Updated!
Includes analysis of stainless-steel-shielded dispersion tubes.

Steam humidification:

Reducing energy use, airstream heat gain, and condensate production

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Enlightened building owners demand accountability for every resource consumed in the construction and operation of new or renovated buildings. Meeting conservation benchmark standards requires measurable building performance, for it is commonly understood that if you can't measure it you can't improve it.

Commercial and industrial steam humidification is considered essential for most process, preservation, and health applications such as semiconductor manufacturing, printing plants, museums, schools, and health care facilities. Given the significant number of large buildings requiring steam humidification, it is time to make strides toward measuring and improving the energy efficiency and water consumption of these building systems. Recent advances in materials and manufacturing techniques are bringing attention to this issue, specifically the energy and water wasted when dispersing steam into cool airstreams. This article describes these materials and includes data about their performance.

Steam dispersion basics

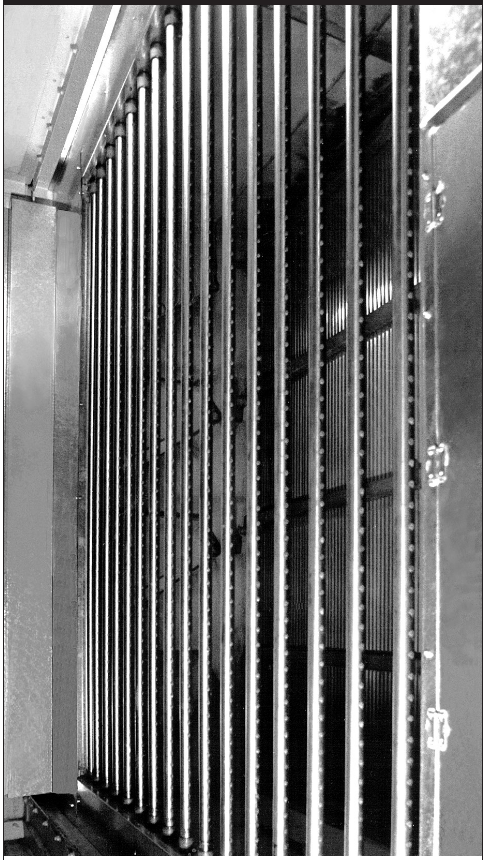
Humidifying with steam requires two essential functions: steam generation and steam dispersion.

Direct steam injection humidification systems disperse steam into duct or AHU airstreams from on-site boilers or unfired gas or electric steam generators. Unique to direct steam injection applications is the dispersion of pressurized steam.

Humidification steam can also be generated in a nonpressurized gas or electric steam generator connected to a dispersion assembly. This type of steam is often called "evaporative" steam because the steam chamber operates at or near atmospheric pressure.

Whether dispersing pressurized or nonpressurized steam, the function of a dispersion assembly doesn't vary: receive steam from the steam generator, discharge steam into the airstream through

Figure 1-1
Typical dispersion assembly



Shown here is a typical steam dispersion tube panel with uninsulated stainless steel tubes installed to span the full height and width of an air handling unit. These dispersion tubes discharge steam from both sides, perpendicular to airflow.

The only variable that can be changed to reduce heat transfer is the thermal conductance of the dispersion tubes. This can be accomplished with insulation.

calibrated openings in stainless steel dispersion tubes, and drain condensate to a floor drain or pipe it back to the steam generator. (Note that some steam generators are not designed to accept returned condensate.)

Steam dispersion assemblies are available in a multitude of configurations designed to meet a variety of absorption and load requirements. Whether it's a 30-cm tube or a 3-meter panel, the purpose of a dispersion assembly remains essentially the same: distribute steam into the airstream.

This appears to be a simple process, but substantial thought goes into effective dispersion assembly design, primarily to accommodate the complex properties of steam while discharging it into a cool airstream.

