Greenhouse Steady State Mass Balance Model

To evaluate the inside relative humidity for a given ventilation rate and a rate of moisture production, a mass balance calculation was performed. In this study, it was assumed that moisture loss from the air by condensation on the surfaces was small and was neglected. Also, the plant transpiration was assumed to be the only source of moisture production in naturally and fan ventilated greenhouses. When the evaporative cooling system was used, additional moisture was added to the greenhouse environment by the cooling system. The overall mass balance was:

$$M_v = M_{et} \quad (12)$$

where M_v was the amount of moisture transferred from the inside air to the outside air via ventilation (Kg $_{H2O}$ /s), which was expressed as:

$$M_v = (1/v)\ V_a\ (w_i - w_0) \quad (13)$$

where w_i and w_0 were the humidity ratios of the inside and outside air, respectively, in $Kg_{H2O}/Kg_{dry\ air}$.

The variable M_{et} in equation (13) was the amount of moisture added by transpiration (Kg $_{H2O}$/s).

The relationship for relative humidity (RH) expressed as a percent was given by the equation:

$$RH = [e(T) / e^*(T)] *100 \quad (14)$$

where e(T) was the partial pressure of the water vapor in moist air (Pa) and $e^*(T)$ was the saturation vapor pressure (Pa). The partial pressure of water vapor was defined by:

$$e(T) = (w + P_{atm})/(w + 0.622) \qquad (15)$$

where P_{atm} was the atmospheric pressure (Pa).

The saturation vapor pressure for a given temperature was computed with the equation given by ASHRAE Handbook of Fundamentals, (1993):

$$e^{*}(T) = \exp [-5800.2206/T + 1.3914993 - 0.04860239\ T + 0.41764768E\text{-}4\ T^2 - 0.14452093E\text{-}7\ T^3 + 6.5459673 \ln (T)] \qquad (16)$$

where T was in K and e(T) was in Pa.

Water use during the mass transfer process between the air and water for the evaporative cooler was evaluated by the steady flow mass balance equation:

$$m_a w_o + m_w = m_a w_e \qquad (17)$$

where m_w was the evaporative cooling system water intake (Kg_{H2O}/s), m_a was the mass flow rate of the outside air through the cooling system ($Kg_{dry\ air}/s$), and w_e was the humidity ratio of the leaving air passed through the cooling system ($Kg_{H2O}/Kg_{dry\ air}$).

Therefore,

$$m_w = m_a (w_e - w_o) \qquad (18)$$

or

$$m_w = (1/v) V_{av} (w_e - w_o) \qquad (19)$$

Equation (19) can be used to evaluate the water evaporation rate in the evaporative cooling system for a given air flow rate through the greenhouse. However, a general formula for water intake for the cooling system as a function of outside conditions needed to be evaluated. Cooling load of the evaporative cooling system of a greenhouse was expressed as:

$$Q_v = Q_{sr} - Q_e - Q_{cd} - Q_t \quad (20)$$

The volumetric ventilation rate with an average inside design temperature was defined as:

$$V_{va} = [I_{sri} - Q_t/A_f - a\,(T_i - T_o) - ET\,L_v]\,/b\,(T_i - T_e) \quad (21)$$

where a and b were described in equation (10).

Since the evaporative cooling process is an adiabatic exchange of heat, the amount of sensible heat removed from the air equals the amount of heat absorbed by the water evaporated as latent heat of vaporization. Therefore, the difference (w_e-w_o) was expressed as:

$$(w_e - w_o) = C_p/L_v\,(T_0 - T_e) \quad (22)$$

Substituting equations (22) and (21) in equation (19) yielded:

$$m_w = \{[I_{sri} - Q_t - a\,(T_i - T_0) - ET\,L_v]\,/(T_i - T_e)\}\,d\,(T_0 - T_e) \quad (23)$$

where $d=1/L_v$.

In Equation (23), water intake by the evaporative cooling system was a function of solar radiation, ambient and inside temperatures.

LIST OF REFERENCES

ASHRAE guide and data book fundamentals. 1981. American Society of Heating, Refrigerating and Air-conditioning Engineers . New York

ASHRAE guide and data book fundamentals (SI edition). 1993. American Society of Heating, Refrigerating and Air-conditioning Engineers . New York

Idso, S. B. 1981. A set of equations for full spectrum and 8-μm to 14-μm and 10.5-μm to 12.5-μm thermal radiation from cloudless skies. Water Resources Res. 17: 295-304.

Kindelan, M. 1980. Dynamic modeling of greenhouse environment. Transactions of the ASAE, 23:1232-1239.

Walker, J. N. 1965. Predicting temperatures in ventilated greenhouses. Transactions of the ASAE 8(3): 445-448.