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Paper machine room ventilation guidelines

Scope

This Technical Information Paper provides an overview of principles and guidelines for designing and optimizing paper machine room ventilation systems.

Safety precautions

Normal safety precautions should be taken when working around operating machinery, hot surfaces, and steam systems.

Application note

This Technical Information Paper provides general guidelines for estimating airflow requirements for machine room ventilation systems. It also provides a description of ventilation system operation and typical system requirements. It is intended to provide an overview to paper machine room ventilation and does not attempt to address every possible application. Engineers with experience in paper machine room air handling should be consulted for specific design work and to address specific operating problems.

Calculations are presented in both English and SI units. Metric tons are referenced as tonnes. Refer to Table 1 for English to metric conversions. Two sample calculations are included at end of the TIP, one for a linerboard paper machine and one producing copy grade paper.

Ventilation principles

Purpose and benefits

Ventilation air is a raw material needed to make paper, just like fiber, water, additives, steam, electricity, and instrument air. The amount of air required to produce a ton of paper can be 75 tons or more, depending on the grade.

Ventilation air is used to improve drying uniformity and capacity, improve the working environment, reduce maintenance of roof and building equipment, reduce product contamination, and extend process equipment life.

Ventilation air serves two primary purposes:

- contain and remove contaminants: water vapor, heat, and dust
- replace air removed as part of the process, drying, and vacuum systems

The benefits, such as improved environment for personnel and reduced building maintenance in most cases, do not translate into an immediate financial return unless they remediate an unsafe condition or impact production. A well ventilated building has the following attributes:

- good visibility throughout the building (no fog)
- no condensation on surfaces
- thermal comfort (with respect to ambient condition) in operating areas
- no stagnant airflow areas
- controlled airflows in and out of the building to prevent disruption of paper drying and sheet handling
- minimum energy requirements

Contaminants

The three major contaminants present in a paper machine environment are water vapor, heat, and dust.

Water vapor

Papermaking is a dehydration process with numerous sources of water vapor being transferred to the building environment. The largest source of water vapor is contained and exhausted through the dryer section hood. A significant amount of water vapor is generated in the forming and press sections. Other sources are savealls, thickeners, pulpers, open chests, and flumes.

The amount of water vapor evaporating from a source is a function of temperature (vapor pressure), surface area, and surface agitation or machine speed.

Uncontained water vapor will spread throughout the building primarily by convective air flows and, to a lesser degree, by diffusion.

Fog and condensation occur when the surface water partial pressure exceeds the equilibrium vapor pressure, which is dependent on the local temperature. The local temperature is a function of the amount of cold air introduced into the building (or exhaust rate), equipment heat gain, and heat loss through the siding.

Heat

Papermaking is also an energy intensive process requiring large amounts of steam and electricity. The equipment and system inefficiencies become a source of heat into the building. Typical process heat loads removed by the exhaust system are listed as follows:

Area/Source	Floor Level	Heat		
		Btu/ton	kW-h/tonne	
Stock Preparation				
- Refiners	Bleached Board: Corrugating: Fine Paper: Linerboard: Publication:	Operating	73 900	19.6
			37 000	9.8
			88 000	23.4
			51 700	13.7
			59 100	15.7
- Cleaners (based on footprint)	Operating	1 000 Btu/h/ft²	3.15 kW/m²	
- Pumps & Piping	Ground	20 000	5.3	
Former & Press				
- Vacuum System	Ground	37 000	9.8	
- Pumps & Piping	Ground	75 000	19.9	
PM Drive				
- Forming & Press	Operating	51 600	13.7	
- Main Dryer	Operating	18 500	4.9	
- Size Press	Operating	3 200	0.9	
- After Dryer	Operating	6 400	1.7	
- Calender	Operating	14 500	3.9	
- Coater	Operating	27 100	7.2	
- Reel	Operating	8 600	2.3	
- Winder	Operating	44 400	11.8	

Heat gains vary according to each machine and grade. The above loads offer a starting point for design when the information is not readily available.

Heat stress, as defined by National Institute for Occupational Safety and Health (1), is the sum of the heat generated in the body (metabolic heat) plus the heat gained from the environment minus the heat lost by the body to the environment. The body's response to heat stress is called heat strain and leads to heat-induced illness, disorders, and accidents.

