# FROST-LESS HEAT PUMP

**BY**

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# Frost-less Heat Pump

There are two major concerns associated with heat pump applications in heating season operation. One is that periodic defrosting is required when the ambient temperature is below 4.4°C (40˚F), and the other is the "cold blow" effect (delivery of air at less than body temperature) that compromises indoor thermal comfort. Conventional defrosting by cycle reversing has an inherent energy penalty because it absorbs heat from the indoor air during the defrosting period.

A new frost-less heat pump technology has been developed at Oak Ridge National Laboratory. If a moderate amount of heat is added to the refrigerant stream in the accumulator, the suction pressure and temperature can be raised. As a result, frost accumulation on the outdoor coil is retarded. Most of the heat added to the accumulator will be delivered to the indoors in the form of a higher heat pump supply air temperature, reducing the cold blow effect. The frequency of defrosting cycles can be drastically reduced, estimated, based on the temperature bin method, by a factor of five (5) in the Knoxville, Tennessee area in the ambient temperature range from 0 to 4.4°C (32 to 40°F).

The new technology also includes a new energy-efficient defrosting scheme. When the ambient temperature is below 0˚C (32°F), cycle reversing defrosting will be initiated, because a moderate amount of heat added to the accumulator will not retard frost accumulation effectively. With the new defrosting method, the indoor fan is not energized during the defrosting period. Two-phase refrigerant flowing through the indoor coil remains two-phase as it enters the accumulator; it then boils as a result of the heat added to the accumulator, or the accumulator functions as the evaporator. An obvious advantage is that the heat pump will not produce cold air during the defrosting period. Energy consumption for defrosting is modest, around 1 kW, compared with an average of 7–10 kW for resistant heating coil during conventional defrosting**.** Laboratory experiments indicated that the new frost-less concept saves energy, a projected 12% in the Knoxville area compared with baseline test data. While the field test is still going on, limited field test data indicated that the frost-less heat pump worked as expected. The new heat pump design concept can be implemented cost-effectively. This paper presents the new concept and both laboratory and field test data.

## Introduction

Heat pump is an efficient system for both heating and cooling. Although it behaves like an air-conditioning system for summer cooling operation, winter operation requires periodic coil defrosting if the ambient temperature is below 4.4˚C (40°F) (lower for high efficiency heat pumps). Cycle-reverse defrosting is the most common method used to defrost the outdoor coil. The reverse-cycle method is inefficient because it takes heat from the indoor air to defrost the outdoor coil, resulting in a power surge because a 7- to 10-kW resistance-heating element is energized to make up for the heat lost. In addition, every time the cycle is reversed, the heat pump suffers pressure and thermal shocks. Further, the perception of "cold blow"[1] will be even more severe during the defrosting period. It is obvious that heat pump manufacturers must improve coil frost management and defrosting technique, as well as alleviates the cold blow effect and improve energy efficiency.

[1] Cold blow occurs because the temperature of the supply air from a heat pump is often lower than the human skin temperature and thus induces a cold feeling when the supply air is in contact with the body.

The industry made a previous effort to tackle the heat pump thermal comfort issue by increasing the supply air temperature to above 40.6˚C (105°F) [1]. However, at the end of the project, the participants reached a conclusion that the cost was too high to achieve the targeted goal.

In the area of coil frost management, much work has been reported in heat pump frosting and defrosting performance [2,3]. Work was also reported on shortening the defrosting cycle by adding heat to the accumulator during the defrosting period [4]. However, there is practically no reported work discussing the possibility of reducing the number of defrosting cycles by retarding frost on the outdoor coil. In addition, heat pump manufacturers have generally practiced cycle-reversing defrosting, and no effort has been made in recent years to improve the current defrosting technology.

Oak Ridge National Laboratory (ORNL) has derived a new heat pump design [5,6] that addresses all the aforementioned problems. ORNL, under the sponsorship of the U.S. Department of Energy (DOE) and the Tennessee Valley Authority (TVA), has developed a new frost management method and a defrosting concept called “frost-less” technology.

A split heat pump system was modified with the new frost-less feature and was tested in a two-room environmental chamber at various simulated outdoor temperatures. The results indicated that frost-less operation was as expected that it retarded frost accumulation on the outdoor coil significantly. The new defrosting concept was also tested and worked as expected. The defrosting time was almost identical to that of the conventional defrosting method, and only about 1 to 1.2 kW of power was input to the accumulator. Compared with conventional defrosting technology, which energizes a 7- to 10-kW resistance heating element during the defrosting period, the new defrosting technology is much more energy-efficient, and it does not take heat from indoor air. Field test, with the participation of Parker-Hannifin and Modern Supply Co., started near the end of 2004 winter and is still underway.

