Ventilation model

Key to symbols

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| **Symbol** | **Description** | **Units** |
| *ρ* | air density | kg m-3 |
| *a*min | Minimum height of ventilation aperture, expressed as a proportion of *H*max | - |
| *A*plan | plan area of housing | m2 |
| *A*wall | total surface area of wall | m2 |
| *C* | specific heat of the air | J kg-1 K-1 |
| *f*sens | proportion of *Q*tot that is sensible heat |  |
| *h* | wall height | m |
| *H*max | Maximum average vertical opening of ventilation apertures | m |
| *k*s | parameter used to account for the sensible heat converted to latent heat through evaporation of water outside the animal |  |
| *Q*sens | sensible heat output | W |
| *Q*sup | Supplementary heating (force-ventilated housing) | W |
| *Q*supmax | maximum heating capacity of the housing (force-ventilated housing) | W |
| *Q*tot | total heat output per animal | W |
| *T*max | Maximum acceptable temperature (naturally-ventilated housing) | K |
| *T*min | Minimum acceptable temperature (naturally-ventilated housing) | K |
| *T*o | outside air temperature | K |
| *T*targ | target inside temperature (force-ventilated housing) | K |
| *U*roof | thermal transmissivity of the roof material | W m-2 K-1 |
| *U*wall | thermal transmissivity of the wall material | W m-2 K-1 |
| *V* | Ventilation rate | m3 s-1 |
| *V*max | maximum ventilation rate | m3 s-1 |
| *V*min | minimum ventilation rate | m3 s-1 |
| *v*opt | Adequate air speed to provide a safe and comfortable environment for both humans and livestock (naturally-ventilated housing) | ms-1 |
| *W*tot | Total width of ventilation apertures (naturally-ventilated housing) | m |

# Introduction

The major simplification made in comparison with the animal house model of Cooper et al (1998) is that the building is considered to be square in plan and no account is taken of the orientation relative to the compass.

The notation used is from Cooper et al 1998, with minor modifications.

The total heat output per animal (*Q*tot; W) is an input for both controlled and natural ventilation. This can either be obtained as a standard value or calculated as a diet- and climate-dependent value from the energy balance of the livestock. The sensible heat output (*Q*sens; W) equates to the *Q* variable in Cooper et al and is calculated by estimating the proportion of *Q*tot that is sensible heat (*f*sens). The CIGR report of 2002 provides a method for calculating the sensible heat from an estimate of the total heat production, using a non-SI unit (heat production unit). *f*sens is calculated by reworking the relationship given in the CIGR report of 2002:



Where *k*s is a parameter used to account for the sensible heat converted to latent heat through evaporation of water outside the animal (e.g. wet floors, moist animal feed). Since Ti is unknown at the start of the calculation, we assign *T*i to *T*o. This introduces some bias in the estimate but since the difference between *T*i and *T*o rarely exceeds 4-5 Celsius, it is deemed acceptable.

# Controlled ventilation

Heat is lost from the animal house by transmission through the walls and roof and in the ventilation air. The effect of solar heating of the housing is ignored.

The animal house is defined in terms of the plan area (*A*plan; m2) and the wall height (*h*; m). The total surface area of wall (*A*wall; m2) is then:



If the outside air temperature (*T*o; K) is below the target inside temperature (*T*targ; K), the following equation must be true, if the inside temperature is to be maintained at *T*targ.



where *Q*sens (W) is the sensible heat generated by the livestock present, *U*roof and *U*wall are the thermal transmissivities of the wall and roof materials respectively (W m-2 K-1), *C* is the specific heat of the air (J kg-1 K-1), *ρ* is the air density (kg m-3) and *V* is the ventilation rate required to maintain *T*targ (m3 s-1).

*V* is therefore given by:



If *V* is calculated to be greater than the maximum ventilation rate (*V*max; m3 s-1), or *T* o*>=T*targ, V = *V*max and the temperature inside the housing (*T*i; K) is given by:



If *V* is below the minimum ventilation rate (*V*min; m3 s-1), supplementary heating *Q*sup (W) is applied, given by:



If the supplementary heating necessary to maintain *T*targ exceeds the maximum heating capacity of the housing (*Q*supmax; W), the inside temperature is given by Equation , replacing *Q*sens with (*Q*sens+*Q*supmax).

# Free ventilation

With freely-ventilated housing, the farmer manages the environment by opening/closing apertures in the walls or roof. The ability of the farmer to control the environment in the housing depends on their objectives, the construction of the housing, the livestock kept and the climate. Most freely-ventilated housing has some apertures that can be controlled (e.g. windows, blinds, roof vents) and a proportion that cannot (e.g. weatherboarding). For simplicity, we assume that the ventilation apertures are all in the walls and that the ventilation is controlled by adjusting the vertical extent only. The ventilation aperture is defined in terms of a total width (*W*tot; m), a maximum average vertical opening (*H*max; m) and the minimum size (*a*min) expressed as a proportion of *H*max. Note that *W*tot is the sum of aperture widths on all sides of the housing.

The temperature difference between inside and out can be calculated by adapting Equation 11 to 21 of Cooper et al (1998). The following assumptions are made:

* The net long wave emission (Cooper et al Equation 9) is calculated by assuming that the sky temperature and surface temperature of the roof both equate to the outside temperature.
* The input of solar energy to the housing (Cooper et al Equation 14) is calculated assuming that the sun strikes the plan area of the housing at an angle of 90º.
* The wind strikes only one side of the housing and does so at an angle of 90º.

## Management of ventilation

Assumptions concerning farmer objectives and responses are:

* That the farmer wishes the temperature to remain above some minimum, *T*min (K)
* The farmer aims to maintain the air velocity at some specified value, *v*opt (ms-1) that is intended to provide a safe and comfortable environment for both humans and livestock.
* If the housing temperature exceeds some specified maximum desirable value, *T*max (K), the farmer will seek to increase ventilation, even if the air velocity will exceed the previously specified value.
* If the outside temperature exceeds *T*max, the apertures are assumed to be fully open.

## Management algorithm

Step 1

If *T*o > *T*max, *H*=*H*max in Cooper Equation 17. If the aperture is fully open then the value of UA is calculated as:



*V* is calculated using Cooper Equation 21. *T*i can then be calculated from:



The calculation is now complete; steps 2 to 6 are omitted.

Step 2

We assume initially that the desired airspeed (*v*opt) can be achieved. We estimate the aperture to be half open, so:



It is assumed that the wind strikes one wall only and at an angle of 90º. The ventilation rate is then



*T*i can then be calculated using Equation .

Step 3

If *T*i is calculated in Step 2 to exceed *T*max, we assign UA according to Equation and recalculate V so that *T*i= *T*max:



Step 4

If *T*i has been calculated to be less than *T*min, we assign UA according to:



*V* is recalculated so that *T*i= *T*min using Equation but replacing *T*max with *T*min.

Step 5

The minimum ventilation rate achievable under the conditions (*V*min; m3 s-1) is calculated with Cooper Equation 19, setting *H*=*a*min*H*max in Cooper Equation 17. If the current value of *V*<*V*min, *V* is equated to *V*min and *T*i is assigned the value calculated by Cooper Equation 17.

Step 6

The maximum ventilation rate achievable under the conditions (*V*max; m3 s-1) is calculated with Cooper Equation 19, setting *H*=*H*max in Cooper Equation 17. If the current value of *V*<*V*max, *V* is equated to *V*max and *T*i is assigned the value calculated by Cooper Equation 17.