HEAT FLOW CALCULATIONS

APPLICATION NOTE TSI-124 (US)

The instrument calculates heat flow by making temperature, humidity, and flow measurements upstream and downstream of the coil in the duct. The following steps and calculations are utilized to make the heat flow measurement:

- Flow measurements must be referenced to standard air density conditions. Set the instrument to **Standard** within the **Actual/Standard Setup** menu.
- Select **HEATFLOW** under the applications menu.
- The current upstream measurements of temperature, humidity, and flow are displayed. Highlight the desired measurement and hit the measurement key. This will update the reading. The flow rate will be calculated using either the thermal anemometer or pitot tube depending if the TA probe is attached.
- Select **Downstream** to make readings downstream of the coil.
- The unit will display real time values based on the temperature and humidity readings from the probe.

The Equations used for the calculations are described below.

Sensible Heat Flow

Sensible heat is dry heat. It causes a change in temperature in a substance, but not a change in the moisture content of that substance.

$Q_S = 60c_p\rho q\Delta t$ (English units) **OR** $Q_S = c_p\rho q\Delta t/3600$ (metric units)

where Q_S = sensible heat flow in Btu/hr (kW)

c_p = specific heat in Btu/lb °F = 0.2388 Btu/lb °F (1.0048 kJ/kg K)

ρ = air density at standard conditions = 0.075 lb/ft^3 (1.202 kg/m^3)

q = measured air flow in ft^3/min (m^3/hr) (assuming flow is the same at first and second measurement location)

Δt = temperature difference in °F (°C) (difference between first and second measurement location)

Replacing constant values gives:

$Q_S = 1.0746q\Delta t$ (English units) **OR** $Q_S = 1.21q\Delta t/3600$ (metric units)

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Latent Heat Flow

Latent heat is the heat that when supplied to, or removed from, a substance there is a change in the moisture content of the substance (change in state), but the temperature of that substance does not change.

$Q_L = 60h_{fg}\rho q\Delta W$ (English units) **OR** **$Q_L = h_{fg}\rho q\Delta W/3600$** (metric units)

where Q_L = latent heat flow in Btu/hr (kW)

h_{fg} = latent heat of vaporization of water in Btu/lb = 1060 Btu/lb (2,465.56 kJ/kg)

ρ = air density at standard conditions = 0.075 lb/ft^3 (1.202 kg/m^3)

q = measured air flow in ft^3/min (m^3/hr)

ΔW = humidity ratio difference in lb water/lb dry air (kg water/kg dry air) (difference in water content of air between first and second measurement location)

Replacing constant values gives:

$Q_L = 4770q\Delta W$ (English units) **OR** **$Q_L = 0.8287q\Delta W$** (metric units)

Total Heat Flow

Total heat is the sum of latent heat and sensible heat.

$Q_T = Q_S + Q_L$

where Q_T = total heat flow in Btu/hr (kW)

Q_S = sensible heat flow in Btu/hr (kW)

Q_L = latent heat flow in Btu/hr (kW)

Sensible Heat Factor

The sensible heat factor equals sensible heat divided by total heat in the air.

Given at measurement location 1 (conditions inside room):
dry bulb temperature t_1 = 76 °F
%RH_1 = 49.0% (ϕ_1 = .490)
barometric pressure = 29.921 in. Hg

Given at measurement location 2 (conditions of supply air entering room):
dry bulb temperature t_2 = 53 °F
%RH_2 = 88.0% (ϕ_2 = .880)
flow rate q = 15,000 std ft^3/min

Find: sensible heat flow Q_S, latent heat flow Q_L, total heat flow Q_T, and sensible heat factor SHF.

Sensible heat flow Q_S

$Q_S = 1.0746q\Delta t = 1.0746\ (15000)(|53-76|)$ = 370,737 Btu/h of heat removal

Latent heat flow Q_L

$Q_L = 4770q\Delta W$, so we need to find W_1 and W_2.

