Tech Tip # 61

HEATING, AIRCONDITIONING & REFRIGERATION DISTRIBUTORS INTERNATIONAL

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Why 400 CFM per Ton is used for Determining "Standard Air" Conditions Air Volumes

Equations that explain relationship between temperature and air quantities show why CFM requirements for summer air conditioning change with varying heat loads.

"The conditioned air quantity for air conditioning should be about 400 CFM per ton of cooling capacity."

Does this rule-of-thumb strike a familiar note? Although many dealer-contractors may say, "Sure, we've known that for a long time," how many can explain the relationship? Those who can know that they have a broader base from which to seek solutions to air conditioning problems than do those who cannot. Rules-of-thumb are useful guide posts, but only the most simple air conditioning problems can be solved with such rules alone.

In an air conditioning system, the circulating air serves as a carrier of heat and moisture either to or from the conditioned space. Let us first consider air as a carrier of heat. We are not so much interested in the total amount of heat the circulating air carries as we are in the change in heat between the point where it enters the conditioned space and the point where it leaves. The difference is the amount of heat which the air has either added to or removed from the space.

By careful measurement it has been found that it takes 0.24 Btu to raise one pound of air one degree Fahrenheit. This is known as the specific heat of air. Since we normally deal with cubic feet, not pounds, of air in air conditioning work, we must know another fundamental value, the number of cubic feet which one pound of air will occupy. Because this value varies considerably with the temperature and pressure, calculations are generally based upon air at so called "standard conditions" (dry air at 70° F and 14.7 lb/sq in.) which has a volume of 13.34 cu ft/lb. The actual volume occupied by a pound of air at almost any condition may be read from a psychrometric chart.

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Temperature and its Relation to Quantity

We are now prepared to relate air to heat. Suppose we are supplying 300 CFM to a heater. The air enters at 70° F and leaves at 120° F. How much heat has the air picked up in passing through the heater? We use the relationship:

Qs = CFM x 60 x 0.24 x 1/13.34 x (T_2 - T_1) where:
Q is sensible heat in Btuh
60 is min/hr.
0.24 is Btu/lb/deg F
13.34 is cu ft/lb
T_2 - T_1 is temperature change, deg F.

Simplifying: Qs = CFM x 1.08 x (T_2 - T_1)

The simplified equation above is most important and is used both in cooling and heating problems where it is necessary to determine the relationship of air quantity and temperature difference to heat. Notice that in using the factor 1.08 it is assumed that the CFM value is adjusted to standard conditions. Most equipment is cataloged for standard air. Field measured flow can be adjusted to standard conditions by simple proportions of temperature and pressure (using absolute values).

The preceding equation shows that the same amount of heat may be conveyed using a large air flow and a small temperature difference or a small air flow and a large temperature difference. Thus, instead of 300 CFM and a 50° F range, we could use 150 CFM with 100° F range or 600 CFM with a 25° F range. Although in each case the total amount of heat is the same, there are practical limitations in each direction. Larger air flows require larger air handling equipment and larger ductwork. Higher temperatures create fire and burn hazards and problems of distribution.

As noted previously, air carries moisture as well as heat. Since evaluation of its moisture carrying capacity is more of a problem with cooling than with heating, we shall consider it in this connection.

The cooling load is more complex than the heating load, and for that reason the relationship of air quantity to load is not as apparent for the former as it is for the latter. Normally the cooling load is broken down into the following categories: internal sensible, internal total, total sensible and grand total.

Internal sensible includes all sources of heat which tend to cause a temperature rise in the conditioned space. These would include heat conducted through walls, floor and roof, solar energy entering through glass, heat from lights, people, appliances, etc., and heat from air which might infiltrate directly.

Internal total heat includes internal sensible heat plus latent heat represented by the moisture originating in the conditioned space from people, appliances and direct infiltration.

Total sensible heat includes internal sensible heat required to reduce the ventilation air from design outside temperature to room temperature.

Grand total heat is the sum of all sensible and latent heat sources represented by the space load calculation and the ventilation load calculation.

Since the internal sensible portion of the load includes all heat sources which tend to cause a temperature rise in the conditioned space, it is this heat value which is used in our equation to determine air quantity. As was the case for heating, we can theoretically use any convenient combination of flow and temperature difference that will balance the equation. The temperature difference in this case tells us how much the selected air quantity must be cooled below room temperature in order to remove the unwanted heat.

Requirements for dehumidification

Just as the internal sensible load is used in determining the amount of air needed to cool a given space, so the internal latent load is used in determining the amount of air needed to dehumidify a given space. If the two problems (heat and moisture) were independent, they could be solved with independent air quantities.

Moisture in a conditioned space is in the form of vapor. A pound of dry air at a given temperature can contain variable amounts of vapor up to a maximum.

At 70° F, for example, a pound of dry air can have associated with it a maximum of 0.015 lb of vapor. The air is said to be saturated at this condition and the relative humidity is said to be 100%. If the pounds were only half of maximum, the relative humidity would be only 50%. Because the amount of moisture per pound of dry air is small when expressed in pounds, it is more convenient to express it in grains, there being 7,000 grains to the pound. The weight of vapor for saturated air at 70° F is 110.5 grains.

Vapor is removed from air by chilling it until it condenses to water. For each pound of vapor condensed, approximately 1,050 Btu must be removed by the cooling coil. This is the heat of vaporization. Its removal takes place at constant temperature just as its addition, in the boiling process for example, takes place at constant temperature.

