feet).

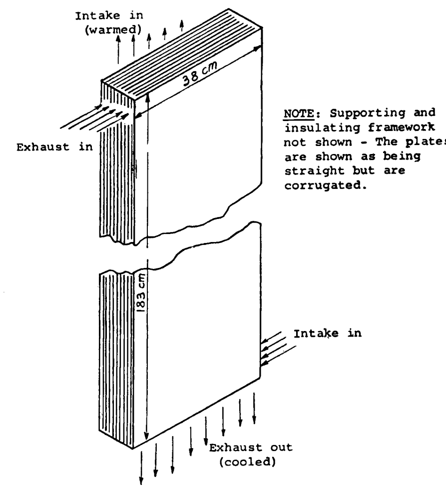

Figure 1. Plate-Type Counterflow Heat Exchanger Unit.

The exchanger was mounted vertically and exterior to the laboratory building with ducts to guide the cold and warm air (figure 2). The warm air entered the exchanger at the top of the unit on the side so as to enter alternate spaces between the sheets. The discharge was out the bottom of the unit directly. The cold air entered the bottom of the exchanger in the opposite corner to the warm air and moved di-

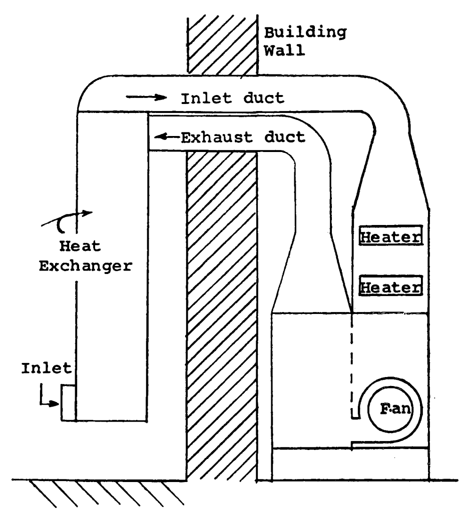

Figure 2. Cross-Section Through System.

rectly out the top through alternate spaces.

A closed circuit system was constructed in order that incoming and outgoing air quantities would be equal. Electric heaters were used to simulate livestock shelter temperature. Provision was made within the system to allow the introduction of contaminants but for the purposes of this paper these will not be considered.

In order to determine temperature variations within the heat exchanger, copper constantan thermocouples were installed at various locations. Since spacing was narrow between the plates a means of isolating the thermocouple from the metal surface was devised. This consisted of wrapping the junction with a thin foam rubber material and covering the whole with plastic tape. A cable of these thermocouples and their leads was made by wrapping the bundle at intervals with plastic tape. A cable was made for the incoming air channel and one for the exhaust air channel. One of the junctions was placed at the bottom of the unit to sense the lowest outdoor air temperature by protruding into the air stream at the inlet. Others at 30.5 centimeters (12 inches) apart sensed the incomng air temperature up one of the intake spaces. A similar arrangement was used in the exhaust space with the lowest thermocouple sensing the exhaust air stream after it passed through the exchanger.

Multiple U tube manometers were used to determine the resistance to air flow. These tubes were mounted on a table capable of adjusting to various angles in order to obtain greater accuracy with small pressure differentials.

Air flow was determined by traversing a section of the intake and the exhaust duct with a hot wire anomometer in a grid pattern. Checks on values determined in this manner were made with manufacturers specifications and with the known electric heat input versus change in total enthalpy of the air passing.

RESULTS AND DISCUSSION

The heat exchanger operated with an efficiency of between 65 and 70 per cent. The laboratory model permitted measurements at any time or season. The electric heaters and the closed system guaranteed a known heat supply and equal air flow on both sides of the exchanger.

In calculating the heat exchanger efficiency, the ratio of temperature increase of the incoming air to the total difference in temperature between the incoming and exhaust air was used.

$$E = \frac{t_i^2 - t_i^1}{t_e^1 - t_i^1}$$

where t_i^1 = temperature of incoming air at entrance

t_i^2 = temperature of incoming air at exit

t_e^1 = temperature of exhaust air at entrance to exchanger

The efficiency of the unit remained constant in the various trials. While it is possible to move more air through a heat exchanger of this type by widening the spaces between the sheets to reduce friction drag, this action lowers the efficiency of the unit.