Figure 2-1: Dispersion panel with PVDF-insulated tubes

Hot dispersion tubes heat the air and produce condensate

When operating, uninsulated stainless steel dispersion tubes are hot — they have a surface temperature just under 100 °C. Dispersion assemblies typically disperse steam into 10–14 °C airstreams. Cool air flowing across hot dispersion tubes causes some steam inside the tubes to condense, releasing latent heat. This heat passes directly through uninsulated stainless steel dispersion tubes into the airstream, increasing downstream air temperature. ***Because of the relationship between latent heat and condensate, downstream heat gain from dispersion tubes is directly proportional to the amount of condensate produced within those dispersion tubes.***

Downstream heat gain wastes resources in the following ways:

- ***Every litre of condensate produced wastes about 2300 kJ*** — the energy originally used to change that pound of water into steam.
- ***Heat added to downstream air increases the cooling load*** in applications that humidify and cool simultaneously (such as hospitals, museums, schools), wasting energy cooling the unnecessarily heated air.
- ***Unnecessary condensate production can cause a humidification system to not meet set point*** when steam expected to meet the humidification load becomes condensate. This can require specifying a higher-capacity steam generator.

- ***Every litre of condensate sent to a drain wastes water treatment chemicals*** (e.g., softened water, deionized or reverse-osmosis treated water, water treated with boiler chemicals). Note that not all humidification systems return condensate to the steam generator.
- ***Heating air with a humidification dispersion assembly is inefficient.*** Dispersion assemblies are not designed to be heating appliances.

The heat transfer rate from dispersion tubes to an airstream is determined by airstream temperature, airstream velocity, dispersion tube quantity (surface area), and dispersion tube thermal conductance. In a typical application, air temperature and velocity are defined by HVAC system parameters; and steam pressure and dispersion tube quantity are functions of humidification requirements and cannot be reduced without a resulting drop in humidification performance. The only variable that can be changed to reduce heat transfer is the thermal conductance of the dispersion tubes. This can be accomplished with insulation.

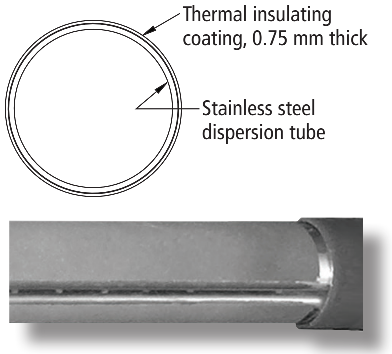
Insulate dispersion tubes to reduce downstream heat gain

Dispersion tube insulation must withstand the environmental extremes of steam humidification while meeting strict plenum requirements for smoke and flame. In addition, insulation thickness must not significantly obstruct airflow, which could cause an excessive pressure drop. There are three types of dispersion tube insulation that meet these requirements: thermal insulating coating, stainless-steel-shielded air gap, and PVDF insulation (Figure 3-1).

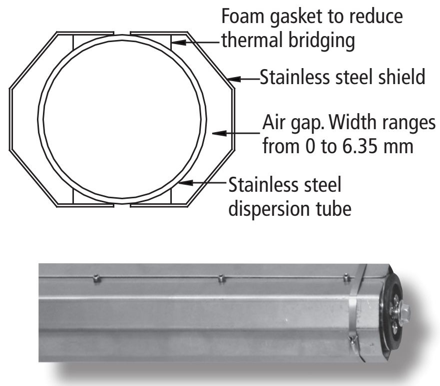
1. **Thermal insulating coating.** Commonly referred to as a “TIC” or as “ceramic insulation,” this coating is factory-applied to a dispersion tube as a liquid or semi-liquid that dries or cures to form a coating typically 0.75 mm thick (the maximum thickness of a single coating).
2. **Stainless-steel-shielded air gap.** A stainless steel shield, factory-applied or retrofitted to a dispersion tube, creates an air gap that provides insulating value. The air gap varies in thickness from 0 to 6.35 mm thick.
3. **PVDF (polyvinylidene fluoride) insulation.** PVDF insulation is factory-applied or retrofitted to a dispersion tube. PVDF is dense, closed-cell insulation, 3.20 mm thick.

