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Technical Note

Summary An elementary practical relation is developed for the temperature of air after saturation with water vapour, in terms of its initial conditions, and the fraction of the latent heat of evaporation taken from the initial sensible heat of the air.

Adiabatic saturation temperature of air: Practical application

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List of symbols

- c Specific heat capacity of air (1000 J kg^{-1} K^{-1})
- f Fraction of the latent heat of evaporation taken from the sensible heat of the air being cooled
- g Water vapour content of air (kg kg^{-1})
- L Latent heat of evaporation of water (2.26×10^6 J kg^{-1})
- m Mass of air (kg)
- s Fraction of saturation of incoming air
- T Temperature (°C)
- w Mass of water vapour (kg)

Subscript

- 0 Initial condition

If cooling is required anywhere in the western world, we mostly use a heat pump incorporating a mechanical compressor. A prime mover or fuel for the compressor is nearly always available or easily obtained. Not so in the developing world, where cooling has mostly to be obtained otherwise.

The author, with colleagues from Algeria and Egypt, is working on projects to use the sun to provide cool ventilation. In one approach we cool the air by the evaporation of water, for which we claim no originality. A simple relation for the resulting temperature drop when the air is saturated, as a function of its initial condition, and of the fraction of cooling removed by the air is given below.

Consider mass m of air at temperature T_0 and saturation s. If it were saturated its moisture content would be g_0. The initial mass of water vapour in the air is sg_0m. Now add a mass w of water vapour to saturate the air, and assume that a fraction f of the heat absorbed in the process of evaporation comes from the sensible heat of the air. The moisture content of the air will now be

$$g_{sat} = (sg_0m + w)/m = sg_0 + w/m$$

and the heat removed by the air will be wLf, where L is the latent heat of evaporation of water, if f is the fraction of the required heat taken from the air. The air will now be at temperature T, and the sensible heat loss will be $mc(T_0 - T)$, where c is the specific heat capacity of air; then

$$mc(T_0 - T) = wLf$$

whence $w/m = (T_0 - T)c/Lf$, so that

$$g = sg_0 + (T_0 - T)c/Lf$$

A relation for the saturation moisture content of air g_{sat}, in terms of its temperature substituted above will give an equation for the temperature of the saturated cooled air. It is not difficult to use the CIBSE psychrometric chart to show that

$$10^3 g_{sat} = 3.80 + 0.303T + 0.005T^2 + 336.7 \times 10^{-6} T^3$$

correct to 0.001 or better. The solution of cubic equations is avoided whenever possible, and here it is not worthwhile, because of the uncertainties in the parameters used, particularly that in f. The cubic relation for g applies from −5°C to 30°C, but for our work the range 30 to 40°C is of more immediate interest, and within that range, the linear relation

$$10^3 g_{sat} = 2.2T - 40$$

will serve. It is less accurate than the cubic relation, but accurate enough for practical needs. Using this relation for g and g_0 gives the temperature drop of the air as

$$T_0 - T = (1 - s)(T_0 - 18.2)/(1 + 0.20/f)$$

If all the latent heat is taken from the air being saturated, $f = 1$, so that

$$T_0 - T = (1 - s)(T_0 - 18.2)/1.2$$

and

$$(T_0 - T)_f/(T_0 - T)_1 = 1.2/(1 + 0.2/f)$$

of which the graph (Figure 1) shows the value as a function of f. We see that provided f is at least two thirds, over 90% of the maximum possible temperature drop is achieved. In our application a high value of f is not very important, because any cooling not entering the room with the ventilating air will enter it later.

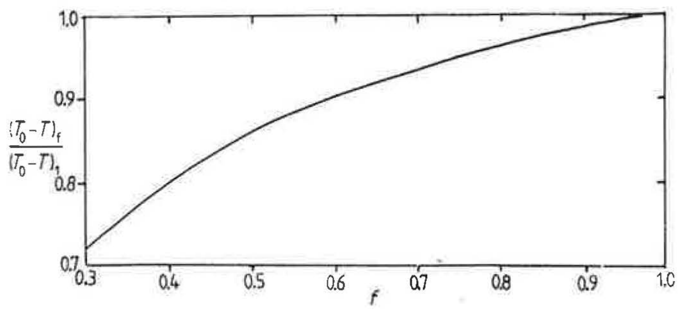

Figure 1 Temperature fall of air upon saturation as a fraction of the fall if $f = 1$

Information given by Evans[1] shows that when it is very hot, with air temperatures around 30°C, at night, the discomfort caused by replacing dry air by air saturated with moisture is equivalent to that of an air temperature rise of about 2 K. During the day this becomes about 5 K. These 'compensating temperature rises' are small compared with the cooling achieved by evaporation.

Reference

1 Evans M *Climate and Comfort* p 23 Table 3.1 (London: Architectural Press) (1980)