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Freeze-control strategy and air-to-air energy recovery performance

In certain climates, freeze-control strategies can significantly affect the seasonal performance of heat recovery ventilators

By *E.G. Phillips, P.Eng.*, Member ASHRAE, *D.R. Fisher, P.Eng.*, Member ASHRAE, *R.E. Chant, P.Eng.*, Member ASHRAE, and *B.C. Bradley, P.Eng.*

During cold weather operation, frost and/or ice may form on the exhaust-side heat exchanger surfaces of heat recovery ventilators (HRVs). Ice forms when exhaust air is cooled below its dewpoint and moisture condenses on heat exchanger surfaces that are below the freezing temperature. Frost forms when the exhaust air stream is cooled below both its dewpoint and the freezing temperature.[1]

Ice and frost reduce energy recovery in two ways:

- Thermal conductance of the transfer surfaces is reduced, so heat transfer rates are less; and
- Exhaust air flow rates are reduced, which reduces the energy available for recovery.

Various freeze-control techniques have been developed and applied to HRVs to address these problems. However, little had been done to compare the seasonal performance of these strategies under different climatic conditions.

Accordingly, ASHRAE Technical Committee 5.5 (Air-to-Air Energy Recovery) sponsored a research project (TRP-543) to compare the seasonal energy performance of residential heat recovery ventilators (HRVs) with different nominal effectiveness, using different freeze-control strategies and operating in different climatic conditions.[2] (HRVs are packaged air-to air heat exchangers complete with fans and controls.)

Whereas the study examined residential-scale air-to-air energy recovery equipment, the findings are equally relevant to large-scale commercial energy recovery applications in cold climates.

A computer program developed for this study[3] provided standardized energy performance comparisons for HRV freeze-control strategies for eight different climatic conditions (see *Figure 1*). Use of standardized heat exchanger performance and climatic data provided a common basis for comparison of freeze-control strategies.

The computer program consists of:

- A finite difference counterflow heat exchanger model that includes the effects of frost and ice on heat exchanger performance;
- An ambient temperature bin data generator that uses the EKB method[4] for selected locations; and
- Freeze-control algorithms that combine HRV frosting and EKB model outputs to predict the seasonal performance of each combination of heat exchanger effectiveness, strategy and climate.

The seasonal performance of the various control strategies was evaluated under the following conditions: inlet air temperatures from −54°to 10°C (−65°to 50°F); the number of hours of operation as determined by bin data for eight representative locations (see *Figure 1*); and three different values of effectiveness (50%, 65% and 80%). Only 80% is presented here because the results were similar except for scale.

About the authors

E.G. Phillips is a consulting engineer with UNIES Ltd., Winnipeg, Manitoba, Canada. He received a BSc in agricultural engineering and an MBA from the University of Manitoba. Phillips is a corresponding member of ASHRAE TC 5.5 (Air-to-Air Energy Recovery) and a member of SPC 136P (Method of Determining Air Change Rates in Detached Dwellings).

D.R. Fisher is the president of Fisher Consultants, Danville, California. He received a BS and an MS in mechanical engineering from the University of Manitoba. Fisher is a member of ASHRAE TC 5.5 and TC 9.8 (Large Building Air-Conditioning Applications).

R.E. Chant is the director of the Office of Industrial Research at the University of Manitoba, Winnipeg, Canada. He received his masters degree in mechanical engineering at McGill University. Chant has been active in several ASHRAE research projects related to air-to-air heat exchangers.

B.C. Bradley is a consulting engineer with UNIES Ltd. He received a BSc in engineering physics from the University of Saskatchewan.