Figure 3-1:
Dispersion tube insulation types with drawings in cross section

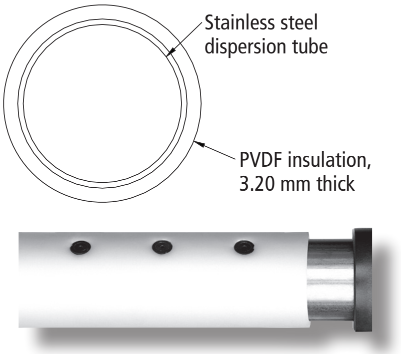
1. Thermal insulating coating



2. Stainless-steel-shielded air gap



3. PVDF insulation



Heat transfer basics and TICs

Heat transfer occurs in three ways: conduction, convection, and radiation.

Conduction is the transfer of thermal energy in solids and liquids at rest, such as through a stainless steel dispersion tube.

Convection describes thermal energy transferred between a solid surface and a fluid moving over the surface, such as cool air flowing over a hot dispersion tube.

Radiation is thermal energy transferred by electromagnetic waves and requires no medium; it will travel through a vacuum. Heat loss via radiation from a dispersion tube is only 1-2% of the total heat loss from convection. Heat loss via radiation is strongly dependent on the surface emissivity and temperature of that surface to the fourth power. For example, a 1 m section of DN40 tubing with a surface emissivity of 0.3 and surface temperature of 99.7 °C radiates only about 26 W. The surface temperature of the tube is too low to contribute any significant heat loss via radiation. However, for very hot surfaces, radiation can become the dominant heat transfer mechanism. For example, that same tube at 500 °C radiates about 714 W; 27 times more than at 99.7 °C.

Because thermal insulating coatings (TICs) are most effective at reducing heat transfer via radiation, they are often used in applications such as on building roofs to reduce heat transfer due to solar radiation. This is an important benefit for this application. However, at 0.25 to 0.75 mm per coating, TICs cannot provide much resistance to heat transfer via conduction through a roof.

Take care when comparing effectiveness of insulating materials. First understand the difference between *R* value (thermal resistance), λ factor (thermal conductance), and the type of heat transfer you wish to reduce (radiation, convection, conduction). Then, choose the appropriate insulating material.

Comparing thermal conductivity *(λ)* and thermal resistance *(R)* values

Thermal conductivity is the property that indicates how well a material conducts or transfers thermal energy. A material with a high thermal conductivity, such as metal, conducts heat more readily than a material with a low thermal conductivity such as plastic. Materials that resist the conduction of heat have low thermal conductivities and are called insulators. A thermal conductivity value is also commonly called a λ factor.

For example, a typical λ factor for a thermal insulating coating is 0.0324 W/m•K. This means that heat will transfer through this material at a rate of 0.0324 W given a 1 degree K temperature difference (one side of the material is 1 degree K cooler than the other) over an area of 1 square meter through a thickness of 1 meter.

The thermal conductivity (λ) factor of a material is independent of thickness. For example, an 200 mm-thick thermal insulating coating has the same λ factor as a 0.75 mm-thick thermal insulating coating: 0.0324 W/m•K. However, the thermal resistance *(R)* value of a material, is dependent on thickness:

R = material thickness (in meters) / λ

Therefore, the R value of a typical thermal insulating coating with a thickness of 0.76 mm (0.00076 m) is:

$R = 7.625 \bullet 10^{-4} / 0.0324 = 0.0235\ m^2 \bullet K/W$ or $R = 0.0235$

The R value of PVDF insulation with a thickness of 3.2 mm (0.0032 m) is:

$R = 0.003172 / 0.0107 = 0.296$

Table 4-1:
Insulation λ factors and *R* values

Insulation	Thickness	lambda (λ)	*R* value
	m	W/m•K	thickness/λ
Thermal insulating coating	$7.625 \bullet 10^{-4}$	0.0324	0.0235
Stainless-steel-shielded air gap	0 to 0.00635	0.0624 (average)	0.084 (average)
PVDF insulation	0.003172	0.0107	0.296

Comparing TIC to PVDF insulation

For the thermal insulating coating to have the same R value as PVDF insulation it would need to have a thickness of 9.55 mm (0.00955 m):

$$R = 0.00955 / 0.0324 = 0.295$$

Note that the thermal insulating coating would need to increase in thickness by a factor of 12.5 to have the same R value as 3.2 mm of PVDF insulation.