Factors affecting heat stress are as follows, with the first two directly impacted by the building ventilation system:

- air temperature
- humidity
- radiant heat load
- physical activity
- body cooling

Dust

Dry end paper handling and winding generate a considerable amount of paper particulate matter that becomes airborne, creating health and housekeeping problems. Particulate levels are greater with lighter grades, such as tissue, and grades with high recycle and filler content and surface coatings.

Airborne dust in high concentrations is an occupational health concern and can become a fire fuel source.

The major sources of dust are poor broke handling practices, sheet exit doctor blades, and winder slitters. Over-drying the sheets increases dusting.

Air lances should be avoided in cleaning areas since they cause dust to become airborne.

Dust prevention should be the primary focus, with cleaning and collection being the last steps.

Recommended levels

Temperature:

Location	Minimum		Maximum, above ambient	
	°F	°C	°F	°C
Ground Floor	65	18	10	6
Operating Floor - Tending	75	24	5	3
Elsewhere	65	18	5	3
Operating Floor - Drive	75	24	10	6
Elsewhere	65	18	10	6
Mezzanine	65	18	20	12
Underside of Roof	80	27	25	14

Humidity

Humidity level shall be limited to the lower of the two values listed below:

Location	Maximum		
	RH	Humidity, above ambient	
	%	grains H ₂ O/lb DA ¹	g H ₂ O/ kg DA
Ground Floor	95	50	7
Operating Floor - Tending	95	50	7
Operating Floor - Drive	95	50	7
Mezzanine	95	100	14
Underside of Roof	95	150	21

1. 1 lb = 7000 grains, DA = dry air



Dust

Contained at sources. Current Occupational Safety and Health Administration (2) permissible exposure limit (PEL) for total dust is 15-mg/m³ and 5-mg/m³ for respirable dust.

Factors affecting ventilation performance

The amount of ventilation air required is a function of a number of factors, including the following:

Factor	Impact on Building Ventilation
Production Rate	Higher production rates have higher evaporation rates and, correspondingly, require more air
Grade of Paper	Lighter grades are more susceptible to air drafts
Machine Speed	Higher heat and mass transfer with increased machine speed
Type of Former	Top wire and gap formers require higher exhaust rates than fourdrinier formers
Stock Temperature	Increase mass transfer rate with increase in temperature
Type and Condition of Dryer Hood	Open hood requires more exhaust air than a closed hood
Climate	- Colder climates require higher building air balance - Warmer climates require higher ventilation rates during the summer
Building Geometry	Air follows the path of least resistance leading to short-circuiting of air
Equipment Layout	Multiple machines in the same building are more difficult to ventilation than single-machine rooms
Building Construction	- Building pressure dependent on building tightness - Increased risk of condensation with less wall and roof insulation

Air movement

Building air movement is a function of pressure, momentum, and density. Air movement in a building, for the most part, flows in the path of least resistance from regions of high to low pressure. When air is discharged from a duct or location at high velocities, its initial momentum primarily determines the flow pattern downstream of the jet until the energy is dissipated. Air discharged from a one-foot diameter opening reduces to ten percent of its initial velocity thirty feet from the opening. If the airflow were exhausted, ten percent of the velocity through the opening would be measured one foot away from the face of the opening.

The difference between inside and outside temperature and humidity levels results in a variation of density within the building, which gives rise to a natural convective flow within the building from the pressure variation. This “stack effect” causes cool and dry air to enter the building at the ground floor level as warm, moist (less dense) air rises to the underside of the roof, resulting in a vertical pressure difference with respect to the building exterior. In a machine room with equal supply and exhaust flows, a neutral pressure level, or null point, would occur at or below the mezzanine floor level with a positive pressure above the null point and negative pressure below it. Above the null point, air will exfiltrate out of the building and conversely infiltrate into the building below the null point.

The effectiveness of dryer section hoods to contain the heat and water vapor in the hood is greatly affected by the stack effect. The hoods and basement enclosure are basically a building within the machine room with greater difference in temperature and humidity than the surrounding room. The hood null point should be above the sheet entrance or exit to contain the evaporated water within the hood, i.e., air is drawn into the hood below this point. Increasing the hood exhaust or reducing the supply flow rates raises the null point. On the other hand, decreasing exhaust or increasing supply flows lowers the null point. Opening doors below the null point introduces more air into the enclosure, which is comparable to increasing the supply flow and in turn lowering

the null point. Opening a felt-loading door, above the null point, is equivalent to increasing the exhaust flow rate and raising the null point, even though hot and humid air would be “dumped” into the machine room.

