Frost-protection measures in energy recuperation with multiple counterflow heat exchangers

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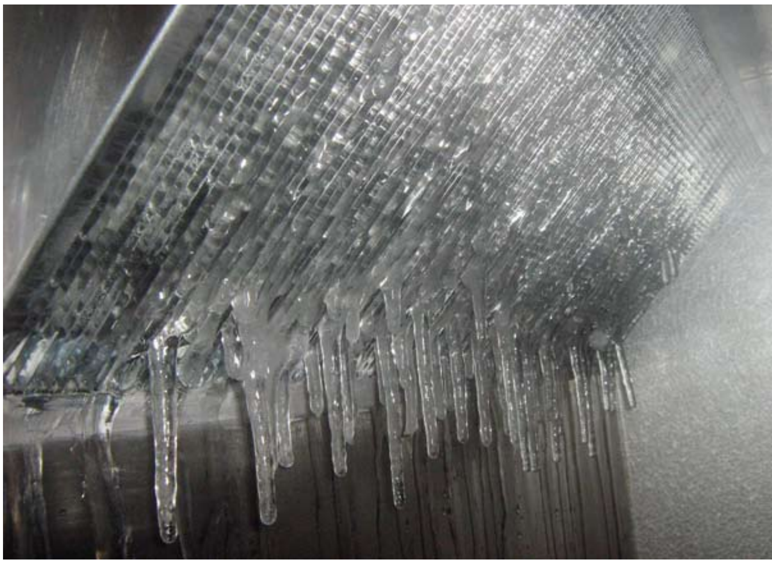
Manufacturers of air handling units (AHUs) continuously improve the electrical and thermal efficiency of their systems. These efforts include the optimization of energy recovery. The new GEA multiple counterflow principle is intended to achieve high energy-recovery coefficients in conjunction with low pressure drop. Additionally, the new system allows a bypass cycle that prevents pressure drop in the energy-recovery system with free cooling – and offers various possibilities for frost protection. The authors describe the energy costs of several frost protection solutions, in accordance with various climate conditions.

Energy-recovery systems in air handling units (AHUs) now on the market can in some cases already satisfy the high levels of heat-recovery efficiency stipulated by the upcoming ErP Directive. It is important to note, however, that greater heat-recovery efficiency – as a rule – is also associated with greater pressure drop, with negative effect on power consumption. In addition, increasing heat-recovery efficiency will cause extract air to be cooled nearer to the outdoor temperature. This extract air has greater humidity than the outdoor air. On winter days with freezing temperatures, condensate from the extract air may develop on cold surfaces of the energy-recovery system. High heat-recovery efficiencies and therefore lower outgoing air temperatures accordingly raise the risk of ice formation in the energy-recovery system. This, in turn, leads to reduced effectiveness and to even greater pressure drop. The objective is therefore to reach a satisfactory compromise among high levels of heat recovery, low pressure drop, and effective frost protection, to enhance the total efficiency of an air handling unit.



An iced-up energy-recovery system reduces heat-recovery efficiency and increases pressure drops. Effective frost-protection strategies are therefore crucial for efficient operation of an energy-recovery system on cold winter days.

Multiple counterflow heat exchangers

This new energy-recovery system should offer a high heat-recovery coefficient and, at the same time, should be easily kept free of ice. Also desirable here is an energy-recovery system that can be simply circumvented in free cooling mode, so that the system does not cause pressure drop in the transitional period. The GEA multiple counterflow heat exchanger, now in development, offers all these characteristics with a heat-recovery coefficient of more than 80%.

The GEA multiple counterflow heat exchanger is based on a solution with several layers or levels, and with a modular-configured counterflow principle (see **Figure 1**).

If use of the energy-recovery system is not essential, the bypass flaps open on the supply-air and on the extract-air side, and the air flows unimpeded pass the energy-recovery heat exchanger – for example, in free cooling mode. During operation of the energy-recovery system, typical pressure drop can be expected at the order of magnitude of Δp = 80 – 140 Pa (at an AHU face velocity of 1.5–2 m/s).