The heat exchange from exhaust side to incoming side of the exchanger varies with the temperature difference on either side of the plate forming the division. For this unit the total heat exchange is shown in figure 3. This

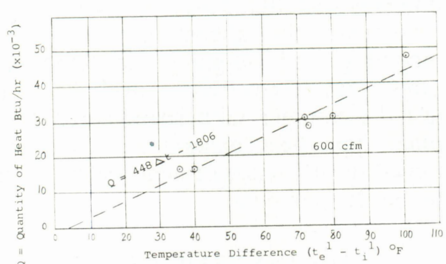

Figure 3. Total heat Exchange Versus Temperature Difference.

graph shows the heat exchange versus $t_e^1 - t_i^1$. This graph does not give a 'U' value or overall heat transfer coefficient. The total exchange Q is a function as shown:

$$Q = UA\theta_m$$

where U = overall heat transfer coefficient Btu/hr — °F — ft^2

A = area of exchange surface, ft^2

θ_m = true mean temperature difference °F

$$\text{and } \theta_m = \frac{t_2 - t_1}{\log_e \frac{t_2}{t_1}}$$

where t_2 = higher temperature difefrence between incoming and exhaust air at one end of exchanger

t_1 = lower temperature difference between incoming and exhaust air temperature at the other end °F

The overall 'U' value ranged from 3.84 to 5.06 Btu/hr — ft^2 — °F which is higher than the predicted by theoretical values in the ASHRAE Guide (6). The air film coefficient listed therein for air is $h = 0.5(v)^{0.8}$ and hence a value such as h = 5.0 is expected. Since the aluminum sheet offers little resistance, the overall 'U 'value equals h/2 = 2.50 Btu/hr — ft^2 — °F. Larger values as found in this investigation might be due to more turbulence induced by the method of introducing air to the unit. Bond (5) obtained a 'U' value of 1.83 for the same spacing of sheets.

The results shown are for an exchanger air flow of approximately 600 cfm (2200-2800 lb. per hour). This air flow resulted in a static pressure of 0.20 inches of water on the exhaust side and 0.18 inches of water on the intake side. The unit was operated at this air flow since normal propeller fans do not operate satisfactorily at pressures higher than this.

The thermocouples within the body of the exchanger were very useful. There thermocouples indicated the air stream temperature on each side of the aluminum and also indicated the probable temperature of the air leaving the exchanger, either incoming or exhaust. Serious errors were averted on occasions when one of the thermocouples sensing the critical terminal temperatures became displaced and did not sense the correct temperature. The reading was quickly observed as incorrect on the recording apparatus as it did not line up with the other points of temperature change within the exchanger.

SUMMARY AND CONCLUSIONS

This exchanger operated within the range of air flow and static pressure normally available from propellor fan ventilation systems. The efficiency of heat transfer was 65 to 70 per cent. The exchanger functioned well in the vertical position. The straight through exit allowed for use of more of the exchanger surfaces than a side exit. The unit removed heat from the exhaust air at the rate of Q = 448△t — 1806 Btu/hr when used at 600 cfm. Further work is planned with this unit to evaluate the effect of dust and humidity in the air.

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in the balance sheets without any fear of their soil getting too dry. This deserves considerable weight in assessing the value of scheduling.

The second question is, which is the more reasonable procedure, use of formula 1 or formula 2? Interviews with a large number of growers indicate a natural tendency to irrigate without stop during the heat of the summer, irrespective of whether or not they can get around faster with the sprinkler lines than they need to. Perhaps somewhere between formula 1 and formula 2 would be more nearly correct.

The use of canal flow as a basis for normal irrigation may be subject to some question. Some leakage occurred along the canal, and some excess water was discarded over spillways. It was not possible to determine whether or not leakage and spilling were proportional to water use. It is conceivable, therefore, that savings calculated on this basis may not be entirely accurate; on the other hand, there is no good reason for discounting the results obtained.

In spite of the above qualifications, it is obvious that in this investigation substantial savings in water and time were effected by scheduling; and this was accomplished with (as far as is known) complete security in so far as maintenance of soil moisture within the optimum range was concerned.

The re-designing of growers' irrigation systems brought about negligible savings in time and water. The growers were, of course, specially selected. On the whole, they were not applying too much water at each application prior to 1962. Many growers, however, do apply excessive amounts of water (3). Scheduling provides a means whereby advice can be given with respect to the design of the sprinkler system, and this has been found to save much water in individual cases where growers are doing their own scheduling. The additional contacts brought about between extension personnel and growers constitute a distinct benefit from the ...duling procedure.

SUMMARY

...s were scheduled for four ...rchards on soil types vary- ... soil texture and depth. ... by the sprinkler method ...rtable lateral lines. As compared with steady irrigation, scheduling saved from 25 to 54% of the water and operating time, depending on the year and the method of measurement. Estimates were also made of normal savings without scheduling. Measurement of canal flow showed average use of 88% and 95% of peak use in 1964 and 1965 respectively. Adjusting for this, scheduling by growers brought about net savings of from 15 to 55% of the water and time. A similar study based on a closed system in 1965 showed net savings of 25 to 32% as a result of scheduling. It is concluded that scheduling can save much water and operating time, without fear of adverse effects on the soil moisture content.

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