A 0.75 mm-thick thermal insulating coating would need to increase in thickness by a factor of 12.6 to have the same R value as 3.2 mm of PVDF insulation.

Comparing stainless-steel-shielded air gap to PVDF insulation

The R value of PVDF insulation (0.296) is 3.5 times higher than the R value of the stainless-steel-shielded air gap (0.084). While air can be an excellent insulator, open spaces between the stainless-steel shield and dispersion tube allow air circulation, which increases convective heat loss. Compare this to the most effective insulation types, which have numerous small air pockets that prevent air from circulating.

The R value of PVDF insulation (0.296) is 3.5 times higher than the R value of the stainless-steel-shielded air gap (0.084).

Note that stainless-steel shields are very effective for reducing and deflecting heat transfer via radiation; however, only 1-2% of dispersion tube heat loss is from radiation.

Note also from Table 5-1 that stainless-steel-shielded tubes weigh approximately 50 times more per linear foot than PVDF insulation.

Table 5-1:
Characteristics of dispersion tube insulating materials

Characteristic	Thermal insulating coating	Stainless-steel-shielded air gap	PVDF insulation
Flame/smoke rating	5/5[*]	0/0	0/0
Ultraviolet light ageing resistance	Good resistance to UV light UVC resistance data not available	Stainless steel not affected by any type of UV light; data not available on foam	Inherently resistant to UV light, including UVC; no additives required[1]
Microbial growth resistance	Data not available	Stainless steel does not support microbial growth; data not available on foam	Does not support microbial growth[2]
Material life	Expected to meet or exceed dispersion tube lifetime	Expected to meet or exceed dispersion tube lifetime	Expected to meet or exceed dispersion tube lifetime
Weight, kg/linear meter	0.060	0.74	0.015
Typical air duct pressure loss[3]	27 Pa	27 Pa	36 Pa
Peeling and particle shedding	Data not available	Stainless steel does not shed particles; data not available on foam	None[4]
Outgassing	Data not available	Stainless steel does not outgas; data not available on foam	None[5]

[*] Per manufacturer's literature
[1] Xenotest 1200, CEPAP, Ci3030, and other tests
[2] DO160 D, Section 13 Category F, and other tests
[3] 1830 mm x 1220 mm dispersion panel with DN40 dispersion tubes installed 75 mm o.c., duct air speed 5.1 m/s
[4] ASTM C 1071 Section 12.7 Erosion Resistance; and ASTM D 3330 Peel Adhesion
[5] ASTM D 5116, EPA Method IP-1B, ASTM D 6196

Downstream heat gain sources

Downstream heat gain from the sensible heat of steam injected into air cannot be reduced, as it is an inherent property of steam.

However, the convective transfer of heat from hot dispersion tubes to a cool airstream can be reduced significantly by using insulated dispersion tubes.

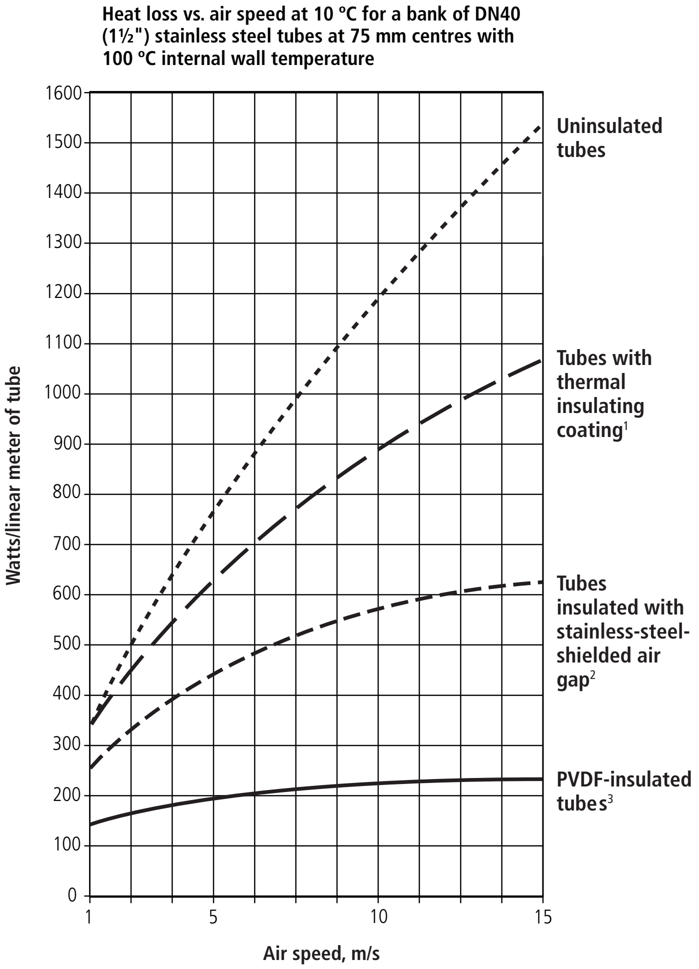
See the back cover for more information.