$W = 0.62198p_{ws}(t_d)/(29.921 - p_{ws}(t_d))$

$p_{ws}(t_d) = (\phi_1)(p_{ws}(t))$

Definitions of terms used to calculate W:

$p_{ws}(t_d)$ = saturation pressure of the air stream at the dew point temperature (inches Hg)

$p_{ws}(t)$ = saturation pressure of the air stream at ambient temperature (inches Hg)

ϕ = humidity (expresses as a value between 0 -1, not as %RH)

To find W_1:

$p_{ws}(t_1) = p_{ws}(76\ °F) = 0.90532$ in. Hg

$p_{ws}(t_{d1}) = (\phi_1)(p_{ws}(t_1)) = (0.490)(0.90532) = 0.4436068$

$W_1 = 0.62198p_{ws}(t_{d1})/(29.921 - p_{ws}(t_{d1})) = 0.62198(0.4436068)/(29.921 - 0.4436068) =$ 0.00936021 lb H_2O/lb dry air

SHF = Q_S/Q_T

where SHF = sensible heat factor (ratio of sensible heat load to total heat load)

Q_S = sensible heat flow in Btu/hr (kW)

Q_T = total heat flow in Btu/hr (kW)

EXAMPLE 1: (Imperial Units)

To find W_2:

$p_{ws}(t_2) = p_{ws}(53\ °F) = 0.40516$ in. Hg

$p_{ws}(t_{d2}) = (\phi_2)(p_{ws}(t_2)) = (0.880)(0.40516) = 0.3565408$

$W_2 = 0.62198p_{ws}(t_{d2})/(29.921 - p_{ws}(t_{d2})) = 0.62198(0.3565408)/(29.921 - 0.3565408) =$ 0.00750094 lb H_2O/lb dry air

To find Q_L:

$Q_L = 4770q\Delta W = 4770(15{,}000)(|0.00750094 - 0.00936021|) = 133{,}031$ Btu/h heat removed

Total heat flow Q_T

$Q_T = Q_S + Q_L = 370{,}737 + 133{,}031 = 503{,}768$ Btu/h heat removed

Sensible Heat Factor SHF

$SHF = Q_S/Q_T = 370{,}737/503{,}768 = 0.74$

EXAMPLE 2: (Metric Units)

Given at measurement location 1 (conditions inside room):
dry bulb temperature $t_1 = 24.4\ °C$
$\%RH_1 = 49.0\%$ ($\phi_1 = .490$)
barometric pressure = 760 mm Hg

Given at measurement location 2 (conditions of supply air entering room):
dry bulb temperature $t_2 = 11.7\ °C$
$\%RH_2 = 88.0\%$ ($\phi_2 = .880$)
flow rate q = 25486 std m^3/hr

Find: sensible heat flow Q_S, latent heat flow Q_L, total heat flow Q_T, and sensible heat factor SHF.

Sensible heat flow Q_S

$Q_S = 1.21q\Delta t/3600 = 1.21\ (25486)(|24.4 - 11.7|) = 108.79$ kW of heat removal

Latent heat flow Q_L

$Q_L = 0.8287q\Delta W$, so we need to find W_1 and W_2.

$W = 0.62198p_{ws}(t_d)/(760 - p_{ws}(t_d))$

$p_{ws}(t_d) = (\phi_1)(p_{ws}(t))$

Definitions of terms used to calculate W:

$p_{ws}(t_d)$ = saturation pressure of the air stream at the dew point temperature (mm Hg)

$p_{ws}(t)$ = saturation pressure of the air stream at ambient temperature (mm Hg)

ϕ = humidity (expresses as a value between 0 -1, not as %RH)

To find W_1:

$p_{ws}(t_1) = p_{ws}(24.4\ °C) = 22.922$ mm Hg

$p_{ws}(t_{d1}) = (\phi_1)(p_{ws}(t_1)) = (0.490)(22.922) = 11.232$ mm Hg

$W_1 = 0.62198p_{ws}(t_{d1})/(760 - p_{ws}(t_{d1})) = 0.62198(11.232)/(760 - 11.232)$
$= 0.00933$ kg H_2O/kg dry air

To find W_2:

$p_{ws}(t_2) = p_{ws}(11.7\ °F) = 10.312$ mm Hg

$p_{ws}(t_{d2}) = (\phi_2)(p_{ws}(t_2)) = (0.880)(10.312) = 9.075$ mm hg

$W_2 = 0.62198p_{ws}(t_{d2})/(760 - p_{ws}(t_{d2})) = 0.62198(9.075)/(760 - 9.075)$
$= 0.00752$ kg H_2O/kg dry air

To find Q_L:

$Q_L = 0.8287q\Delta W = 0.8287(25486)(|0.00752 - 0.00933|) = 38.228$ kW heat removed

Where $\Delta W = W2 - W1$

Total heat flow Q_T

$Q_T = Q_S + Q_L = 108.79 + 38.228 = 147.018$ kW heat removed

Sensible Heat Factor SHF

$SHF = Q_S/Q_T = 108.79/147.018 = 0.74$

The $p_{ws}(t)$ and W that are being used in these equations are the same W that is calculated when finding the wet bulb temperature.

UNDERSTANDING, ACCELERATED

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