Ventilation methods (3,4)

Mixed ventilation (dilution) – make-up air is supplied at high velocity into the space causing the air to be well mixed, in turn, reducing or diluting the contaminant concentration and temperature levels. Air is exhausted from the space through a combination of local locations close to the source or general building exhaust. Mixing ventilation is less effective for reducing contaminant and thermal level than the other methods. Earlier ventilation systems using this method became even less effective since the flow rates were rarely increased with higher heat and vapor loads resulting from higher production rates.

Unidirectional ventilation (piston airflow) – make-up air is supplied at low velocity and in the same direction as the exhaust to remove contaminants. These systems are the most effective in removing contaminants and typically applied to smaller areas where airflows can be controlled.

Displacement ventilation (passive thermal displacement) – low-velocity make-up air is supplied near the floor level, displacing heat and contaminants up to the upper level of the building where it is exhausted. Method uses the natural buoyancy of warm humid air coupled with cooler make-up air supplied low to displace heat and water vapor to the building upper level to be exhausted. Displacement ventilation was first applied in Scandinavian mills and has become the standard for new facilities.

Localized ventilation (spot cooling) – air supplied to work areas, creating comfort zones.

Displacement ventilation is the recommended method for paper machine building ventilation, with local ventilation applied to isolated areas.

General guidelines

1. Capture heat and water vapor as close to its source as possible since it will require less exhaust air than diluting it.
2. Minimize the amount of air exhausted to reduce energy costs.
3. Move air from areas of low heat and water vapor concentrations to high: dry-end-to-wet-end and tending-side-to-drive-side. Introduce air into the building such that it removes as much heat and water vapor as practical before being exhausted.
4. A balance of supply and exhaust systems is required for either system to function as designed.
5. General ventilation should primarily be used for comfort control, with water vapor control usually a secondary consideration. Dilution ventilation reduces overall water vapor concentration and temperature.
6. Use make-up air for personnel ventilation only.
7. Supply air should have sufficient heat to prevent condensate and fog from forming.
8. Displace heat and water vapor from operating personnel zones with large quantities of make-up air. Distribute air directly to work zone (below 10 feet) to provide effective dilution ventilation. Avoid high velocity discharges, which entrain warm and humid air streams.
9. Care should be taken to avoid unintentional short-circuiting.
10. The exhaust discharge, whether local or general, should be directed so as to reduce the possibility of reentry. Exhaust discharges should be located away from windows and air intakes.
11. Avoid locating ventilation ducts in the upper building levels unless insulated.
12. Perform regular maintenance on ventilation equipment and systems to ensure optimum performance.
13. Test ventilation systems periodically to determine how well they operate.

System description and dimensioning

Exhaust systems

The first priority of a good ventilation system is to capture heat and vapor at the source. All sources of latent heat and vapor should be contained before they migrate into the machine room. Effective vapor capture is essential at a number of machine components. Vapor spill from dryer hoods and wet end formers is the major cause of poor machine room working conditions. Paper machine room ventilation systems should include:

- Former exhaust
- Dryer section hood exhaust
- Saveall exhaust
- Pulper exhaust
- Building exhaust
 - Wet end false ceiling
 - Size press and coater false ceilings
 - Roof exhaust

Former exhaust

Former exhaust systems contain and exhaust water vapor from between and below the wire.

On modern high-speed machines, the forming section transfers the greatest amount of water vapor into the machine room. High stock temperatures, wire cleaning showers, steam showers, and high machine speeds increase the amount of vapor generated at the wet end. It is critical that this vapor be contained at the wet end and not be allowed to drift throughout the building. The former and showers should be shielded, as much as possible, and vapor should be exhausted from the drive side. Make-up air supplied to the tending aisle, opposite the forming and press sections, promotes a tending-side-to-drive-side airflow and increases the effectiveness of former exhaust systems. Mist elimination systems can make a significant impact in containing high-pressure shower water and improving system cleanliness.

Fourdriniers

Air is exhausted from four areas along the fourdrinier:

- Inside wire loop – between the wire and saveall
- Inside wire loop – below the saveall
- Wire pit
- Couch pit

Inside the wire loop – between the wire and saveall – On off-machine flume and silo machines, air is drawn from between the wire and saveall through the covered flume. The exhaust rate is limited by the cross sectional area above the operating water level and the top of the flume. In many cases, the area is too small to effectively evacuate the area. On-machine silo arrangements have no provision for exhausting from between the wire and saveall.