Charting performance

Figure 6-1 shows dispersion tube heat loss at various airflow speeds. Note from the graph that:

- At low air speeds there is little or no benefit from the thermal insulating coating.
- Tubes insulated with a stainless-steel-shielded air gap have two to three times more heat loss than tubes with PVDF insulation.
- Insulation efficiency increases with air speed for all types of insulation.
- Tubes with PVDF insulation reduce heat loss more than tubes with a thermal insulating coating or stainless-steel-shielded air gaps.

Figure 6-1:
Dispersion tube heat loss



Notes:

Heat loss calculations based on: Kakac, S., Shah, R.K., and Aung, W. (Eds.). (1987). *Handbook of single-phase convective heat transfer* (pp. 6.1-6.45). New York: John Wiley & Sons.

1 Tube with thermal insulating coating has a 0.75 mm-thick spray-on coating with a thermal conductivity of 0.0324 W/m•K and an *R* value of 0.0235.

2 Stainless-steel-shielded air gap ranges from 0 to 6.35 mm thick, has an average thermal conductivity of 0.0624 W/m•K, and an average *R* value of 0.084.

3 PVDF insulation on tube is 3.2 mm thick and has a thermal conductivity of 0.0107 W/m•K and an *R* value of 0.296.

Conclusion

Dispersion tube heat loss is directly proportional to downstream heat gain and condensate loss in dispersion tubes. To reduce downstream heat gain and condensate loss, insulate dispersion tubes with one of the three methods discussed in this paper. To reduce wasted energy and water up to 85% (as demonstrated in Table 10:1), insulate dispersion tubes with PVDF insulation.

To reduce wasted energy and water up to 85%, insulate dispersion tubes with PVDF insulation.

See the sample problem, starting on the next page, which compares energy and water savings per year for a typical dispersion tube installation using the three insulation methods described in this paper.

Use the tables at the end of this document to calculate savings for your particular application.

What is "efficiency" measuring?

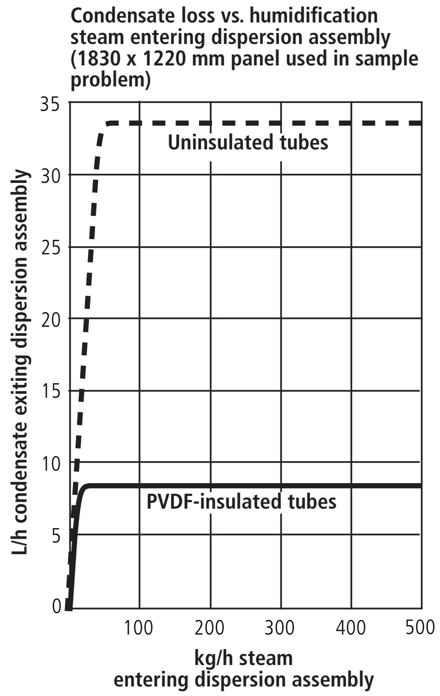
The "Efficiency" columns in Table 10-1 describe the efficiency of insulated dispersion tubes compared to an uninsulated dispersion tube, based on surface temperature, heat loss, and condensate production per linear foot of tube. Note that efficiency varies with airspeed; efficiency also varies with air temperature, but air temperature is constant in this table.