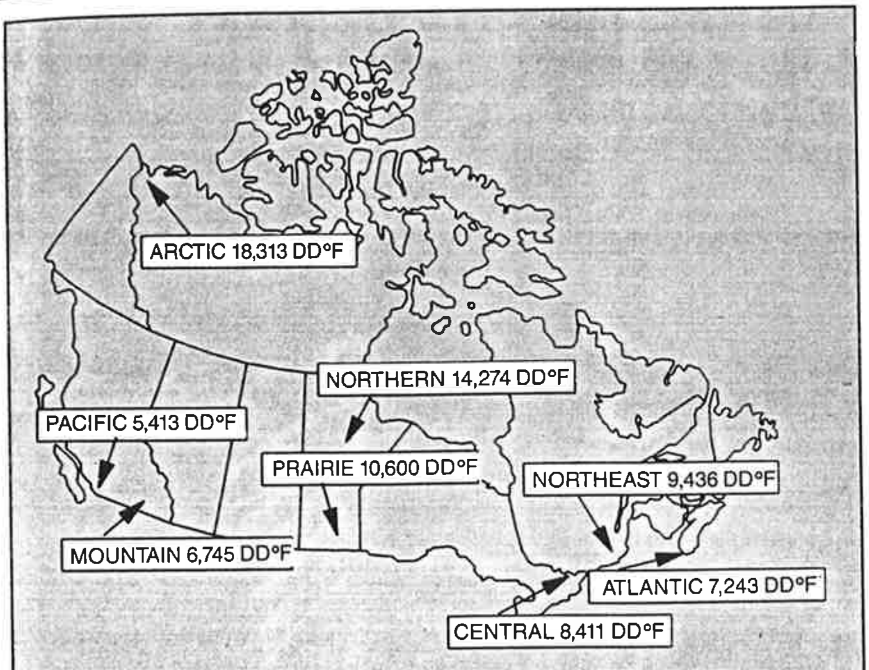

Figure 1. Eight different climatic conditions (see Phillips 1988 and 1989).

Variations of each freeze-control strategy were simulated to assess the benefits of optimizing the control strategy.

Freeze-control strategies

Frost prevention refers to methods of preventing frost or ice from forming on heat exchanger surfaces. Defrost refers to methods that remove frost and ice from heat exchanger surfaces. Jointly, these are referred to as freeze-control strategies. The following describes the freeze-control strategies evaluated.

Ideal freeze-control strategy (IDEAL). The heat recovery performance of an HRV equipped with the hypothetically ideal freeze-control strategy is not affected by frosting or icing on the heat transfer surfaces. Its seasonal effectiveness is essentially equal to its nominal effectiveness under all operating conditions.

Defrost by supply-fan shutoff (S.F.OFF). During the defrost cycle, the outdoor supply air through the HRV is shut off while exhaust air flow continues, thereby melting any frost or ice formations. There is no energy recovered during defrost. The defrost cycle operates for a set length of time (two minutes at 20-minute intervals) when outdoor temperatures are below some preset estimated surface frosting condition.

Defrost by warm-air recirculation (RECIRC.). During the defrost cycle, the outdoor air supply is stopped. Exhaust air is recirculated through the core and returned to the house. The defrost cycle operates for a fixed period of time. There is no outdoor air supply during the defrost cycle, so the design air flow rates must be increased to compensate. Increasing the design air flow rates will reduce the heat exchanger effectiveness.

Frost prevention by supply-air preheat (FIX. PH., STG. PH., VAR. PH.). The supply air is heated above the frost threshold temperature before it enters the HRV. This may be accomplished by a single fixed-capacity heater, staged fixed-capacity heaters or a heater with a variable output. Preheat reduces the energy available for recovery.

Frost prevention by reducing heat exchanger effectiveness (RED.E.). Reducing the heat exchanger effectiveness (by tilting heat pipes or by reducing the speed of a rotary heat wheel) raises the exhaust air outlet temperature. With this strategy, exhaust air outlet temperature is kept above its dewpoint whenever core temperatures fall below freezing.

Frost prevention by reducing supply air flow rates. Part of the supply air is bypassed around the heat exchanger core so that the exhaust air temperature remains above its dewpoint during cold weather. This strategy has the same impact on seasonal performance as reducing heat exchanger effectiveness (RED.E.).

Control optimization

The operation of all practical freeze-control strategies results in a reduction of recovered energy and, thus, seasonal heat recovery efficiency. The purpose of optimizing a freeze control is to minimize this reduction. This is achieved by adjusting the temperature at which the freeze control is initiated or altering the frequency, duration or amount of freeze control to closely match the need at various operating conditions.

Freeze control is required whenever outdoor air conditions fall below the frost threshold temperature; that is, the temperature at which frosting begins to occur in the heat exchanger core. The frost threshold temperature varies with the relative humidity of the exhaust air stream and heat exchanger design and effectiveness.[5]

Adjusting the freeze-control initiation temperature to the frost threshold temperature will minimize the time spent in freeze-control mode and, thus, maximize the energy recovered.

Increasing the frequency of (shortening the time interval between) defrost cycles will reduce the average frost thickness on heat exchanger surfaces, resulting in higher average heat transfer rates.

Adjusting the defrost cycle duration (shorter during mild weather, longer during cold weather) according to the time needed to defrost the heat exchanger core will result in less time in the defrost mode.

Observations and conclusions

The energy benefits of improved freeze-control strategies become more significant as heat exchanger effectiveness increases. Higher effectiveness means greater amounts of energy are available for recovery at all temperatures. Furthermore, the frost threshold occurs at higher temperatures as effectiveness increases, thereby requiring freeze-control to be invoked for more time.

Figure 2 shows seasonal efficiency against heating degree days data for various freeze-control strategies. *Figure 3* shows annual energy recovered. The following three conclusions are illustrated by these figures.

First, in moderate climates with less than 7,500 Degree Days Fahrenheit (DD°F; 4,200 DD°C), the freeze-control method has little impact on seasonal HRV performance. In cold climates (colder than 7,500 DD°F; 4,200 DD°C), the freeze-control strategy selected may have a significant impact on seasonal energy performance. Reducing heat exchanger effectiveness and bypassing or preheating supply air are not well suited to cold climate applications.

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Freeze-control strategy

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Second, the two defrost strategies examined (warm-air recirculation and supply-fan shut off) function very close to the ideal freeze-control strategy if they are operating properly. Manufacturers and designers should adapt these strategies for cold climate applications. Operators should ensure that controls operate according to their design specifications, and designers and manufacturers should optimize the defrost setpoints and duration for the climate.

Finally, whereas frost prevention strategies (preheating supply air, reducing the heat exchanger effectiveness and bypassing supply air to prevent frosting) may be cost effective in moderate climates, they greatly reduce the energy available for recovery during cold weather. As such, they are not well suited for climates colder than 7,500 DD °F (4,200 DD °C). The energy that can be recovered with these strategies during cold weather is limited by the enthalpy difference between the exhaust air inlet condition and its dewpoint.

The benefits of control optimization are greatest in cold climates and increase with increased heat exchanger effectiveness. The colder the climate, the more hours frost control is invoked. The higher the effectiveness, the greater the amount of energy available to be recovered through control optimization. The results predicted for the various freeze-control optimization methods lead to the following observations and conclusions.

Reducing the time between warm-air recirculation defrost cycles from 21 to 15 minutes (and reducing the duration a corresponding amount) resulted in a less than 1% per year increase in recovered energy in all cases examined. As invoking defrost results in the cycling of components with finite operating lives, there are practical reasons to extend the time between defrost cycles.

Marginal improvements in seasonal performance can be realized by varying the duration of supply-fan shut off with outdoor temperature. For the Arctic case (18,000 DD °F; 10,000 DD °C), savings of up to 3% per year were predicted by having defrost cycle durations of one, two or three minutes (depending on outdoor temperatures) instead of a three-minute defrost cycle regardless of outdoor temperature. In milder climates, the benefits are smaller.

Optimizing the frost control setpoint temperature may significantly improve seasonal performance for strategies that reduce heat exchanger effectiveness or bypass or preheat supply air (see *Figure 4*). This could involve manually adjusting setpoints until frosting is observed or using sensors and automatic controls that integrate exhaust air enthalpy and supply-air temperature to determine frost control setpoint.

Using enthalpy-type heat exchangers could reduce the need for freeze control in mild climates by reducing exhaust air humidity, thereby lowering the frost threshold temperature. When coupled with the findings of Barringer and McGugan[6] that enthalpy heat exchangers reduce combined heating, cooling and humidifying energy loads in most climates, this further supports considering their use.

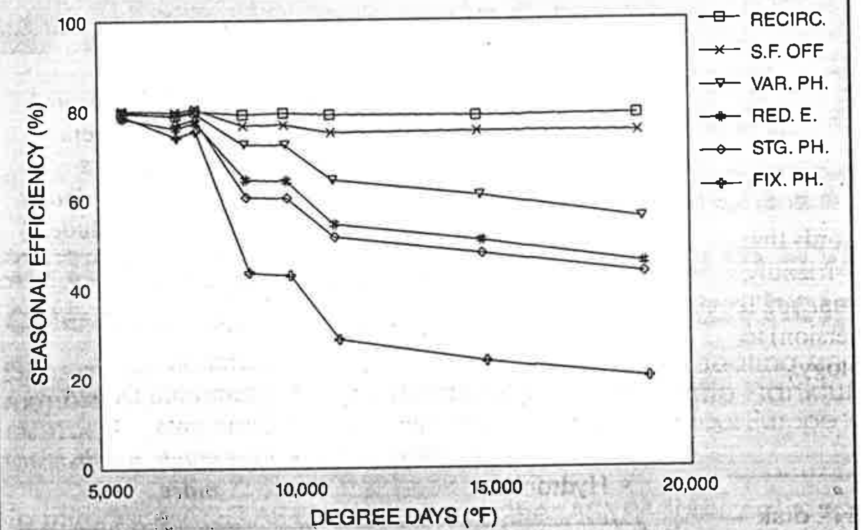

Figure 2. Seasonal efficiency of 80% effective heat exchanger.

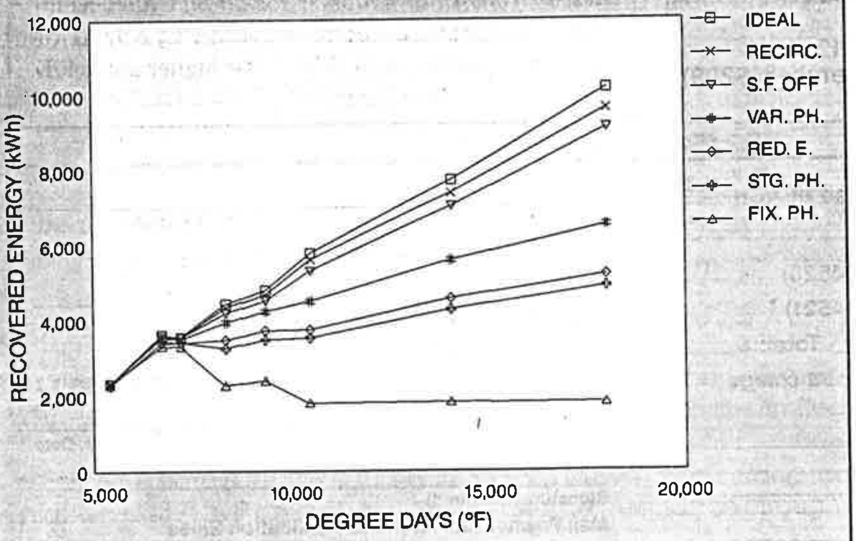

Figure 3. Annual energy recovered from 80% effective heat exchanger.

Summary

To summarize, a defrost strategy and its optimization have little impact on the performance of HRVs in climate zones with less than 7,500 DD °F (4,200 DD °C). In climate zones with more than 10,000 DD °F (5,500 DD °C), the freeze-control strategy can have a significant effect on the seasonal performance of the HRV system.

Recirculation of warm air through the heat exchanger core was shown to be the most effective defrost strategy from an energy performance perspective. Using supply air preheat, reducing effectiveness and reducing supply air flow rates as methods of preventing freezing conditions from occurring in the heat exchanger core are not recommended strategies for cold climates. ■

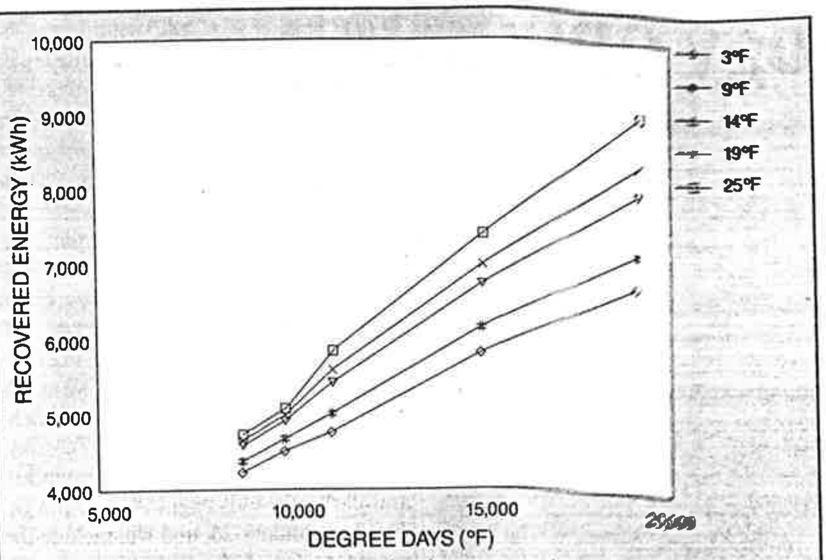

Figure 4. Variable preheat strategy showing recovered energy at various setpoints for 80% effective heat exchanger.

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