One energy-recovery system but many possible frost-protection measures

Multiple counterflow technology offers a selection from various feasible continuous frost-protection variants. Alternatives 1–5 are described and illustrated below.

1. Opening of the outside-air bypass (**Figure 1**), in accordance with the value given by a surface-temperature sensor, with setpoint value ≥ 0°C.
2. Configuration as shown in **Figure 1**; but instead of a fixed setpoint ≥ 0°C, the system takes the dewpoint temperature of the extract air into account. If there is no risk of condensation in the extract air, frost protection remains out of operation.
3. Preheating of the outside air, without re-heater. Before its entry into the multiple counterflow heat exchanger, the outside air is pre-heated to –2°C. (**Figure 2**).
4. Preheating of the extract air, to prevent the outgoing air temperature from falling below 2°C. (**Figure 3**)
5. Recirculation of outside air for preheating of this air to –2°C before entry into the multiple counterflow heat exchanger, by admixture of supply air (**Figure 4**).

The selection of the most effective frost-protection strategies to be used will depend in good part on the climate conditions of the installation location. The following will illustrate these interrelationships by describing simulation of the various frost-protection strategies for different climate conditions. Simulations are based on the following data:

- GEA CAIRplus® SX 096.064 AHU
  - Maximum air flow: 4,000 m³/h
  - Air velocity in free cross-section: approx. 1.8 m/s
  - Energy recovery system: GEA multiple counterflow; heat-recovery coefficient 0.807 at balanced air flows

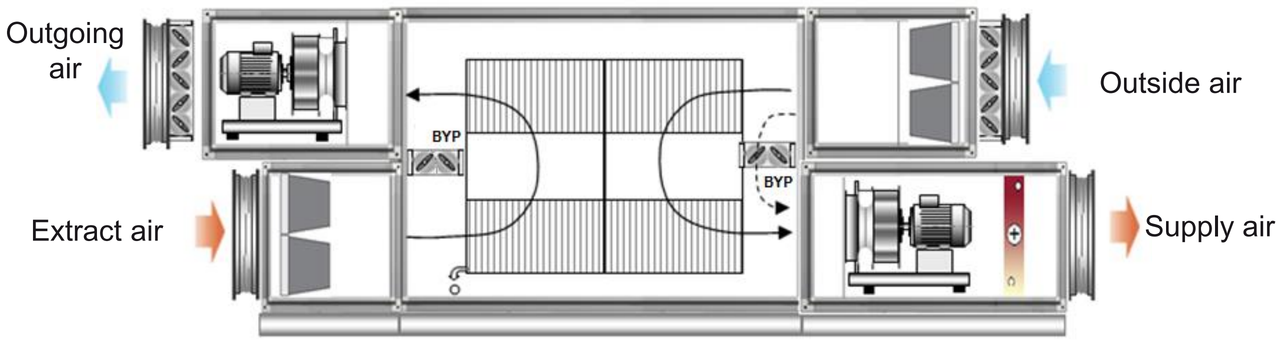


Figure 1. Frost protection by ourdoor air bypass.

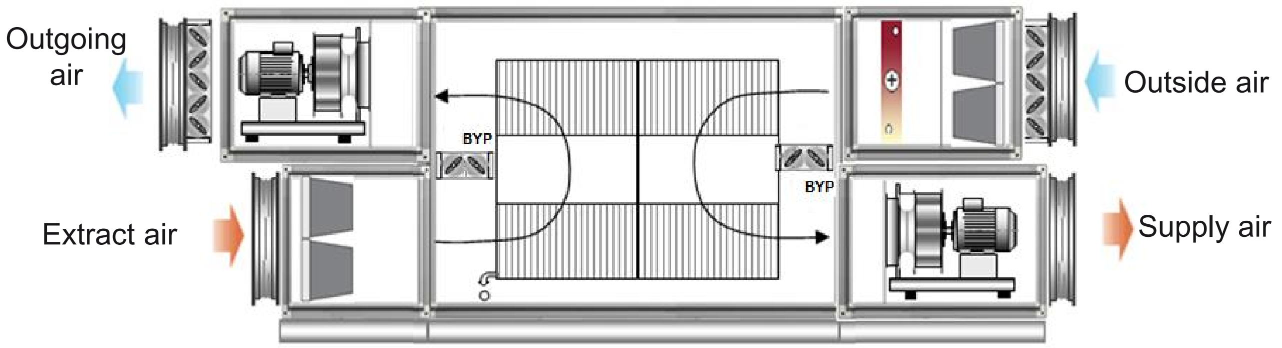


Figure 2. Frost protection with preheating of outdoor air.

- No cooling coil
- Fan efficiency: 60%
- Additional equipment for frost-protection types 3 to 5: secondary-circuit pump for the heater
- Operation: 8,760 h/a at full load
- Supply-air temperature: 17.7°C; extract-air temperature: 22°C
- Humidity load: + 1.5 g/kg

Energy prices were assumed to be 0.06 €/kWh for heat and 0.18 €/kWh for electricity.

Cost of frost protection alternatives in various locations

Barcelona, Spain

At the Mediterranean location of Barcelona, the outside temperatures are so high that, even on winter days, frost protection is not necessary.

Frankfurt am Main, Germany

The simulation situation for Frankfurt am Main is more differentiated. The most expensive frost-protection variant was no. 4, with extract-air preheating, in which the heating and power costs added to 3,773 €/a. This variant is not practically relevant, since heating of the extract air to 54.3°C would be necessary. The supply-air temperature would in this case rise to 42°C. To reduce the flow of supply air to comfortable temperature levels, the air would have to be cooled – or cold outside air would have to be mixed in. Neither solution would be technically feasible.

On the basis of prevailing outside winter temperatures, variant no. 5, with 3,399 €/a, would be the most cost-effective: i.e., for outside-air recirculation. This is effective only for temperatures down to approx. -9°C at maximum recirculation of 45%. During cold winters, temperatures can fall below this limit. Raising the recirculation rate would result in higher costs.

The remaining variants nos. 1, 2, and 3, feasible for Frankfurt, would lead to slightly different energy costs of 3,550 €/a, 3,587 €/a, and 3,436 €/a, respectively. The energetically most favorable solution – i.e., preheating of the outside air – does not feature a re-heater and therefore allows only supply air temperatures below the extract air temperature (here approx. 18°C). This is usually sufficient due to existent internal loads and additional systems for individual temperature control in the particular zones of the building. An extra re-heater would mean additional investment and operating costs due to further pressure drop. For variants 1 and 2, on the other hand, the re-heater is already available. With respect to flexibility of the supply air temperature, solutions with

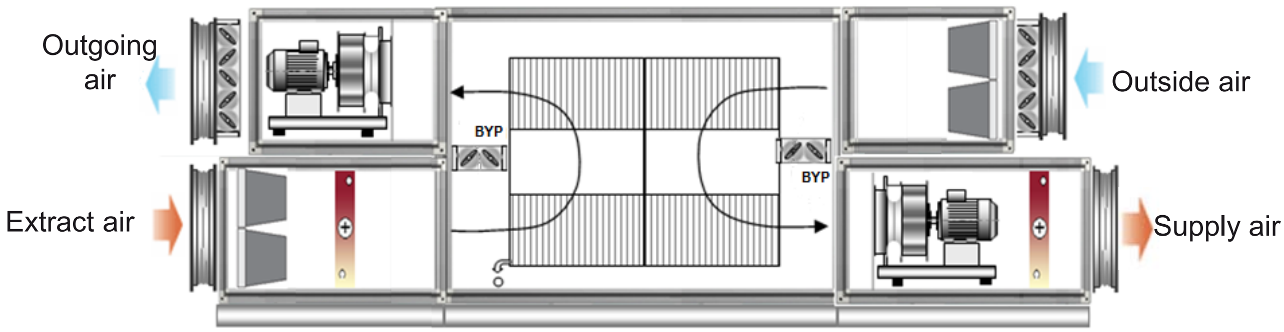


Figure 3. Frost protection with preheating of extract air.