The efficiencies listed in Table 10-1 are for dispersion tubes only and do not include dispersion assembly headers.

These efficiencies do not change when the load changes. If a tube has hot steam running through it, it will produce condensate and give up heat at the rate listed in the table, regardless of load (Figure 7-1).

Do not state efficiencies based on load, for as you can see from Figure 7-1, when the humidification load is 100 kg/h, condensate exiting the PVDF-insulated tubes (from the sample problem on Page 8) is 8.13 L/h (8.13% of load), and when the load is 500 kg/h, condensate exiting the PVDF-insulated tubes is still 8.13 L/h (1.63% of load).

Figure 7-1: Condensate loss vs. load



Sample problem demonstrates savings

For uninsulated steam dispersion tubes; and tubes insulated with a thermal insulating coating, a stainless-steel-shielded air gap, and PVDF insulation as described in this paper, calculate the following:

- Heat loss in Joules
- Condensate production in kg/h
- Total downstream air heat gain in °C
- Btus saved per year when using PVDF insulated tubes instead of uninsulated tubes.

System and conditions:

- Upstream RH: 20%
- Downstream RH: 60%
- Duct air speed: 5.1 m/s
- Humidification load: 197.5 kg/h
- Steam dispersion assembly: Face dimensions W 1830 × H 1220 mm with DN40 (1½") diameter dispersion tubes at 75 mm centres; 23 tubes each 1220 mm long
- Air temperature downstream from dispersion assembly: 13 °C
- Humidification steam pressure: Atmospheric, at sea level (101.3 kPa)
- Humidification system operating hours: 2000 h/yr

Solution to sample problem

1. **Using Table 10-1, determine heat loss per linear foot of tube:**
   a. Uninsulated dispersion tubes:
   732 W/m
   b. Dispersion tubes with the thermal insulating coating:
   623 W/m
   c. Dispersion tubes with stainless-steel-shielded air gap:
   424 W/m
   d. Dispersion tubes with PVDF insulation:
   182 W/m
2. **Determine total length of tubing.**
   The steam dispersion assembly has 23 tubes. Each tube is 1220 mm long, for a total tube length of 28.06 meters. (23 tubes × 1220 mm)
3. **Determine total heat loss:**
   a. Uninsulated dispersion tubes:
   28.06 meters of tube × 732 W/m
   = 20540 W total heat loss
   b. Dispersion tubes with the thermal insulating coating:
   28.06 meters of tube × 623 W/m
   = 17481 W total heat loss
   c. Dispersion tubes with stainless-steel-shielded air gap:
   28.06 meters of tube x 129 W/m
   = 11891 W total heat loss
   d. Dispersion tubes with PVDF insulation:
   28.06 meters of tube × 182 W/m for PVDF insulated tubes
   = 5107 W total heat loss

4. **Determine condensate production per hour:**
   (The latent heat of vaporization and condensation for water is 2256076 J/kg)
   a. Uninsulated dispersion tubes:
      (20540 W) / (2256076 J/kg) = 32.78 kg/h of condensate
   b. Dispersion tubes with thermal insulating coating:
      (17481 W) / (2256076 J/kg) =27.89 kg/h of condensate
   c. Dispersion tubes with stainless-steel-shielded air gap:
      (11891 W) / (2256076 J/kg) = 18.97 kg/h of condensate
   d. Dispersion tubes with PVDF insulation:
      (5107 W) / (2256076 J/kg) = 8.15 kg/h of condensate

5. **Using Table 11-1, determine total downstream air heat gain:**
   Heat from steam + heat from dispersion tubes = total heat gain
   a. Uninsulated dispersion tubes: 0.59 + 1.43 = 2.02 °C
   b. Dispersion tubes with thermal insulating coating:
      0.59 + 1.22 = 1.81 °C
   c. Dispersion tubes with stainless-steel-shielded air gap:
      0.59 + 0.83 = 1.42 °C
   d. Dispersion tubes with PVDF insulation: 0.59 + 0.36 = 0.95 °C