Inside the wire loop – below the saveall – Air is exhausted from inside the loop below the saveall by means of either cross-machine headers or a drive-side plenum. The primary pickup point is around the high-pressure needle shower located near the wire return and couch roll. Secondary pickup points are above the wire return rolls. Unshielded showers require higher exhaust rates.

Wire pit – Below the wire is typically exhausted with a cross-machine header located below the headbox capturing the entrained air from the wire return. On-machine flumes and silos are best exhausted using a drive-side plenum underneath the walkway. The plenum should step far enough back from the machine frame to provide access along

the machine for operation and maintenance personnel. Hinged and/or sliding doors should be provided where needed for equipment access.

Couch pit – The couch pit is a major source of water vapor with air pumped into it by the wire and high shower water rates. Older machines lack a couch pit exhaust connection because of limited space.

Top wires and gap formers

Typical exhaust points from a top wire section are from inside the wire loop, and after the high-pressure cleaning shower.

Top wire sections present a challenge in ventilating a paper machine wet end. Water vapor is entrained by the return wire direction and directed upward with sudden changes in wire direction. On the downward travel, the entrained flow converges with the base sheet entrained air flow, increasing the water vapor load to be exhausted by the overhead roof exhaust fans.

Typical pickup points on gap formers are the headbox area, inner and outer wire loops, and after high-pressure showers. Many of the new installations include tending and drive side shields, eliminating much of the water vapor.

Machinery builders typically provide ventilation air pickup points and recommended exhaust volumes for new and rebuilt formers. Top wire and gap former exhaust rates and pickup points vary greatly according to manufacturer since the savealls and cross machine headers are an integral part of the machine design. Flow rates tabled below provide a starting point for establishing former exhaust rates and pickup points.

Former Type	Exhaust Pick-up Points	Flow Factor, F_i		Flow Adjustment, B_i	
		ft	m	ft ³ /min	m ³ /s
Fourdrinier	1. Below wire – Beneath breast roll/headbox	0.13	0.04	11,000	5.2
	2. Couch Pit	0.13	0.04	0	0
On-machine flume & silo	3a. Below and inside wire loop – drive side plenum ¹	0.47	0.14	0	0
Off-machine flume & silo	3b. Inside wire loop – Cross machine headers or drive side plenum ²	0.26	0.08	0	0
	3c. Flume and silo ³	0.10	0.03	0	0
Top Wire	1. Beneath top former headbox	0.13	0.04	5,500	2.6
	2. Inside top wire loop: saveall pans and rolls	0.21	0.07	0	0
	3. After high pressure shower (Uhle Box)	0.16	0.05	0	0
	– No Temperature Correction Required				
Gap Former	1. Headbox area	0.47	0.15	0	0
	2. No. 1 outer/backing wire loop & saveall	0.28	0.09	0	0
	3. No. 1 stretch roll	0.24	0.07	0	0
	4. No. 2 inner/conveying wire loop & saveall	0.24	0.07	0	0
	5. Silo	0.05	0.02	0	0

1. Increase flow rate, if necessary, to maintain a minimum velocity of 100 ft/min (0.5 m/s) across the tending side face, [(breast roll to wire turning roll) x (wire height from operating floor)].
2. Flow factor is based on shielded showers. For unshielded showers, increase flow rate to maintain a minimum velocity of 100 ft/min (0.5 m/s) across the tending side face, [(breast roll to wire turning roll) x (wire height from operating floor)].
3. Decrease flow rate, if necessary, to not exceed a maximum velocity of 2000 ft/min (10 m/s) at the flume connections through the cross sectional area above the water level.

Recommended flow rates (ft³/min or m³/s) are calculated on the basis of a flow factor times machine design speed (ft/min or m/s) times the trim width (ft or m) based on a stock temperature of 120°F (49°C):

$$\dot{V} = \left(\sum_i^n B_i + vw \sum_i^n F_i \right) C_t$$

where

$\dot{V}$ = volumetric exhaust rate, ft³/min or m³/s

v = machine speed, ft/min or m/s

w = reel trim width, ft or m

n = number of pickup points

C_t = stock temperature correction, dimensionless

- = 1.0 for 120°F (49°C)
- = 1.3 for 130°F (54.5°C)
- = 1.8 for 140°F (60°C)

$\sum_i^n B_i$ = sum of flow adjustments, ft³/min or m³/s, refer to above table

$\sum_i^n F_i$ = sum of flow factors based on former type and pickup point, refer to above table

Exhaust air from the forming section is often nearly saturated with water vapor. Exhaust points near high-pressure showers or with high pick-up velocity entrain water droplets and fiber in the air stream, which are removed through a mist eliminator prior to the exhaust fan. Mist eliminators vary in design from drop-out chambers and eliminator blades, to cyclone and swirl tubes. Care is required at the discharge point to avoid recirculating vapor back into air intakes or exhausting air over roadways.