The amount of moisture in air is determined most easily from a psychrometric chart using measured values of the dry and wet bulb temperatures. Let us assume that 300 CFM enters a room at 52° F DB, 50° F WB. The chart shows that the air carries 50 grains of moisture per pound of dry air. A corresponding measurement of air leaving the room shows 76 grains per pound. The latent heat which this air carries from the room is calculated as follows:

$Q_L = CFM \times 60 \times 1/13.34 \times 1/7000 \times 1050 \times (G_2 - G_1)$ where:
Q_L is latent heat in Btuh
60 is min/hr.
13.34 is cu ft/lb
7,000 is grains/lb
1,050 is heat of vaporization (nominal value) in Btu/lb water
$(G_2 - G_1)$ is moisture change, grains/lb dry air.

Simplifying: Q_L = CFM x 0.68 x (G_2 - G_1)
Q_L = 300 x 0.68 x (76 - 50) = 5,300 Btuh

Notice that the equation for Q_L can be satisfied by having a small air quantity and large difference in moisture levels or a large air quantity and small difference in moisture levels. The relationship is similar to that described between air quantity and temperature difference in the equation for sensible heat, Q_S.

Supply Air Varied for Load Requirements

We have seen how air is used to carry both sensible and latent heat and how each form of heat, considered independently, can be the basis for calculating the air needed to carry it. We can now proceed to the solution of practical air conditioning problems which generally require that both types of heat be carried simultaneously with the same air quantity. This requires the designer to: first, establish the air quantity; second, create the temperature difference needed for the selected air CFM to convey the sensible heat; third, create the difference in grains needed for the selected air CFM to convey the latent heat.

In order to see how supply air conditions are "tailored" to meet a load requirement, let us assume that a certain room is to be maintained at 78° F DB, 50% RH. The room loads are as follows: Internal sensible heat 8,000 Btuh, internal latent heat 1,430 Btuh.

The air quantity would be approximated by assuming that the air would be introduced into the room at about 58° F which is 20 degrees below room temperature. Using the equation Q_S = CFM x 1.08 x (T_2 - T_1) and solving for CFM, we have: CFM = 8,000/1.08 x 20 = 370. If the temperature difference we choose is much larger than 20 degrees, we should have difficulty mixing the cold supply air with room air in a way that would avoid drafts. We might also approach a condition where moisture would freeze on the coil surface. On the other band, if it were much less than 20 degrees, ducts, fans, etc. would become larger and more costly due to the increased CFM.

The now established 370 CFM must pick up the internal latent heat of 1,430 Btuh. Using the equation Q_L = CFM x 0.68 x (G_2 - G_1) and solving for the change in grains of moisture per pound, we have (G_2 - G_1) = 1,430/0.68 x 370 = 5.7. In other words, if we introduce air into the room at the rate of 370 CFM which has a moisture level 5.7 grains/lb below the desired room level, we can remove moisture at the rate indicated by the load (1,430 Btuh). From the psychrometric chart, we find the room level of moisture at 78° F DB, 50% RH is 71 gr/lb. The supply air must, therefore, be at 71 - 5.7 = 65.3 gr/lb as well as at 58° F. These two conditions establish the supply air wet bulb temperature as 56.5° F. Summarizing then, 370 CFM at 58° F DB, 56.5° F WB will remove 8,000 Btuh sensible heat and 1,430 Btuh latent heat from a room and hold it at 78° F DB, 50% RH.

The final step in the simple problem above would be to select a cooling coil from cataloged values which could cool the required amount of air between the two points. In trying to make a selection, we may find that practical limitations make it advisable for us to revise our original assumption of 20 degrees of cooling to a slightly lower or higher value. This would, of course, change the CFM and the other related values.

In the procedure described above, we were required to maintain an exact room condition of 78° F DB, 50% RH. In comfort air conditioning, we strive for exact control of temperature, but we are not so particular about summer humidity as long as it is less than the design value. It is this fact that makes the package or self-contained air conditioner practical. These units are factory engineered with psychrometric characteristics which meet most conditions of average application. In other words, the balance between the sensible and latent heat removing capacities is such that if they are selected for their sensible capacity, they will have at least enough and probably more latent capacity than is needed. If the latter is the case, the room will balance out at a slightly lower relative humidity than was intended by design. We usually do not object to this on a small job. In a large job, however, this might possibly mean more refrigeration capacity and higher operating cost than the design intended and so must be checked carefully.

In our opening statement we quoted a rule-of-thumb about air conditioning requiring 400 CFM per ton. This value is usually the basis for rating self-contained air conditioners. Thus, we have a 2-ton unit handling 800 CFM, a 3-ton 1,200, a 5-ton 2,000, a 10-ton 4,000, etc. With 80° F DB 50% RH (77 gr/lb) air entering, these units usually will do about 70 percent sensible cooling and 30 percent latent cooling. On this basis, a 3-ton unit would do 36,000 Btuh total cooling, 25,200 Btuh sensible cooling and 10,800 Btuh latent cooling. With 400 CFM per ton, air would be cooled according to: $T_2 - T_1 = 25{,}200/1{,}200 \times 1.08 = 19.4°$ F and would leave the coil at 80° F - 19.4° F = 60.6° F. Air would be dehumidified according to: $G_2 - G_1 = 10{,}800/1{,}200 \times 0.68 = 13.2$ grains and would leave the coil at 77 - 13.2 = 63.8 grains or 57° F WB.