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Comparison of Freezing Control Strategies for Residential Air-to-Air Heat Recovery Ventilators

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ABSTRACT

A comparison of the energy performance of defrost and frost control strategies for residential air-to-air heat recovery ventilators (HRV) has been carried out by using computer simulations for various climatic conditions. This paper discusses the results and conclusions from the comparisons and their implications for the heat recovery ventilator manufacturers and system designers.

INTRODUCTION

Air-to-air heat exchangers with built-in fans and controls (now called heat recovery ventilators or HRV) form an energy-efficient ventilation system in many new houses. In certain climatic regions, cold temperatures cause frosting of exhaust-side heat exchange surfaces. This reduces energy recovery in two ways:

1. Frost "fouls" heat exchange surfaces, reducing thermal conductance and heat transfer rates, and

2. Frost blocks exhaust airflow passages, reducing the energy available for recovery.

As a result, HRV manufacturers have developed strategies to prevent or limit the build-up of ice and frost in heat exchangers. However, little has been done to analytically compare the seasonal performance of these strategies under different climatic conditions.

ASHRAE T.C.-5.5-sponsored research project TRP 543, "An Investigation of Freezing Control Strategies for Residential Air to Air Heat Exchangers," had the following objectives:

- To analytically characterize freeze-control strategies used for residential air-to-air heat exchangers (HRV).
- To compare the need for, and effect of, various freeze-control strategies on the seasonal thermal performance of residential heat recovery units operating in different climates.
- To optimize specific freeze-control strategies and evaluate the associated energy savings.

This paper presents the results of this research project.

APPROACH

Work tasks in this project included an extensive literature review, the development of a computer model to simulate HRV performance during freezing conditions, and the development of algorithms to simulate the energy performance of various frost control and defrost strategies.

A computer program based on findings from a literature study and first principles was developed for this study to provide a standard method to compare the energy performance of HRV freeze-control strategies under different climatic conditions. The computer program consisted of three major components:

1. The HRV frosting model (a finite difference model of a counterflow heat exchanger to generate heat exchanger performance data vs. time at outdoor temperatures between 50°F and −65°F [10°C and −54°C]).

2. The Erbs, Klein, Beckman (EKB) ambient temperature bin data generator (Erbs et al. 1983), which was used to estimate the number of hours in temperature bins for selected locations.

3. Defrost and frost control algorithms. These used the HRV frosting and EKB model outputs to generate performance data for combinations of HRV, climate, and freeze-control strategy.

The HRV frosting model was run at 2°C temperature bins from 10°C to −54°C for HRV effectivenesses of 50%, 65%, and 80%. Data related to energy recovery rates and frost or ice accumulation (e.g., location, temperature, mass, thickness) were recorded at one-minute simulated time intervals for each temperature bin. The defrost and frost control strategy algorithms were applied to the HRV frosting model output and temperature data to predict the seasonal performance of the various effectiveness/climate/strategy combinations. Variations of each freeze control strategy were simulated to assess the benefits of optimizing the control strategy. Freeze control strategies are usually designed to ensure ventilation is maintained under extreme (i.e., cold) operating conditions. Optimization of control strategies was simulated by adjusting the fre-

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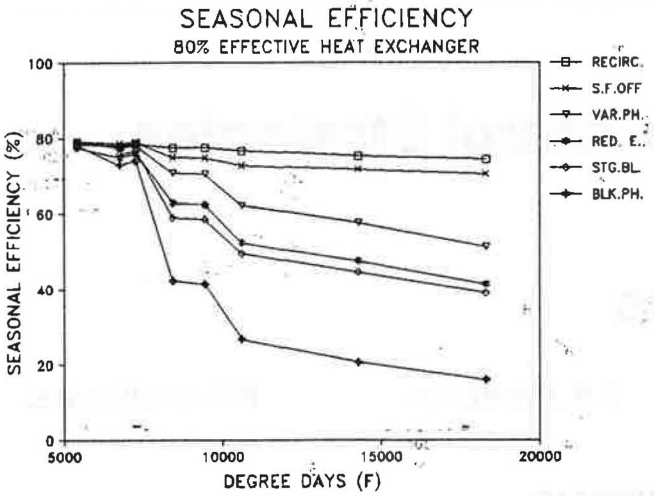

Figure 1 *Predicted seasonal efficiency for an 80% effective HRV with various frost control strategies operating in different climates*

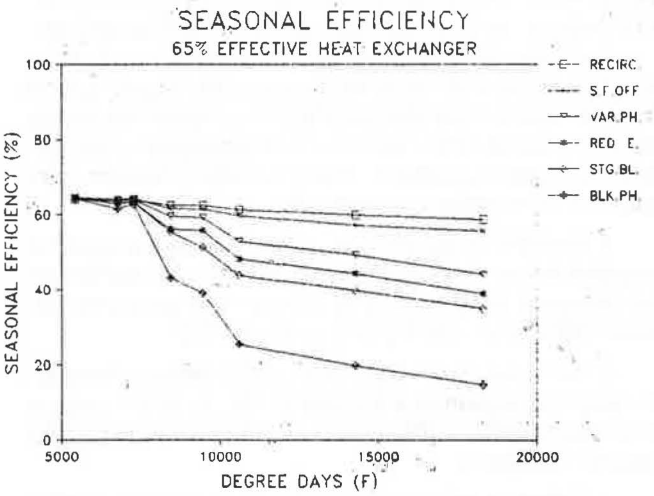

Figure 2 *Predicted seasonal efficiency for a 65% effective HRV with various frost control strategies operating in different climates*

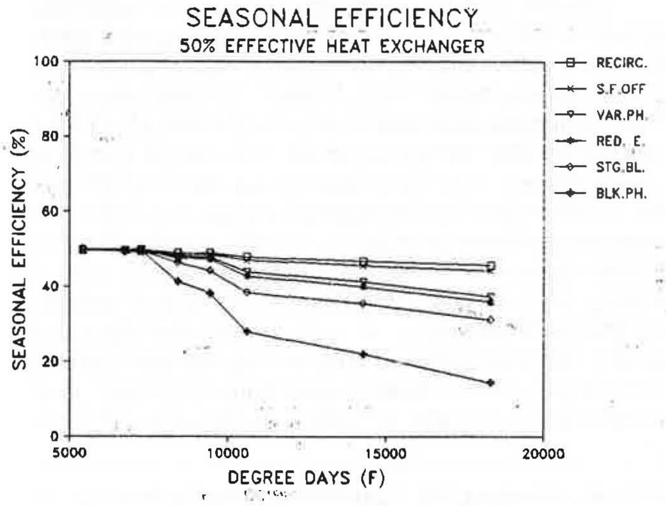

Figure 3 *Predicted seasonal efficiency for a 50% effective HRV with various frost control strategies operating in different climates*

quency, duration, or amount of frost control or defrost used when the system operated under less extreme conditions.

All freeze control strategies were evaluated using the same heat exchanger performance and temperature bin data. The use of common HRV and temperature data for each strategy allows solid comparisons of the various strategies even if the simulated heat exchanger performance data or bin temperature data do not precisely represent the performance of a particular HRV or the temperature distribution of a given climate.

(For a detailed description of the computer models, see Phillips et al. 1989.)

FROST CONTROL AND DEFROST STRATEGIES EVALUATED

In this paper, frost control refers to methods that prevent frost from forming in the heat exchanger, while defrost refers to methods that routinely remove frost from heat exchange surfaces. Jointly these are referred to as freeze control strategies. In the study, freeze control strategies examined included ideal strategies and variations of strategies used in commercial/industrial and residential applications.

The following describes the frost control and defrost strategies evaluated in this study.

Ideal Freeze Control Strategy

The ideal control strategy continuously removes frost from heat transfer surfaces without putting energy into the removal process. Thus heat exchanger fouling would not occur, and the latent and sensible heat from cooling and freezing water vapor would be recovered. This represents the maximum amount of energy that could be recovered in a heat exchanger of the specified effectiveness.

Ideal Less Ice Energy

This control strategy is similar to the ideal freeze control strategy, except the energy required to melt frost and ice that has accumulated in the heat exchanger core has been deducted from the energy recovered.

Defrost by Supply Fan Shutoff

Outdoor air supply is stopped while exhaust air continues to flow uninterrupted. There is no heat recovery during defrost. Defrost is enabled when outdoor temperatures fall below a predetermined temperature. The HRV operates in the defrost mode for set time periods (e.g., 5 minutes) at fixed intervals (e.g., every 40 minutes) when defrost is enabled. This strategy is used in some production model HRV.

Defrost by Warm Air Recirculation

Ventilation is temporarily stopped and house air is recirculated through the HRV to melt ice and frost deposits. The unit is operated in the defrost mode for a fixed time period (e.g., 2 minutes) at fixed time intervals (e.g., every 20 minutes) whenever outdoor temperatures are below the defrost setpoint. Airflow rates through the heat exchanger must be increased to ensure the design ventilating rate is maintained, on average, during periods when the defrost mechanism can operate. This increased airflow decreases heat exchanger effectiveness.

This strategy is considered to be the state-of-the-art freeze-control method. It is used in several residential HRV models.

Frost Control by Supply Air Preheat

Frosting is avoided by heating supply air above the frost threshold temperature before it enters the heat exchanger. Block-switched and variable-output heater controls were modeled. Block-switched controls change the preheater output in blocks (e.g., 1 kW), thus increasing supply air temperatures a fixed amount. Variable-output heater controls warm supply air to a temperature just above the frost threshold.

Supply air preheat is used in some residential air-to-air heat exchangers. Supply air preheat is also used in commercial and industrial applications.

Frost Control by Reducing Heat Exchanger Effectiveness

Heat exchanger effectiveness may be reduced by tilting heat pipes or by reducing the speed of a rotary heat wheel. Whenever core temperatures fall below freezing, heat exchanger effectiveness is reduced so that exiting exhaust air is kept above its dew point.

This freeze control method is used in some commercial air-to-air heat exchanger applications.

Frost Control by Reducing Supply Airflow Rates

The supply airflow through the heat exchanger is reduced during cold weather so exhaust air exit temperatures are kept above the dew point. The algorithms used for this strategy were the same as those used for reducing heat exchanger effectiveness.

This freeze control strategy is used in some commercial air-to-air heat exchange applications.

RESULTS AND CONCLUSIONS

Figures 1, 2, and 3 plot seasonal efficiency against heating degree data for various freeze control strategies and nominal HRV effectivenesses. The strategies plotted are:

- warm air recirculation (RECIRC.)
- supply fan shutoff (S.F.OFF)
- variable preheat (VAR.PH.)
- reducing heat exchanger efficiency or reducing supply airflows (RED.E.)
- staged block preheat (STG.BL.)
- fixed block preheat (BLK.PH.)

Figures 4, 5, and 6 plot the energy recovered against heating degree days data for the same freeze-control strategies and nominal heat exchanger effectivenesses. These figures also include a line for the ideal freeze control strategy. (In Figures 1, 2, and 3 the ideal would have a seasonal effectiveness equal to the nominal HRV effectiveness for all climates.)

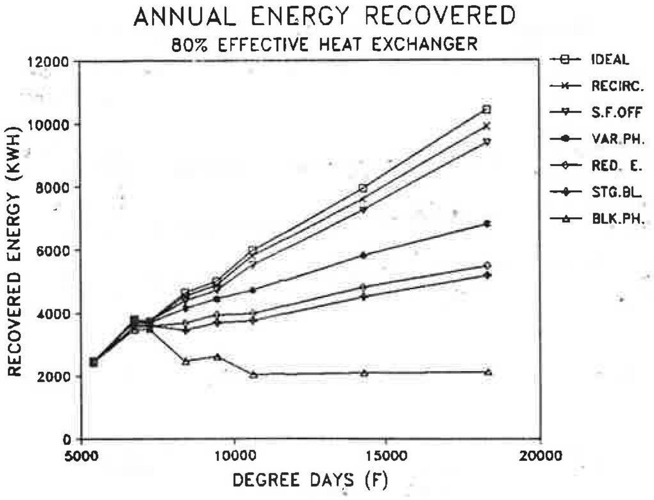

Figure 4 *Predicted annual energy recovered for an 80% effective HRV with various frost control strategies operating in different climates*

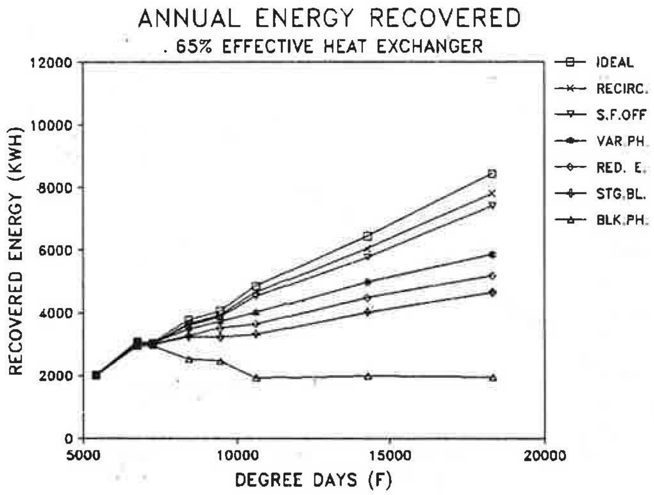

Figure 5 *Predicted annual energy recovered for a 65% effective HRV with various frost control strategies operating in different climates*

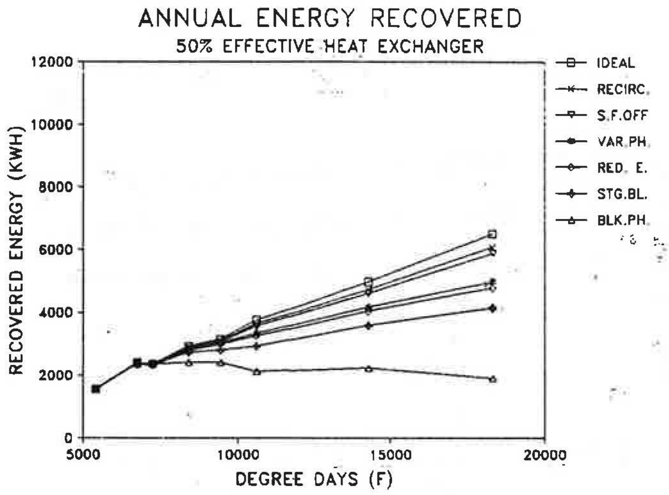

Figure 6 *Predicted annual energy recovered for a 50% effective HRV with various frost control strategies operating in different climates*

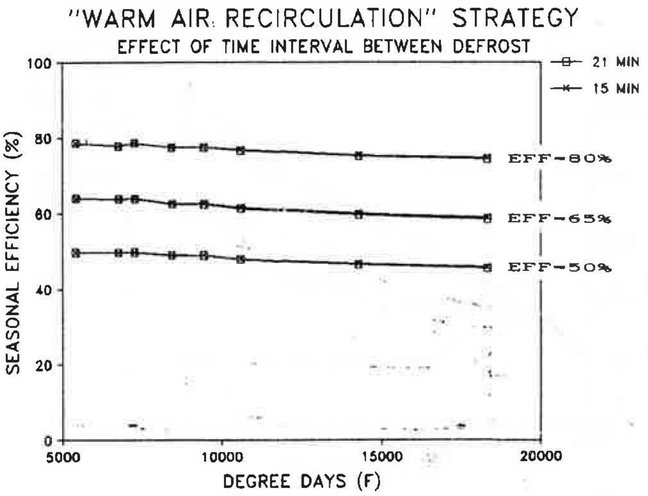

Figure 7 *Predicted effect of reducing the time between defrost from 21 minutes to 15 minutes for the "warm air recirculation" defrost strategy*

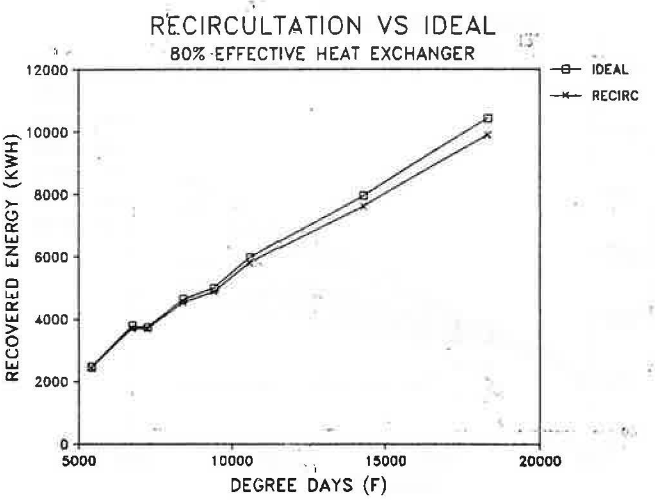

Figure 8 *Comparison of the predicted annual energy recovered for "the warm air recirculation" defrost strategy and the "ideal" strategy for an 80% effective HRV*

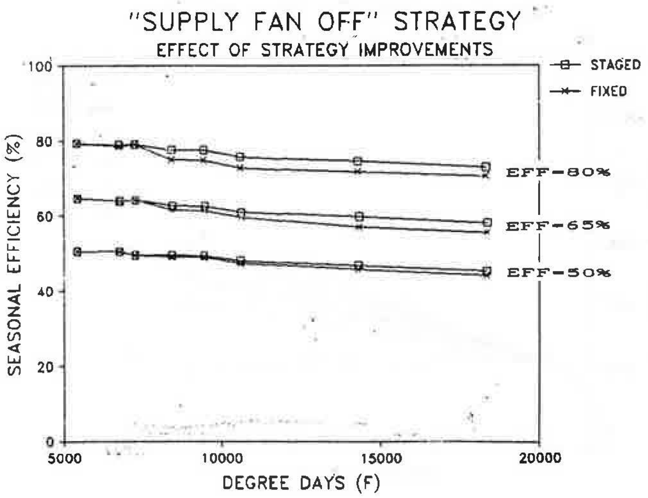

Figure 9 *Comparison of seasonal efficiency for staged (i.e., improved) and fixed defrost intervals for the "supply fan off" strategy*

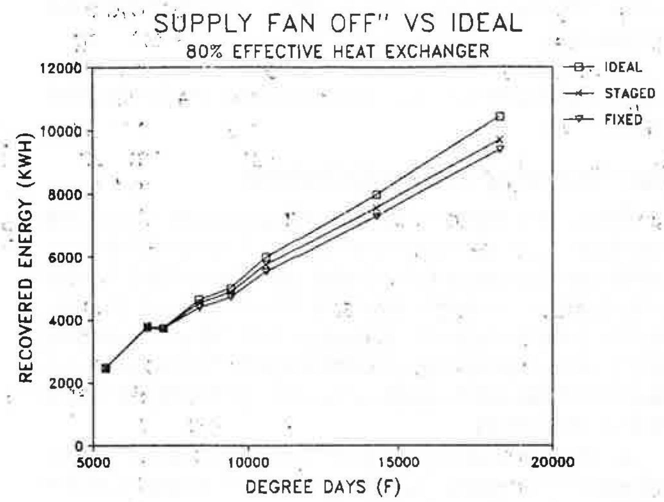

Figure 10 *Comparison of the predicted annual energy recovered for an 80% effective HRV with "supply fan off" defrost strategy to the ideal*

Conclusions drawn from Figures 1 through 6 are:

1. Current state-of-the-art freeze control strategies function close to the ideal.

2. In climates with less than 7500 DD F (4200 DD C), the method of freeze control has little impact on seasonal performance, regardless of HRV effectiveness. In climates colder than 7500 DD F there are marked differences between the seasonal energy performance of the various defrost strategies.

3. Greater energy savings are available in colder climates, since lower temperatures occur, and for more hours. Thus the benefits of optimizing HRV freeze control strategies are greater in colder climates.

4. The higher the effectiveness of the HRV, the greater the energy benefits of improved frost control and defrost strategies. This is primarily because higher effectiveness means greater amounts of energy are available for recovery at all temperatures. A second reason is that freezing conditions begin at higher supply air inlet temperatures as effectiveness increases; thus, in a given climate, the heat exchanger with the higher effectiveness requires its frost control strategy to be invoked for more hours.

5. Defrost by warm air recirculation, which appears to be the most efficient strategy in severely cold climates, is not the most efficient in milder climates. The reason is the decline in HRV effectiveness due to the increased airflow rate is suffered at all times, while the benefits of this strategy are realized only at low outdoor temperatures.

6. In cold climates, preheating supply air to avoid frosting conditions significantly reduces recovered energy.

7. Reducing the heat exchanger effectiveness or supply airflow to prevent frosting is an inefficient defrost strategy in cold climates. In temperature bins below the frost control setpoint, reducing supply airflow yielded the same energy recovery rate for all heat exchangers, regardless of effectiveness. This is because the maximum energy that can be recovered is the amount that cools the exhaust air to the dew point.

Figures 7 and 8 illustrate the effect of reducing the time frame between defrost cycles for the warm air recirculation strategy. Reduced time frames between defrost cycles result in higher mean efficiencies, with the benefits being greatest in colder climates. However, the degree of improvement realized is small. Cutting the time between defrost cycles from 21 minutes to 15 minutes increases the energy recovered by less than 1% in all cases examined. As initiating defrost results in energy losses not factored into the simulations and the cycling of components with finite operating lives, there are practical reasons to extend the time between defrost cycles. Figures 9 and 10 show that modest improvements in mean annual HRV performance can be realized with the supply fan shutoff defrost strategy by varying the duration of the defrost cycle with outdoor temperature. For the Arctic case, 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 predicted benefits were smaller.

Figure 11 shows preheater energy consumption vs. recovered energy for each supply air preheat strategy for the 80% effective HRV. Staged block or variable preheaters are essential if preheater capacity exceeds 1 kW. Variable preheaters are significantly more energy efficient than fixed-output preheaters in colder climates.

Figures 12 and 13 show the impact of being able to reduce the setpoint of a variable preheater for the 80% effective HRV. Enthalpy-type heat exchangers normally reduce the exhaust air humidity in cold weather, thus lowering the temperature at which frost control or defrost is needed. This could eliminate the need for defrost or frost control mechanisms in some mild climates. Reduced humidity would result in reduced frosting and exchanger surface fouling, thus higher energy recovery rates than for sensible heat exchangers. This fact (coupled with the findings that enthalpy heat exchangers reduce combined heating, cooling, and humidifying energy loads in most climates [Barringer and McGugan 1988]) strengthens the arguments for using enthalpy-type HRV.

RECOMMENDATIONS

1. Actual seasonal performance data from field monitoring are limited but are continuing and should be encouraged. However, to establish if the data are compatible, a survey of annual monitoring in progress should be made to standardize field testing methods with the aim of adopting consistent methods.

2. A review of definitions used to establish the heat recovery performance of HRVs is needed. The many different components that are being encompassed by HRV systems are introducing new terminology to describe different efficiencies which can be reduced to simpler terms.

3. Since several manufacturers are using crossflow cores, their performance and frosting conditions need comparing to the generic counterflow model studied in this project.

REFERENCES

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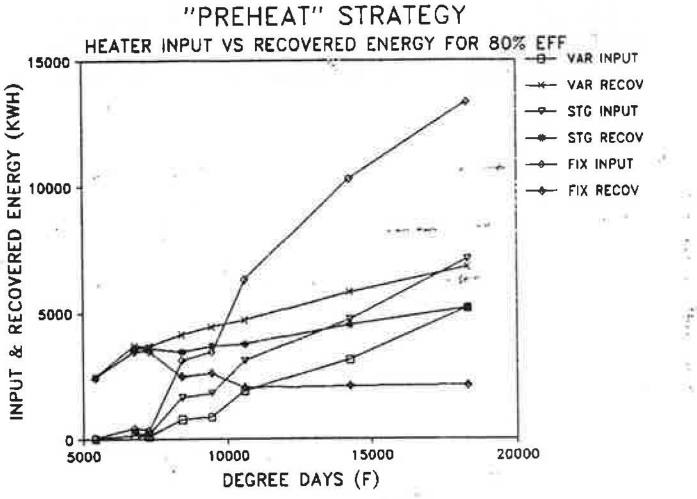

Figure 11 *Comparisons of the predicted annual energy recovered and preheater input energy for various preheat strategies for an 80% effective HRV*

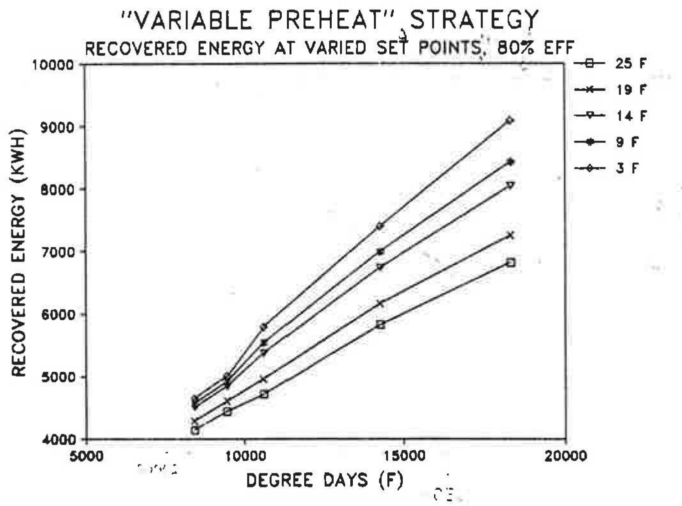

Figure 12 *Comparison of the predicted annual energy recovered using various preheater setpoint temperatures for an 80% effective HRV*

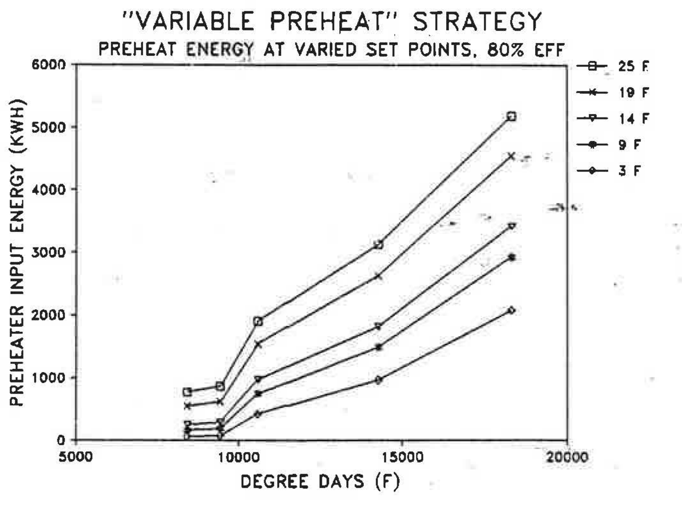

Figure 13 *Comparison of the predicted annual preheater input energy using various preheater setpoint temperatures for an 80% effective HRV*

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