No system actually “eliminates” mist at the discharge point; rather, it removes it from the former. The water/fiber separator removes most particulate and water droplets from the air stream, but air that is expelled to the atmosphere is still saturated with water, which appears as mist when the mixture is discharged into cooler outside air. Introducing heated air into the exhaust stream prior to discharge reduces the fog formation associated with cold weather operation.

Vacuum pump/blower exhaust

Building air is exhausted to the atmosphere through the paper machine vacuum system. Some machines use blowers on the lower vacuum applications or multi-stage compressors for the higher vacuum cases instead of liquid-ring vacuum pumps to generate wet end vacuum.

Exhaust streams from blowers and compressors are hot and humid and contain a lot of energy. Some mills attempt to recover this energy by introducing it directly into pocket ventilation systems. High humidity in this supply air stream, however, reduces pocket ventilation effectiveness and the added water increases hood exhaust and building make-up air requirements. An alternative is to use indirect heat exchangers to recover heat from vacuum blower exhaust.

Vacuum flow rates are a function of paper and board grades and machine configuration, and are typically specified by the machine supplier. TIP 0502-01 (5), “Paper machine vacuum selection factors”, and TIP 0404-27 (6), “Press fabric dewatering and conditioning-suction box (Uhle box) design and vacuum requirements”, provide guidelines for sizing vacuum systems. Typical vacuum flow rates range from 90-to-150 scfm/in trim (1.67-to-2.79 sm³/s/m) from the former and press sections.

Dryer section hood and associated air systems

Refer to TIP 0404-24 (7), “Recommended operation of dryer section hood air systems”, and TIP 0404-17 (8), “Recommended minimum dryer pocket air requirements” for exhaust and pocket ventilation system description, guidelines for operation, and dimensioning.

One of the largest sources of heat and water vapor in the machine room is from the dryer section when hood doors are left open, especially if hood exhaust is not properly designed, dimensioned, and functioning. The front lift, rear sliding, and basement enclosure doors must be kept closed for the ventilation system to be effective in capturing and exhausting water vapor.

A tightly closed dryer section hood and properly balanced airflows are needed to prevent moisture spill from a conventional dryer section. The exhaust rate is directly proportional to the evaporation rate for a given hood type. A high performance hood requires less exhaust than an open hood. Refer to TIP 0404-24 for specific requirements for sizing hood exhaust and supply systems for the various hood construction types.

Sufficient make-up supply and humid air exhaust are required to isolate dryer air systems from building ventilation systems. Too little exhaust results in sweating and condensation on hood panels; spill to the machine room; equipment deterioration; and hot, uncomfortable conditions. Too much exhaust air wastes energy and can cause sheet flutter and edge over-drying. Exhaust flow rates also affect pocket humidity levels and can cause poor cross-machine sheet moisture profiles on machines with poor pocket ventilation.

Pulper exhaust

Modern ventilation systems also include local exhaust from pulpers to prevent vapor from spilling from these areas. The correct amount of pulper exhaust depends on pulper design and open area from the pulper to the operating floor. A net inflow velocity into the pulper of at least 150 ft/min (0.75 m/s) is desirable. It can be difficult to provide sufficient exhaust without making pickup velocities too high and pulling broke and water into the duct system. As a result, many old pulpers were not designed with exhaust systems.

Several pulper suppliers provide exhaust pickup points with recommended air volumes and static pressures. Typical exhaust rates per trim width per location are as follows:

Location	Flow Rate	
	ft ³ /min/ft	m ³ /s/m
Press Pit (1-48" wide slot)	720	1.11
Size Press (1-40" slot)	600	0.93
Reel (2 slots - 12" & 36")	720 + Trim Conveying	1.11 + Trim Conveying
Winder (1-36" slot)	540	0.84

Additional exhaust is required if a trim conveying system discharges into the pulper. The key to providing a net down-flow into the pulper is to minimize size of broke openings. Manual or pneumatic doors should be used at broke openings.