6. **Determine annual energy savings in Joules using PVDF insulated tubes instead of uninsulated tubes.** Assume 2000 hours per year operation.
   Annual heat loss of uninsulated tubes per year – annual heat loss of insulated tubes = annual energy savings

$$\frac{(20540\ \text{W} \times 2000\ \text{h/yr}) - (5107\ \text{W} \times 2000\ \text{h/yr})}{1000}$$

   = 30866 kW/h (1 kW/h = 3600 kJ)
   (30866 kW/h x 3600 kJ/Kw) = 111117600 kJ

Table 9-1:
Results summary for sample problem: 1830 × 1220 mm dispersion panel; DN40 (1½") dispersion tubes at 75 mm centres; 5.1 m/s air speed, operating 2000 h/yr

	Uninsulated tubes	TIC-insulated tubes	PVDF insulated tubes	PVDF insulated tubes compared to uninsulated tubes	
				Savings	Percentage improvement
Heat gain to downstream air from dispersion tubes	1.43 °C	1.22 °C	0.36 °C	1.07 °C	75%
Heat loss per hour	20540 W	17481 W	5107 W	15433 W	
Heat loss per year	147888000 kJ/yr	125863200 kJ/yr	36770400 kJ/yr	111117600 kJ/yr	
Condensate production per hour	32.78 L/h	27.89 L/h	8.15 L/h	24.63 L/h	
Condensate production per year	65560 L/yr	55780 L/yr	16300 L/yr	49260 L/yr	

Table 10-1:
Heat loss from a 1830 × 1220 mm dispersion panel with DN40 (1½") dispersion tubes installed at 75 mm centres

	Stainless steel tube (uninsulated)	Stainless steel tube with thermal insulating coating		Stainless steel tube with stainless-steel-shielded air gap		Stainless steel tube with PVDF insulation	
Air speed	Heat loss	Heat loss	Efficiency	Heat loss	Efficiency	Heat loss	Efficiency
m/s	W / linear meter of tube	W / linear meter of tube	%	W / linear meter of tube	%	W / linear meter of tube	%
1.27	304	319	-5	245	19	128	58
2.54	472	448	5	314	33	156	67
3.81	610	545	11	374	39	172	72
5.08	732	624	15	424	42	183	75
6.35	843	691	18	465	45	191	77
7.62	946	751	21	500	47	197	79
8.89	1043	804	23	529	49	203	81
10.16	1134	852	25	551	51	207	82
11.43	1222	896	27	569	53	210	83
12.70	1306	937	28	584	55	213	84
13.97	1387	974	30	596	57	216	84
15.24	1466	1009	31	606	59	218	85

Notes:
Heat loss calculations based on: Kakac, S., Shah, R.K., and Aung, W. (Eds.). (1987). Handbook of single-phase convective heat transfer (pp. 6.1-6.45). New York: John Wiley & Sons, with the following inputs:

- DN40 (1½") stainless steel tubes
- Internal wall temperature of tube = 100 °C
- Air temperature outside of tube = 10 °C
- Thermal insulating coating:
  - Thermal conductivity = 0.0324 W/m•K
  - *R* value = 0.0235
  - Thickness = 0.75 mm
- Stainless-steel-shielded air gap:
  - Thermal conductivity (average) = 0.0624 W/m•K
  - *R* value (average) = 0.084
  - Thickness = 0 to 6.35 mm
- PVDF insulation:
  - Thermal conductivity = 0.0107 W/m•K
  - *R* value = 0.296
  - Thickness = 3.2 mm

Shaded cells refer to sample problem starting on Page 8.

Table 11-1:
Airstream heat gain from a 1830 × 1220 mm dispersion panel with DN40 (1½") dispersion tubes installed at 75 mm centres (12.78° downstream air temp, 20% upstream RH, 60% downstream RH)