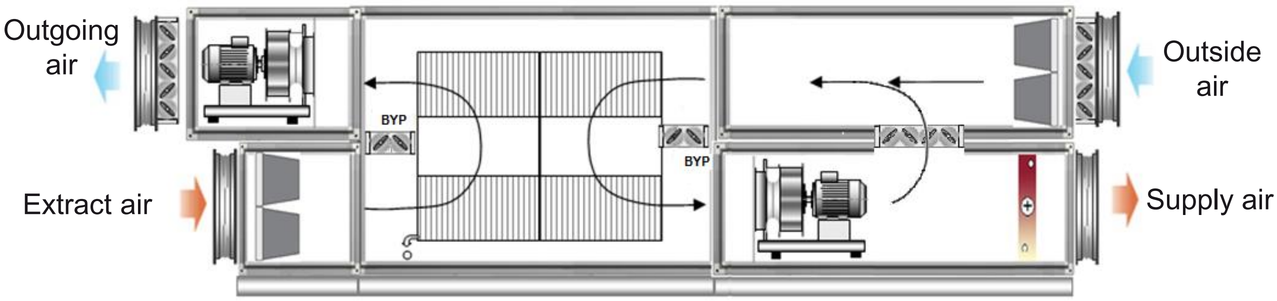


Figure 4. Frost protection with recirculation.

	Outside Air Bypass Concerning Temperature of PHE Surface	Outside Air Bypass Concerning Dew-Point Temperature of PHE Surface	Outside Air Preheating	Extract Air Preheating	Outside Air Recirculation
Auxiliary Energy	0	0	26	98	0
Heating	2821	1184	1339	4958	612
Fans	3261	3292	3320	3428	3527

Figure 5. The operational cost (heat and electricity) of frost protection in the case study with an air handling unit of 4 000 m³/h.

frost protection via outside-air bypass are advisable; with respect to operating costs, however, variant no. 3 applied without re-heater is the most favorable.

Moscow, Russian Federation

The exclusion criteria applied for Frankfurt am Main also apply to Moscow, which is much colder in winter (daily low outside temperatures of down to –24°C, according to weather statistics). Variants 1 to 3 would be feasible for selection here as well. Of these three options, the purely temperature-controlled outside-air bypass (variant 1) would represent by far the most expensive. The air heater in this case would necessarily provide heating duty of 56 kW to raise the air temperature to 17.7°C, due to heat recovery being completely bypassed under extreme winter conditions.

If surface dewpoint temperatures were used to control the bypass (variant no. 2), the operating costs would be 26% lower compared to the purely temperature-controlled outside-air bypass (variant no. 1) – and would moreover represent the strategy with minimal expenses. The bypass would be in operation 500 h/a less, and the flap would never have to be opened 100%. This is because a temperature drop below the dewpoint could hardly be expected, owing to the dry cold in conjunction with the assumed humidity load of only 1.5 g/kg. For cases with higher humidity load or AHUs with humidifiers, the results would be worse and tend more to those of variant 1.

For the case of frost protection by outside-air preheating, the operating expenses would not be even 5% more expensive than variation no. 2. Despite the disadvantage of only being able to provide supply air temperatures below the exhaust air temperature if no additional re-heater is applied, a factor in favor of outside-air preheating is the fact that the outcome of energy consumption is independent of extract-air humidity. For this reason, this variant is likewise advisable – or in cases with humidification – even superior. This solution is also supported in terms of investments by the fact that the heating coil and the heat generator can be dimensioned at 30 kW, which is 46% less than required for variant 1 or 2. A detailed consideration of the individual case may lead either to the most economic variant of dewpoint controlled bypass, or to outside-air preheating.

Conclusion

These simulations reveal that one preferable frost-protection strategy for all of Europe is not possible. Only extract-air preheating and outside-air recirculation do not come into consideration at all. The multiple counterflow solution enables the possibility of implementing two cost-effective frost-protection strategies, high heat-recovery coefficients, and low-loss free cooling. Product launch of the new GEA multiple counterflow system is scheduled for late 2013. ■