Systems with one-sided connections tend to be problematic with broke pick-up. The preferred design is a cross-machine header incorporated into pulper design with multiple inlet points to minimize broke carryover.

Retrofitting an exhaust system to an existing pulper can be difficult. Location of exhaust openings is critical. Openings should be located away from the sheet run into the pulper to prevent reduced airflows or system plugging during sheet break conditions.

Access doors are required in the duct approximately every 20 feet (6 m) starting at the connection to the pulper.

Saveall exhaust

Wet end savealls and broke thickeners are typically hooded and exhausted to maintain an inflow of air when the inspection doors or covers are open. Most modern disc filters and broke thickeners are furnished with tight fitting hoods, which require a vent to atmosphere or a minimum exhaust rate such as 2500 ft³/min (1.2 m³/s). Open hoods require a considerably higher exhaust rate and are designed with an inflow velocity around the perimeter of 150 ft/min (0.75 m/s).

Building exhaust

Building exhaust systems remove the heat and water vapor that cannot be captured at the source of origin. Wet end exhaust rates for water vapor removal, in most cases, exceed the requirements for heat removal from the forming and press sections. Supplemental exhaust is required from stock preparation and the building dry end for temperature control.

Wet end false ceiling and exhaust

A wet end false ceiling and ducted fans exhaust air and water vapor from above the former and press section. Water vapor not contained by the former exhaust system adds to the vapor load to be removed by the overhead exhaust system. The false ceiling exhaust has one of the highest concentrations of exhaust in the machine room.

A false ceiling is typically installed over the forming and press sections in machine rooms with structural steel framing to provide a physical barrier to prevent water vapor from rising into the truss space. Air is exhausted from the drive side to promote a tending-side-to-drive-side air flow. A curtain, extending from the underside of the truss to beneath the mezzanine, is mounted along the length of the false ceiling to limit the amount of air drawn from the drive side.

A false ceiling should extend in the machine direction from the headbox to the furthest point of the press section, typically the press overhang. In the cross machine direction, the false ceiling should extend from the drive side crane column to beyond the tending side of the wire. The false ceiling should extend beyond the machine edge by a minimum of 3.6-feet (1.1-meter) for every twenty feet (6 meters) the false ceiling is from the operating floor. Some mills extend the false ceiling the full width of the tending aisle to reduce the risk of water vapor rising into the truss space. Exhaust should be taken from the underside of the false ceiling on the drive side edge or along the top of the side curtain.

Wet end false ceiling and exhaust systems remove water vapor from the building by diluting and mixing the water vapor with warm air. Exhaust points are located at the wet end to move air from areas of low water vapor concentration to areas of high concentration with the heated air. Sufficient exhaust flow and heat are required to prevent condensation or fog. Insufficient exhaust causes the buoyant water vapor to rise and spread along the under side of the roof. In extreme cases, the water vapor will spread to the dry end of the building and condense on “cold” surfaces.

Steam boxes and cleaning showers may require heated air supplied along the tending side to push water vapor towards exhaust locations.

The amount of exhaust depends on the width of the machine, machine speed, stock temperature, type of former, climate, length of former and press section, and use of steam showers. Tempered supply air distributed along the tending aisle across from the former and press section helps to create tending-side-to-drive-side airflows, improve machine room comfort, and improve vapor capture. Supply air or wall openings on the back side of the former or exhaust fans over the tending aisle cause back-to-front air movement, which can result in vapor spilling over the tending aisle and towards the dry end, and should be avoided.

Recommended flow rates are calculated from the product of exhaust rate per area, machine design speed (ft/min or m/min), and trim width (ft or m) based on a stock temperature of 120°F (49°C):

$$\dot{V} = \left[(0.0107v + B) AC_t C_w + nDw \right] E$$

where

$\dot{V}$ = volumetric exhaust rate, ft³/min or m³/s

v = machine speed, ft/min or m/s

A = area, ft² or m² reel trim width x distance from headbox to dryer section, including press overhang

B = flow constant

= 6.53 ft³/min/ft²

= 0.0322 m³/s/m²

C_t = stock temperature correction, dimensionless

= 1.0 for 120°F (49°C)

= 1.38 for 130°F (54.5°C)

= 1.87 for 140°F (60°C)

C_w = wire surface area adjustment, dimensionless

- = 1.00 for fourdrinier
- = 1.25 for top former or gap former
- D = steam box and lazy steam shower adjustment
- = 2,000 ft³/min/ft
- = 3.1 m³/s/m
- E = exhaust correction, dimensionless
- = 1.00, rear curtain in place
- = 1.25, no rear curtain
- n = number of steam boxes and/or lazy steam showers
- w = reel trim width, ft or m

Size press and coater false ceiling and exhaust

Dryer hood breaks for breaker stacks, size presses, etc., are sources of vapor to spill into the machine room. These areas are ventilated similarly to the forming and press section, with false ceilings with drive side exhaust. The false ceiling should extend beyond the machine edge by a minimum of 3.6-feet (1.1-meter) for every twenty feet (6 meters) the false ceiling is from the operating floor, with a back side curtain closing down to the mezzanine floor level.

Recommended flow rates are calculated from the product of the exhaust rate per area, the machine speed (ft/min or m/min), and trim width (ft or m) based on a surface temperature of 150°F (66°C):

$$\dot{V} = (0.0242v + B)A$$

where

$\dot{V}$ = volumetric exhaust rate, ft³/min or m³/s

v = machine speed, ft/min or m/s

A = area, ft² or m² reel trim width x distance between main and after hoods, or length of coater section

B = flow constant

= 14.8 ft³/min/ft²

= 0.0752 m³/s/m²

Supplemental roof exhaust

High-level roof exhaust is required to remove any vapor that escapes from local exhaust systems and from areas with high thermal loads, such as stock preparation, coater, winder, and roll wrap areas. The exhaust rate is based on the ground and operating floor heat loads with the majority being from motors and piping. The heat loads listed under "Heat Contaminants" are typical and can be used as a starting point.

The minimum cold weather exhaust rate is calculated on the basis of removing the total process heat gain with a 25°F (14°C) temperature differential. The minimum flow rate should equal or be less than the total process exhaust rate including the wet end false ceiling exhaust. Additional roof exhaust in stock preparation and the building dry end is added to meet the minimum exhaust rate.

An added minimum of twenty-five percent of the wet end false exhaust rate should be drawn from the truss space to remove vapor not captured by the false ceiling and forming section exhaust systems. This is typically achieved by adjusting the stock preparation roof exhaust rate.

Similarly, an additional ten percent of the dryer section exhaust should be drawn from the truss area to remove vapor escaping from dryer section hood(s) when the doors are periodically opened. Here, the dry end exhaust rate is adjusted to meet the vapor load criteria.

Exhaust should be located over the drive aisle from both the wet end and dry end roof areas.

Summer roof exhaust

In most cases, it is desirable to increase the ventilation rate by adding roof exhaust fans that operate only in the summer months. Exhaust should be concentrated along the wet end drive aisle of the machine to promote tending-side-to-drive-side and dry-end-to-wet-end air flows. Some mills use two-speed fan drives to provide higher air flows in summer months and reduced flows in winter months without shutting fans off completely, preventing back-draft airflows and condensation. Other mills shut down some exhaust fans in winter.

This additional exhaust allows infiltration air to be introduced into the building through wall louvers and building openings along the operating floor and basement tending and drive aisles. Tight shut-off panels should be used to seal louvers in winter months. Exhaust fans not operated in winter must also have tight shut-off systems. In extreme cold climates, insulated construction is required to prevent sweating. A close look should be taken at airflows through the building with increased exhaust flows. Some mills use powered, but unheated, supply fans to balance summer exhaust. This method allows ducting directly to particular operating areas.

Special attention should be given to wet end truck doors that are left open during the summer and affect dry-end-to-wet-end airflow patterns.

Exhaust alone can seldom eliminate hot working conditions on the machine room floor. Use of forced summer ventilation is a common practice in warm-climate mills.

The minimum summer exhaust rate is calculated on the basis of reducing the temperature rise to 10°F (6°C) of the ground floor heat gain since most of the heat will be drawn up through the operating floor. Additional fans are added in the stock preparation, coater section, and building dry end to offset the heat loads.

Supplemental air supply, such as wall fans or air make-up units, should be added to maintain a minimum balance of 75%. Depending on the airflow patterns, the powered supply air flow rate can be as low as 50% of the warm weather exhaust rate.

Supply systems

Make-up air

Air exhausted from the building must enter the building either through a make-up air system or by infiltration from outside. Exhausting air without replacing it with heated make-up air draws cold air, in the winter, through doorways and openings, which reduces the building air temperature, causing fog and condensation in the forming and press sections. Fog and condensation are less severe during warmer weather and are replaced by hot working conditions along the operating floor.

Most modern ventilation systems are designed with a 100-to-105% winter air balance. That is, air exhausted from the machine room is replaced through heated make-up air units. Some warmer climate (southern) mills are designed with 70%–80% balance based on high exhaust rates. Operations located in cold climates or producing coated and food grade products require higher building air balance to prevent freezing or contaminated air from entering the building.

Displacement ventilation introduces cool (ambient in summer) air at low levels and displaces contaminants vertically using the buoyancy forces. Supplying fresh, low-humidity air along the tending side within eight feet or two-and-half meters of the operating floor provides operator comfort before picking up heat and humidity as it moves up and across the machine toward exhaust points.

Air make-up units are typically located either on the roof, mezzanine, or on the ground floor. Each location has advantages and disadvantages. Locating the units outside on the roof or at the ground floor level places them out of the way, but at the expense of having to go outside to inspect and service the units. Placing the units inside and making them readily accessible increases the likelihood that they will be maintained.

The air make-up unit location, ground floor or roof, determines the best approach to supplying air to the operating floor. Roof-mounted units supply air to the operating and ground floor levels through air chases constructed of insulated siding between the building columns, terminating approximately eight feet or two-and-half meters above the operating floor. Ground floor units supply air through distribution plenums located between the columns on the operating floor. Discharge velocity through the plenum or air chase (height above the operating floor x column spacing) should be in the range of 100-to-250 ft/min or 0.5-to-1.3 m/s. Higher discharge velocities entrain and mix with room air, defeating the displacement effect.

Older ventilation systems were designed to dump most supply air into the ground floor level and use mancoolers to pull air up to the operating floor. Although dump systems balance the building, they do little to improve operating floor working conditions. These systems are not as effective as those distributing air directly to the operating floor. Instead of cooling operating areas, dump systems and mancoolers transfer heat from the ground floor level onto the operating floor level where personnel are located.

Mancoolers tend to blow hot, humid air collecting beneath the operating floor to the area above. Different mancooler designs can increase effectiveness. Examples include skirts to pull air from a lower level or fans mounted on the basement floor and ducted up to the mancooler. Many of these systems have been retrofitted with ducts from the ground floor outlets to the mancoolers.

Distribution

All exhaust should be concentrated on the drive side of the machine room, with the majority located at the wet end of the building. Supply air distribution should be concentrated on the tending aisle at operating floor level creating two basic airflows through the building: tending side to drive side, and dry end to wet end.

Guidelines for supply air distribution are as follows:

Floor Level	Total	Tending Side	Drive Side	Remarks
Mezzanine	0-to-5%	-	0-to-5%	Spot cooling
Operating	70-to-80%	50-to-60%	10-to-20%	Drive motor cooling supplies air to drive side
Ground	20-to-30%	10-to-20%	5-to-10%	

Infiltration air

Locations of openings into the building and through the operating floor are important. Infiltration air can adversely affect an otherwise theoretically correct building air balance. Some systems have been designed with strong dry-end-to-wet-end airflows, but actually result in air exfiltrating at the dry end and infiltrating at the wet end.

Heating coils

Steam coils have traditionally been used to heat supply air. Glycol/water systems are becoming more common because of reduced maintenance, no freezing problems, and opportunities to use low-grade process heat. Other supply systems use gas-fired heaters, but emission restrictions and operating costs have limited their use.

Traditional steam coil drainage systems use inverted bucket steam traps or float and thermostatic traps (preferred) after coils to separate condensate from uncondensed steam. More modern systems use small, vented separators with dedicated condensate pumps or non-electric pressure-powered pumps where steam is used to convey condensate to a collection tank. Pressure-powered pumps typically need between 0.8–1.2 m (32" and 48") vertical distance between the bottom of the steam coils and the drainage unit. This is easy to achieve for coils installed on upper levels, but can be difficult to achieve for supply units located in the basement.

Freeze protection has always been an issue with steam coils. A number of control schemes such as face-and-bypass dampers and preheat/reheat coils have been developed to minimize risk of condensate freezing in coils exposed to the outside. A freeze protection control scheme should be included, which shuts off the fan, closes the main steam valve, and dumps condensate after the coils in case of power, steam, or instrument air failure.