Air speed	Humidification load	Heat gain from steam	Stainless steel tubes (uninsulated)		Stainless steel tubes with thermal insulating coating		Stainless steel tubes with stainless-steel-shielded air gap		Stain steel tubes with PVDF insulation	
			Upstream air temp.	Heat gain from tubes	Upstream air temp.	Heat gain from tubes	Upstream air temp.	Heat gain from tubes	Upstream air temp.	Heat gain from tubes
m/s	kg/h	°C	°C	°C	°C	°C	°C	°C	°C	°C
1.27	51	0.62	9.8	2.38	9.7	2.49	10.2	1.92	11.2	1.00
2.54	100	0.61	10.3	1.85	10.4	1.76	10.9	1.23	11.6	0.61
3.81	149	0.60	10.6	1.60	10.8	1.43	11.2	0.98	11.7	0.45
5.08	198	0.59	10.7	1.43	11.0	1.22	11.3	0.83	11.8	0.36
6.35	246	0.59	10.9	1.32	11.1	1.09	11.4	0.73	11.9	0.30
7.62	294	0.59	11.0	1.23	11.2	0.98	11.6	0.65	11.9	0.26
8.89	343	0.59	11.0	1.17	11.3	0.90	11.6	0.59	12.0	0.23
10.16	391	0.59	11.1	1.11	11.4	0.83	11.7	0.54	12.0	0.20
11.43	439	0.58	11.1	1.07	11.4	0.78	11.7	0.50	12.0	0.18
12.70	488	0.58	11.2	1.03	11.5	0.74	11.7	0.46	12.0	0.17
13.97	536	0.58	11.2	0.99	11.5	0.70	11.8	0.43	12.0	0.15
15.24	584	0.58	11.3	0.94	11.5	0.65	11.8	0.39	12.1	0.14

Notes:
Heat loss calculations based on: Kakac, S., Shah, R.K., and Aung, W. (Eds.). (1987). Handbook of single-phase convective heat transfer (pp. 6.1-6.45). New York: John Wiley & Sons, with the following inputs:

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  Thermal conductivity (average) = 0.0624 W/m•K
  R value (average) = 0.084
  Thickness = 0 to 6.35 mm
- PVDF insulation:
  Thermal conductivity = 0.0107 W/m•K
  R value = 0.296
  Thickness = 3.2 mm

Shaded cells refer to sample problem starting on Page 8.

For more information visit our High-efficiency Tube option Web page:
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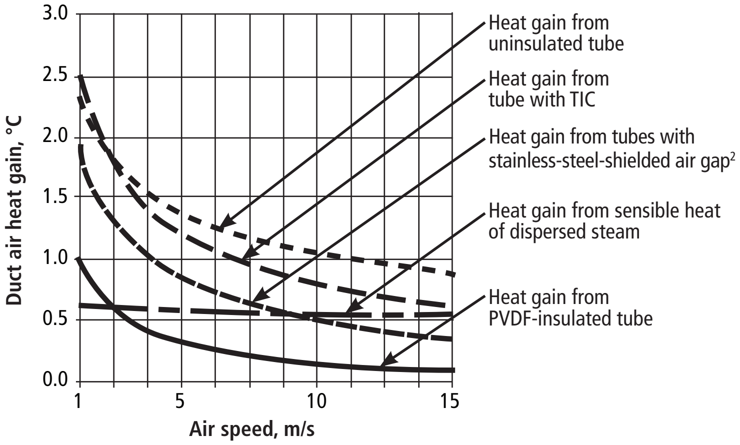
Form No. Heat gain paper 0409 Metric

Figure 12-1:
Duct air heat gain from steam and from dispersion assembly described in sample problem on Page 8



Notes:
Airstream heat gain calculations based on: Kakac, S., Shah, R.K., and Aung, W. (Eds.). (1987). *Handbook of single-phase convective heat transfer* (pp. 6.1-6.45). New York: John Wiley & Sons.

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3 PVDF insulation on tube is 3.2 mm thick and has a thermal conductivity of 0.0107 W/m•K and an *R* value of 0.296.

Reducing downstream heat gain

Figure 12-1 illustrates how dispersed steam and dispersion tubes add heat to a duct or AHU airstream.

The first source of heat gain is from the sensible heat of steam injected into the air. This heat gain is due to the inherent properties of steam and cannot be reduced.

The second source of heat gain is from the convective transfer of heat from hot dispersion tubes to a cooler airstream. This heat gain can be reduced significantly by using insulated dispersion tubes.

For more information contact: