SOME FIELD EXPERIMENTS WITH METHODS OF ESTIMATING THE VENTILATION RATE IN ANIMAL HOUSES

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1. Introduction

The inadequacies of natural ventilation systems when farm animals are housed intensively has compelled an interest in ventilation processes and problems. Housing has perhaps developed furthest for poultry and pigs, where controlled environment houses are common place, but housed 'broiler calves', beef cattle and sheep are of growing importance.

The term 'controlled environment house' is something of a misnomer, for in practice this often means simply the maintenance of a fairly constant internal temperature level. The constant temperature is achieved through ventilation fans tripped by thermostats. The ventilation rate of the building is an important factor in the health and productivity of the animals (Smith 1963), but as long as the external air is taken directly and without modification into the house, then the ventilation rate is a variable quantity, dependent upon the external conditions. There are of course many practical variations to the ventilation system outlined above, but the dependence on the external conditions can only be removed by full air conditioning.

There is an interest then in a simple method of determining ventilation rates, for the ventilation rate has a bearing on the efficiency of production and on housing costs. Condensation is a major problem in the poorly ventilated house and affects its useful life and the cost of its maintenance.

2. The relation between internal and external atmospheres

The assumption that conditions change but slowly inside and outside the house enables us to set up balance equations. At the steady state, the rate of production of heat and moisture by the animals within the house is equal to the rate at which heat and moisture is removed, primarily by the air passing through the house, and we may write

Moisture balance $$\omega = W . \Delta M \qquad (1)$$

Heat balance $$h + h_a = W . s . \Delta\theta + C\,\Delta\theta \qquad (2)$$

where
- ω = moisture produced/animal/hour
- W = mass of air passing through the house/hour
- ΔM = moisture increment of the air leaving over that entering the house
- h = sensible heat production/animal/hour
- h_a = additional space heating supplied/animal/hour
- s = specific heat of air
- $\Delta\theta$ = temperature increment of the air leaving over that entering the house
- C = conductance heat loss through the fabric of the building/animal/hour/deg. F.

As a first approximation, the heat and moisture output of an animal of given weight may be regarded as known. The effect of changing environmental demand and the diurnal variations of output due to feeding habit and rest are then ignored.

A variable radiative and convective heat loss from the building is not taken into account except in so far as the value adopted for the air to air heat transmittance of the building is a function of orientation and degree of exposure to wind. The loss is compensated by a solar heat gain, but the resultant changes of the temperature of the external surface are attenuated at the internal surface. With the standard of insulation adopted for the better houses, the effect on the internal heat balance is likely to be small.

Should it be thought necessary, a procedure is available for calculating the solar heat gain through walls and roofs, together with an estimate of the time lag before the gain becomes apparent internally (I.H.V.E. Guide, 1959).

Heat and moisture production within the house, other than by the animals, needs consideration. Supplementary space heating by fuel oil or gas burnt within the house necessarily gives an output of water vapour and the amounts are always important. Evaporation from drinkers can probably be safely ignored. The frequency and method of removal of faeces and urine has an obvious bearing on conditions within the house. The bacterial decomposition of any bedding or deep litter gives a further source of heat and moisture. The wild heat produced by any electrical equipment can in general be ignored.

Values for the heat and moisture production of poultry and calves, the only animals considered in the present series of experiments, are shown in an appendix, together with estimates of certain supplementary outputs.

3. Estimation of the ventilation rate through psychrometer readings

(i) Theory

It is readily seen from equations (1) and (2) that if the heat and moisture production within the house is known, then a measurement of the temperature and moisture difference between the internal and external atmospheres give an indication of the ventilation rate. The only additional information required is an estimate of the conductance heat loss. If the details of the construction of the building are known, this particular calculation is straightforward and the method is illustrated in an appendix.

The psychrometer enables a rapid survey to be made under conditions of standard exposure, and wet and dry bulb readings may be converted to show the moisture content of the air with the aid of a psychrometric chart, figure 1.

(ii) Practical problems

As far as I am aware, use has not before been made of the procedure suggested.

Some of the approximations and assumptions made in the simple statements of the balance equations have already been discussed. The success of the method is dependent upon a satisfactory estimate of the heat and moisture production within the house and this may vary from house to house and with the system of animal management adopted. We might perhaps expect different results in a house where all droppings were retained until such times as the animals were cleared, e.g. deep litter broiler house, as compared with an animal house where droppings were washed away daily and where standing pools of water were usual.

Any survey within a given house might be expected to reveal the existence of temperature and moisture gradients. The psychrometer will certainly register fluctuations in the external conditions. It becomes necessary to devise an adequate sampling technique and possibly to define a standard procedure or position for measuring temperatures.

(iii) The procedure adopted

To achieve consistent results between the heat and moisture balance methods and results consistent with other independent estimates of the ventilation rate, it was found necessary to operate in equations (1) and (2) with the maximum differences recorded between the internal and external atmospheres. A mean of say 10 readings at various points within a house, where ventilation inlets exist on all sides, is likely to be biased toward the lower external values and to give an over estimate of the ventilation rate. In general extractor fans operate at high level (in the ridge) and in the later work, observations within the houses were concentrated near to the extract fans where, this was practicable. Observations of the external conditions were taken both before and after the observations within the house.

With poultry it was assumed that droppings were retained within the house and that the total heat and moisture output of the birds needed to be taken into account; with broiler calves droppings were run off quickly as a slurry and only the evaporative loss of the animals was important.

Moisture production of the litter was ignored except in so far as it was assumed that the water excreted by the birds was vaporised by the litter. A correction for the moisture output of any space heaters was always made. An allowance for sensible heat transfer from the litter to the air was made when the bulk temperature of the litter exceeded that of the air by 15 degs. F. or more, provided the litter covered the entire floor.

4. Estimation of the ventilation rate with the aid of a radioactive tracer gas

(i) Theory

A tracer gas is introduced into the house and a uniform concentration achieved by some method of mixing. Air passing through the house now removes some of the tracer gas and the rate of change of concentration, measured with a suitable detector, gives an estimate of the ventilation rate.

If mixing is complete, the kinetics of the decrease in concentration of the tracer gas are those of a first order reaction and we may write the rate of change of concentration as

$$-\frac{dC}{dt} = N.C.$$

where C = concentration of tracer gas
N = a constant

(N) is interpreted by placing (C) equal to unity, and is the amount of tracer gas removed in unit time if the concentration is always maintained at unity. Thus (N) is seen as the number of volume changes in unit time.

On integration we have

$$N = \frac{1}{t} \ln \frac{C_o}{C_t} \qquad (3)$$

where C_o = initial concentration of tracer gas
C_t = concentration at the end of time t
N = number of volume changes in unit time.

(ii) Practical problems

The method has been used successfully in domestic accommodation and in larger public buildings where the ventilation was by natural means and where air movements of the order two or three changes per hour enabled the condition of an initial uniform concentration of the tracer gas to be met.

There are obvious sampling difficulties in attempting to apply the technique to an occupied animal house if the proliferation of expensive equipment is to be avoided. For the house may possibly be some 250 feet in length, with air inlets along the length of each side and with a forced ventilation system effecting up to 40 air changes per hour. The animals will in general react to any unusual or sudden happening and their movement may need to be confined. The nature of the flooring i.e. deep litter, wire mesh or slats may prevent the movement of heavy equipment around the house for a rapid survey.

With 40 volume changes per hour, equation (3) indicates that the concentration of the gas will be reduced to one half of its initial value in something less than five minutes. At 20 volume changes per hour, the figure is something less than 10 minutes.

The concentration of the tracer gas is taken as proportional to the flux of emitted particles and to the number of these intercepted by a Geiger-Muller tube. The input from the G. M. tube to a ratemeter will be random in time and fluctuations in the counting rate will be observed. The accuracy of the observations is dependent upon the concentration of the tracer gas employed. For if a count of (n) pulses per second is recorded, the standard error of the observation is $\pm\sqrt{n}$. If a standard error of $\pm$ 5% on a single reading is acceptable, then a counting rate of 400 pulses/second is required. Since limitations on the accuracy were in any event imposed by the initial concentration of the tracer gas desirable for the animals or the observer, little further accuracy was lost by controlling the fluctuations in the counting rate about some mean value by varying the time constant of the measuring circuit.

(iii) The procedure adopted

The tracer gas employed was Krypton (Kr^{85}). It is primarily a beta emitter, with a half life of about 10 years. The particles are soon absorbed in a normal atmosphere and the major contribution to the counting rate comes from a sphere of some 25 cms. radius around the detector.

The recommended concentration of gas of 0.1 millicuries per 1,000 cubic feet gives a counting rate of around 1,000 pulses/minute.

In view of the probable rapid change of concentration of the tracer gas, an initial concentration greater than 0.1 millicuries per 1,000 cubic feet was at times adopted. Equation (3) indicates that a plot of counting rate against time on semi logarithmic paper should give a straight line. The plots obtained tended to depart from this and to be more in the nature of hyperbolae as time progressed. For this reason, after some rapid initial mixing of the tracer, spot readings of the counting rate were taken at one minute intervals for a period of five to fifteen minutes. At the end of this time, readings were commonly approaching the background count.

The measuring apparatus consisted of a general purpose ratemeter (A.E.R.E. type 1037C) capable of indicating a mean pulse repetition rate of 1 to 10^5 pulses per second and a probe unit (A.E.R.E. type 1014) which supplied pulses of fixed amplitude to the ratemeter after triggering by the G.M. tube. The probe unit was modified to carry the tube directly, so that both probe unit and tube could be moved as a single piece of apparatus. The maximum permissible separation of the probe unit and ratemeter was 12 feet.

It is necessary to bear in mind that only a single source of gas could be released at any one time and that the detecting equipment was largely immobile.

In a house where some attempt could be made to obtain an initial uniform concentration, the following procedure was adopted. The tracer gas, supplied in a glass phial, was placed in a rubber tube attached to a blower motor at ground level and behind which was a portable fan. With the ventilation openings closed as far as was practicable, the phial was broken with a sharp blow. The gas was blown down the tube, away from the operator and was dispersed throughout the house by the portable fan. After a suitable interval, the normal forced ventilation system was brought into play and the rate of change of concentration of the tracer gas followed with the detector placed as close as convenient to one of the extractor fans.

It is recognised that in animal housing the pattern of air flow is important as well as the overall ventilation rate. For this reason it is preferable to install a large number of small fans, each effecting some ventilation at all times but capable of an increased fan speed if necessary, rather than to install a fewer number of larger fans which cut in and out. In the first case, the pattern of air movement is reasonably constant and uniform throughout the house, but in the second case, the pattern will change from time to time. It is not unknown for an extractor duct to act as inlet when the fan is switched off.

In a house whose dimensions ruled out the possibility of obtaining an initial uniform concentration of the tracer gas, the method was nevertheless employed in the hope that the uniform pattern of air movement throughout the house could lead to useful results if we operated on a typical cross-section. For example a 200 foot broiler house may have 9 extractor fans in the ridge and uniform inlets along both sides of the house. In such a case, the tracer gas was released beneath a central extractor fan and blown at ground level toward an adjacent extractor fan. After a short initial mixing period, the complete extraction system was brought into operation and the change of concentration of the tracer gas recorded. The detector was set close to the extractor fan to which the mixing fan had directed the bulk of the gas.

5. Estimation of the ventilation rate through fan rating

(i) Theory

Fan manufacturers have a standard procedure for arriving at the characteristics of their products. If the fan dimensions and speed are known, together with the resistance to air movement of the ventilation system in which the fan operates, then manufacturers catalogues will indicate the volume of air moved through the system in unit time.

(ii) Practical problems

A visit to an animal house will probably reveal that even if the fans are being used as intended by the manufacturer, the nominal fan rating is unknown. One must suspect that the fans are no longer 100% efficient for want of maintenance. In any event, the resistance of the ventilation system in which the fan operates will be an unknown quantity, although estimates can be made. In a large house with many fans there may be a complicated control system with some fans operating continuously or on a time switch, the remainder cutting in and out at varying speeds at increasing temperature levels. The rate of air movement at any one time becomes difficult to assess. Wind pressure effects are known to seriously interfere with fan working on occasions, unless certain precautions such as baffling are taken.

An important element in any house is likely to be the presence of adventious air inlets and outlets.

(iii) The procedure adopted

Where information could be obtained from the farmer or from manufacturers catalogues, the fan rating was used to indicate an order of magnitude for the air movement. In a large house, with fans cutting in and out continuously no great confidence could be placed on the result.

The presence of adventious openings was ignored, although in a badly constructed house it has been estimated that between 20 and 80% of the total air movement through the house may be due to infiltration (Payne, 1961).

6. Comparison of results

The heat and moisture balance methods are not completely independent and in view of the approximations involved, comparison with some standard techniques of estimating ventilation rate was desirable.

Table 1 shows the results when simultaneous experiments were made. The table shows the order in which the houses were visited and in the early stages, the practical procedures were being evolved.

Because of the dependence of the ventilation rate on the variable external conditions, an estimate at any one time which is accurate to within 5 or 10% is probably adequate. Table 1 shows that this is the order of agreement between the three methods employed.

7. Recommended procedure

Simplicity suggests a use of the psychrometer technique. External readings should be taken both before and after the internal survey which should be concentrated around the known outlets. The maximum temperature and moisture differences observed between the internal and external atmospheres should be employed in the calculations. A mean of the results from the heat and moisture balance methods should be adopted.

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Table 1

Comparison of results of methods of estimating ventilation rate

Characteristics of house	Air Change rate per hour					Comments
	Heat balance	Moisture balance	Rounded mean	Tracer gas	Fan rating	
1. Broiler house. Dimensions 250' x 36' x 5' to eaves x 12' to ridge.	13.1	12.6	13	-	-	7,500 young birds. Extract fans in ridge & side inlets. Deep litter. Supplementary gas heating.
2. Broiler house. Dimensions 250' x 45' x 5' to eaves x 14' to ridge.	8.9	10.9	10	-	-	11,500 young birds. House adjacent to house number 1 and with a similar system.
3. Battery house. Dimensions 65' x 18' x 8' to eaves x 12' to ridge.	21.3	17.9	20	18	-	Total of 1,100 birds in two tiers. Natural ventilation. Many adventious openings.
4. Battery house. Dimensions 70' x 19' x 8' to eaves x 10' to ridge.	41.8	34.9	38	-	30-40 Estimate 37 if fans efficient	Total of 2,000 birds in 2 tiers. Fans in ridge, side inlets
5. House 4 on a subsequent occasion.	44.7	45.6	45	40	37	-
6. Broiler house. Dimensions 210' x 30' x 6' to eaves x 13' to ridge.	13.2	10.3	12	13	12-36 Estimate 14 if fans efficient	8,300 birds. Fans in ridge and side inlets. Deep litter.
7. Broiler house. Dimensions 175' x 35' x 5' to eaves x 12' to ridge.	15.3	9.0	12	-	12-36	6,300 birds. Adjacent to house number 6 and with a similar system.
8. Calf house. Dimensions 33' x 15' x 6' to eaves x 10' to ridge.	24.1	23.5	24	-	25-34 Estimate 25 if fan efficient	28 calves. Fan extract through ducting at low level at one end. Air entry through straw at other end.
9. Calf house. Dimensions 32' x 16' x 8'.	27.2	21.5	24	-	25-34 Estimate 25 if fan efficient	28 calves. Fan extract at one end. Air entry through peg board in roof. Adjacent to house number 8.

Appendix

1. Basic data

Information presented in figure 2 on the heat and moisture production of chickens is based on the data of Sainsbury (1961) and Mitchell (1933). The information presented for calves in figure 3 has been deduced from the data of Blaxter (1962), Ritzman and Colovos (1943) and Yeck (1956).

2. Heat and moisture output of the litter

Stapleton and Cox (1950) have presented experimental data on this for poultry litter but the attempt must be regarded as unsatisfactory. The litter output was obtained as a residual after other components of the heat and moisture balance equation had been estimated. Elementary observations such as the area of the litter and its temperature were not reported.

A theoretical approach can indicate an order of magnitude. McAdams (1942) recommends as a simplified expression for the natural convective heat transfer coefficient (h_c) appropriate to a horizontal plate facing upwards.

$$h_c = 0.38\,(Ts - Ta)^{0.25}$$

and the resultant heat transfer (q_c) is

$$q_c = h_c\,(Ts - Ta) \text{ B.t.u./sq. ft./hour}$$

where Ts = temperature of plate surface (deg. F)
Ta = bulk temperature of the air.

The additional heat transfer by radiation (q_r) is usually substantial and of the same order as the convective loss for the temperature differences of interest in the present problem. A standard expression takes the form.

$$q_r = 0.173\,E\left[\left(\frac{Ts}{100}\right)^4 - \left(\frac{Ta}{100}\right)^4\right] \text{ B.t.u./sq. ft./hour.}$$

where E = emissitity of the plate surface = 0.9.

These expressions for (q_c) and (q_r) approximate closely to those developed in the I.H.V.E. Guide (1959) for the theoretical heat transmission from plane surfaces. The numerical values tabulated below are for practical purposes identical with both methods of treatment.

Table 2

Theoretical heat transmission from a floor to the air (B.t.u./sq. ft./hrs.)

ΔT (deg. F)	q_c	q_r
5	3	4
10	7	9
15	11	13
20	17	17
25	22	23
30	29	27

where ΔT = (effective temperature of the surface for the process under consideration) $-$ (Ta)

To obtain an order of magnitude for the heat transfer from a litter floor to the air, the following factors need to be borne in mind.

Presumably, as in forced convective heat transfer we must regard the effective surface temperature for natural convection to be that of a bound surface film of air, whose temperature (T_f) is given by

$$T_f = \frac{Ts + Ta}{2}$$

and the effective temperature difference for convective process becomes

$$\Delta T = T_f - Ta = \frac{Ts - Ta}{2}$$

Now the true temperature of the litter surface (Ts) is not as readily obtained as the bulk temperature of the litter (T_L). (Ts) is a function of the thermal conductivity of the litter, the rate at which heat is generated within the litter and the net heat loss from its upper surface.

If we assume

$$Ts' = \frac{T_L + Ta}{2}$$

then

$$\Delta T = T_f - Ta = \frac{Ts - Ta}{2} = \frac{T_L - Ta}{4}$$

Natural convection presupposes a cellular vertical motion. In practice we are likely to find this pattern of air movement interfered with by the pattern imposed by the forced ventilation system and an air motion parallel to the litter surface. Such a pattern of air flow will reduce the rate at which heat is transferred from the litter to the air, it is suggested by a factor of the order one half.

We assume a stocking density of one bird per two square feet of litter and that the surface of the litter exposed to convective and radiative transfer processes is one square foot/bird. We have argued that the effective temperature difference for convective heat transfer (ΔT of table 2 is of the order $\frac{1}{8}(T_L - Ta)$. In practice $(T_L - Ta) \leq 10^\circ$F. is common and $(T_L - Ta)$ is seldom likely to approach 40°F, and then only if the litter is used more than once for adult birds. In this way we place an upper limit to the convective heat transfer from the litter to the air as 3 B.t.u. per hour (if the birds are adult).

For radiative transfer we obtain an effective temperature difference (ΔT of table 2) as

$$\Delta T = Ts - Ta = \frac{T_L - Ta}{2}$$

For common values of the litter temperature i.e., $(T_L - Ta) \leq 10^\circ$F, the net transfer of heat by radiation and convection to the air is likely to be less than 10% of the sensible heat output of the adult bird and may in general be neglected in our computations.

It has already been indicated that we assume that all the water in the droppings is vaporised by the heat generated in the litter. The water produced as an end product of the fermentation processes in the litter has been assumed to be retained in the litter.

3. Heat and moisture output of fuels

The net calorific values of common fuel oils are of the order 18,000 to 20,000 B.t.u. per pound. One pound of fuel when burnt produces about 11,000 grains of water vapour.

4. Calculation of the conductive heat loss for Building

(i) "U values" of components

The resistance which a building offers to the conductive flow of heat through it is dependant upon the nature and thickness of the materials used in the construction. Air films at the internal and external surfaces add to the total thermal resistance.

The heat transfer by conduction (H) through the fabric of the building may be written as

$$H = \frac{\Delta\theta}{R}$$

where $\Delta\theta$ = difference between the bulk temperature of the air inside and outside the building.
R = total thermal resistance of the fabric.

The heat transfer (in B.t.u.) through unit area (1 sq. ft.) of any component of the building in unit time (1 hour) for an air to air temperature difference of one degree F is known as the "Thermal transmittance coefficient" or "U value" of the component. From the above we see that

$$U = \frac{1}{R}$$

The total thermal resistance (R) of a component of a structure is obtained by summation of the resistances of the successive layers which make up the component

i.e. $$R = \frac{1}{U} = Ri + Re + r_1 L_1 + r_2 L_2 + etc. + Ra + Rh$$

where Ri = internal surface resistance (due to air film)
Re = external surface resistance
r_1, r_2 etc. = resistivity of successive layers
= resistance of layers of 1 inch thickness
$L_1 L_2$ etc. = thickness of successive layers
Ra = resistance of any internal air gap.
Rh = resistance of material such as hollow blocks for resisitivity per inch thickness is not appropriate.

Example

We compute the "U value" of a $4\frac{1}{2}$ inch brick wall faced with 4 inches of concrete and lined with a $\frac{1}{2}$ inch fibre board. The fibre board is faced with reflecting aluminium foil and there is a $\frac{3}{4}$ inch air gap between the fibre board and the concrete.

Material	Thickness	Resistivity	Resistance
Brickwork	4.5	x 0.125	.56
Concrete	4.0	x 0.100	.40
Fibre-board	.5	x 1.54	.77
Air gap			2.00
Internal surface			.70
External surface			.45
		Total resistance	4.88

"U value" = $\frac{1}{4.88}$ = 0.20

Resistivity values for typical materials are given below.

(ii) The heat loss calculation

As an example we compute the heat loss of a single storey building 200 ft. x 30 ft. x 5 ft. to eaves x 10 ft. to ridge. The side walls are of 9 inch brick, the end walls of 1 inch tongued and grooved wood, the floor is of concrete and the roof is corrugated iron lined with insulating board. There are 5 windows, each of 20 sq. ft., on either side. Typical "U values" are adopted

Component	Area		U value	Loss B.t.u./hour/deg. F
Side wall	2,000	x	0.47	940
End wall	500	x	0.50	250
Windows	200	x	1.00	200
Roof	6,400	x	0.30	1,920
Floor	6,000	x	0.05	300
			Total loss	3,610

The loss through the floor is assumed to take place primarily through the exposed edges. If the temperature lift of the inside air over the outside air is 20°F, the total conductive heat loss is 3,610 x 20 = 72,200 B.t.u. per hour.

(iii) Typical numerical values

"U values" are commonly quoted to two decimal places, suggesting considerable exactness. However, the exchange of heat between a structure and the external atmosphere is dependent, among other things on the degree of exposure (or forced convective heat loss) and orientation (or solar heat load). With farm buildings, we shall usually be concerned with structures having a "normal exposure". If the buildings are placed on hill sites, the coast or by a riverside, the "normal U values" should be multipled by a factor 1.1 for walls and 1.2 for windows and roofs. To avoid a multiplicity of tables, the variations due to orientation have not been presented, but we show average values. Further details, together with information on most materials in use in buildings are shown in the I.H.V.E. Guide.

Internal Resistance

Walls	0.70
Floor	0.85
Roof	0.60

External Resistance

Walls	0.45
Roof	0.25

Air Spaces

Closed space $\frac{1}{4}$ inch wide or more	0.65
faced with reflective material	1. 0
Closed space $\frac{3}{4}$ inch wide or more	1. 0
faced with reflective material	2. 0
Open, ventilated space	0.65

Resistivities (Resistance of 1 inch slabs of material)

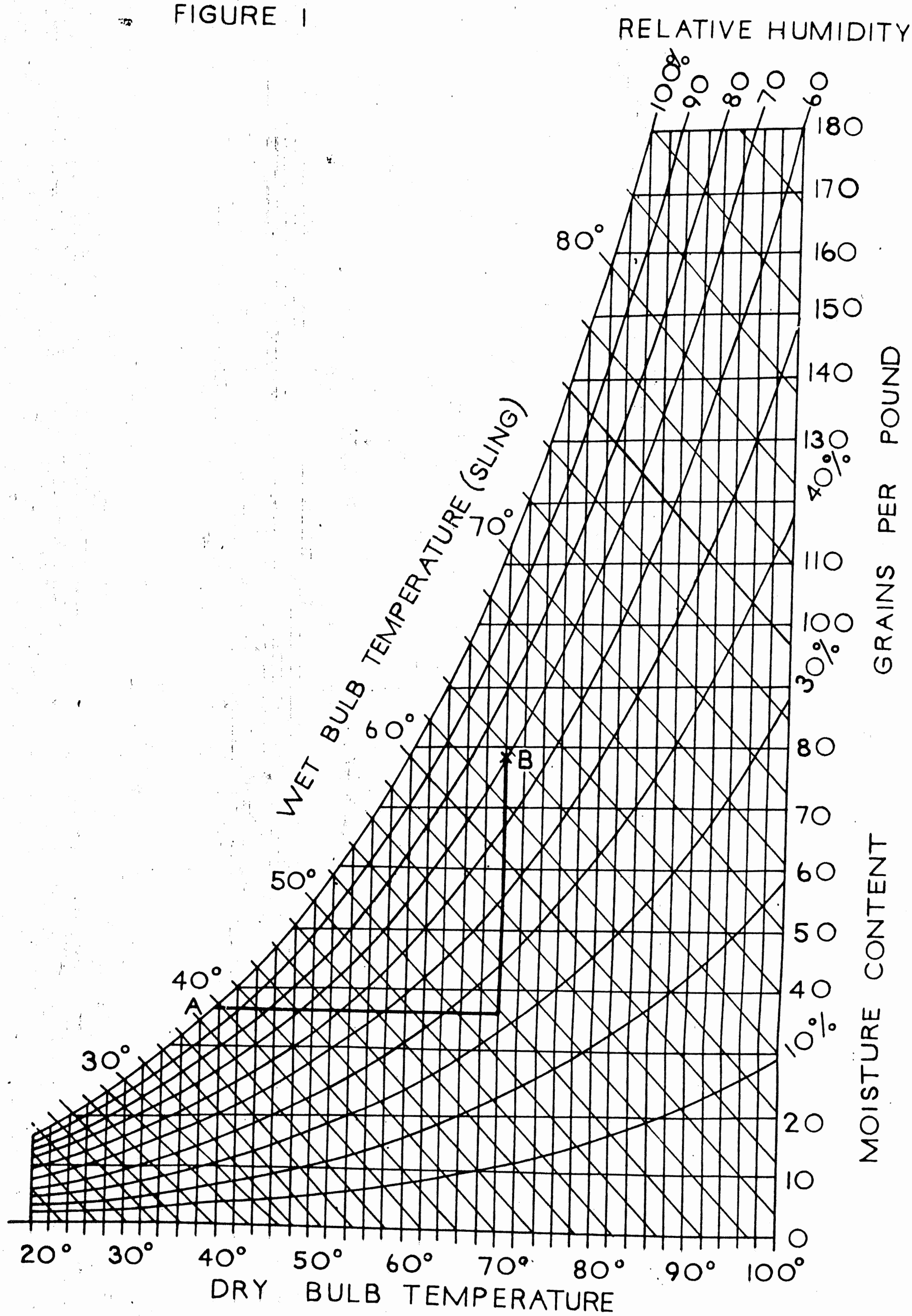
	(r)
Brickwork	0.125
Plaster	0. 25
Concrete	0. 10
Stone	0. 08
Wood	1. 00
Glass (single glazing) r = 0.14 [U value	1. 00 walls 1.2 roofs]
Asbestos millboard	0. 71
Coke breeze block	0. 25
Hardboard	1. 00
Fibreglass	4. 00
Cellular polystyrene	4. 15
Roofing felt	0. 71
Strawslab (insulating grade)	1. 67
Straw (thatch)	2. 00
Fibreboard	1. 54
Overall resistance of hollow concrete and clay tiles	1. 00

The resistance of a corrugated surface is only some 80% of that, of a corresponding plane surface.

The "U values" of solid floors is dependent upon the length of edge exposed. The following values may be taken as typical.

Area	"U Value"
2,500 sq. ft.	.09
5,000	.06
10.000	.05

FIGURE I



RELATIVE HUMIDITY
100%
90
80
70
60
40%
30%
10%
180
170
160
150
140
130
110
100
80
70
60
50
40
20
10
0
MOISTURE CONTENT GRAINS PER POUND
WET BULB TEMPERATURE (SLING)
80°
70°
60°
50°
40°
30°
A
B
20°
30°
40°
50°
60°
70°
80°
90°
100°
DRY BULB TEMPERATURE

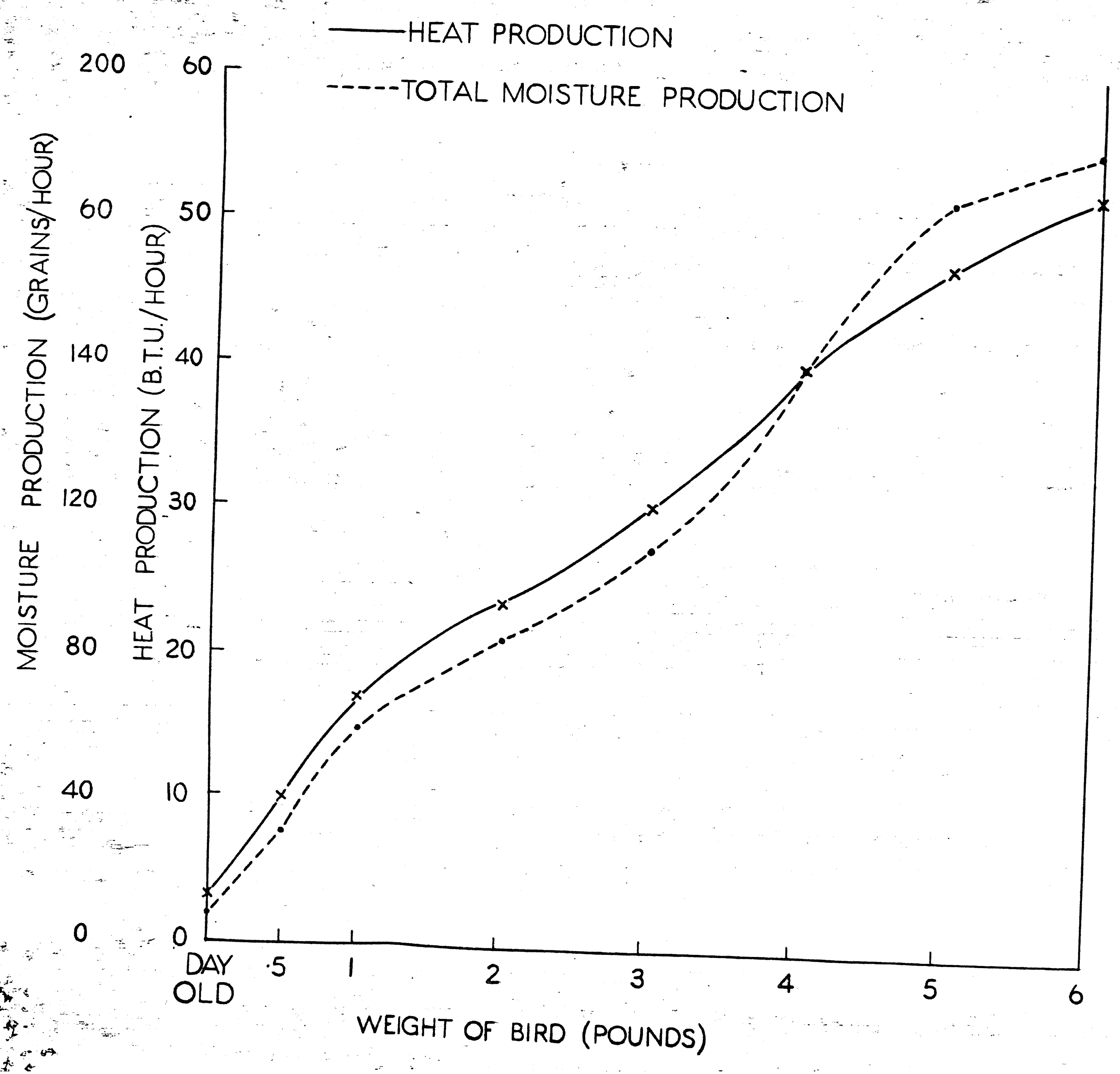


FIGURE 2

HEAT AND TOTAL MOISTURE PRODUCTION OF CHICKENS

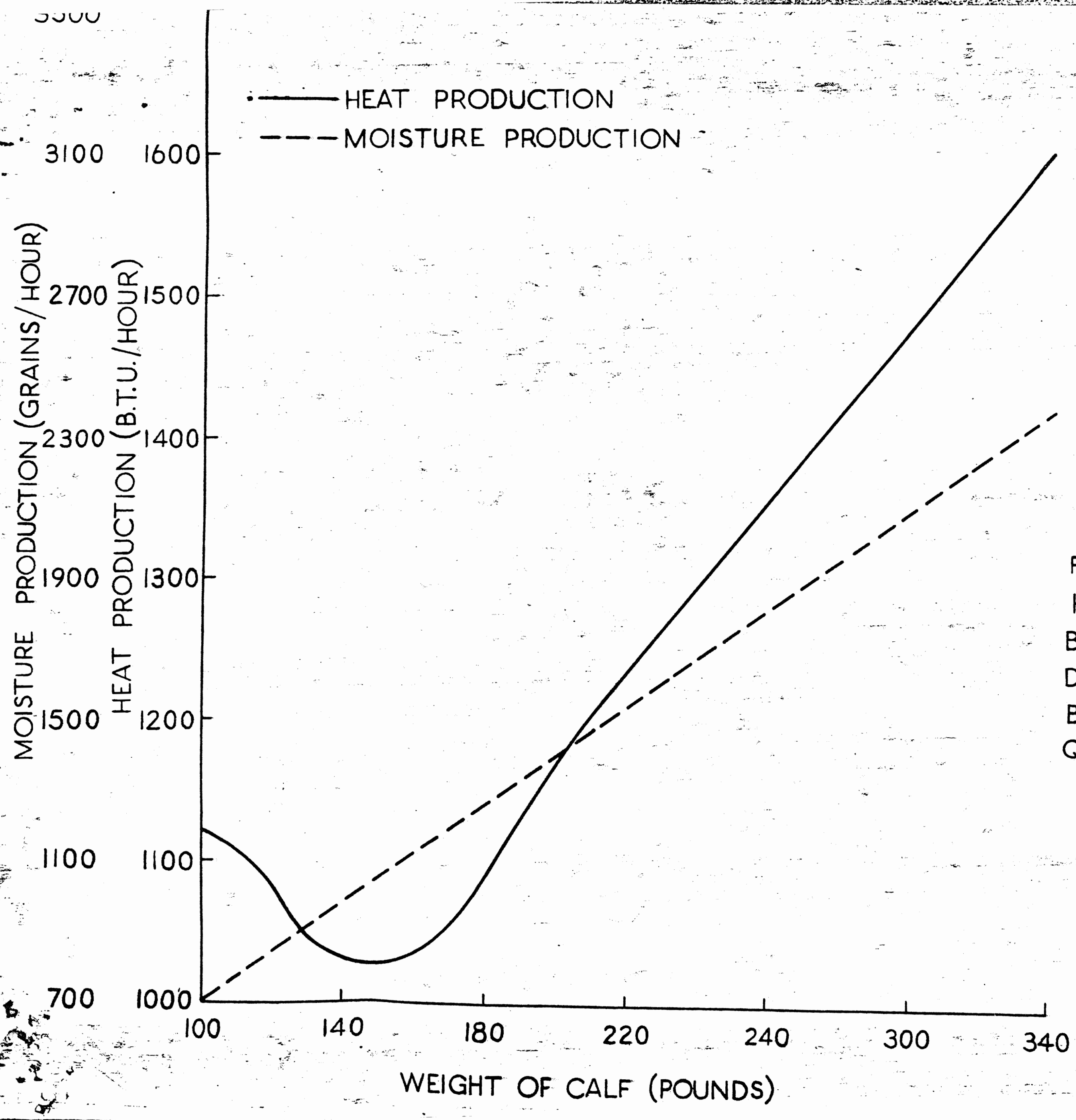


FIGURE 3
HEAT AND MOISTURE VAPOURISED BY BROILER CALVES (ASSUMING AVERAGE DAILY GAIN APPROX 2·5 POUNDS, NO BEDDING AND DROPPINGS REMOVED QUICKLY)