## Frost-less Heat Pump Concept

Experimental results showed that if the outdoor coil temperature is above -2.8°C (27˚F), there will be practically no frost accumulation on the outdoor coil when the ambient temperature is in the range of 0 to 4.4°C (32 to 40˚F), which is the range at which frost is most likely to accumulate. If a moderate amount of heat is added to the accumulator during winter heating-mode operation (Figure 1), the outdoor coil temperature can be increased to around -2.8°C (27˚F). Frost formation on the coil will then be retarded because of the elevated coil temperature. However, most of the heat added to the accumulator will be delivered to the inside of the house as higher-temperature supply air, through more efficient compressor operation with higher suction pressure and mass flow rate. Reduced temperature differential for frost-less operation between outdoor coil and ambient air is compensated by operating the system with cleaner outdoor coil with less frost accumulation, and thus higher heat transfer capability.

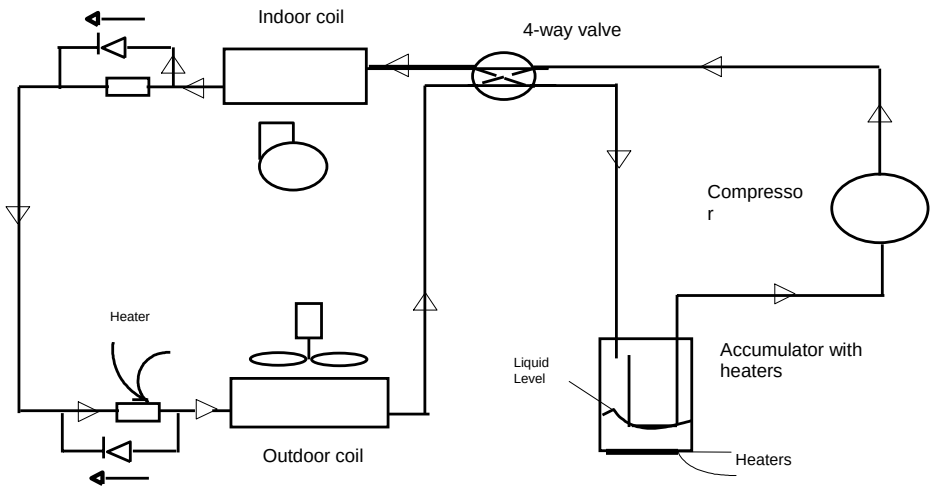


**Fig. 1 Refrigerant side schematic**

It should be noted that "frost-less" is not "frost-free." If the heat pump is operated over a long time at low ambient temperatures, frost will accumulate on the outdoor coil even with heat added to the accumulator. When the ambient temperature is outside the range of 0 to 4.4°C (32 to 40˚F), the heater in the accumulator will be turned off, because above 4.4°C (40˚F) the coil temperature will be warm enough to prevent frost formation, and below 32˚F, the moisture content of the air will be too low for heavy frost accumulation on the coil.
Because the heating capacity is higher with the frost-less system, the heat pump should cycle off before a defrosting cycle is initiated. It is estimated that the frost-less heat pump has the potential to reduce the defrosting cycle by a factor of five (5) in the Knoxville, Tennessee area, based on bin temperature calculation under typical load balance conditions.

## New Defrosting Technology

Cycle reversing is the standard heat pump defrosting method. Some heat pumps use a hot-gas bypass to mix hot gas with the expanded refrigerant to defrost the coil.[2] This method has the advantage of not requiring cycle reversal, with the attendant reversal of high- and low-pressure coils of the system and the sudden surging of liquid into the accumulator and compressor. On the other hand, reduced heat transfer, longer defrost cycles may result, with a corresponding loss of efficiency.
The heat pump tested was equipped with the standard timer and refrigerant temperature sensor for defrosting. The timer was originally set for 60-minute defrosting. It was re-set for 90-minute defrosting for this study, because a more frequent defrosting cycle would tip the energy efficiency to favor the frost-less technology. During the defrosting period, heat is taken from the indoors to defrost the outdoor coil, resulting in the sensation of cold blow even with the indoor resistance heating coil fully energized.

[2] Janitrol "Specifications – Series 38/39" (Tech. Bulletin published by Janitrol, 1976).

The frost-less concept retards frost accumulation on the outdoor coil and increases the heating capacity, thus potentially reducing the number of cycle reversals for defrosting. However, when the ambient temperature is below 0°C (32˚F), the heaters in the accumulator are shut off in heating mode operation because adding a modest amount of heat to the accumulator would not retard frost accumulation on the outdoor coil. Eventually, a cycle-reversing defrosting period will be needed.

However, during the cycle-reversing defrosting period, the indoor blower will be shut off. Liquid refrigerant passing the indoor expansion device will be two-phase throughout the indoor coil without absorbing heat from the house. The two-phase refrigerant will flow to the accumulator, and the heater in the accumulator will be energized during the defrosting period. In other words, the accumulator takes over the function of the evaporator where the refrigerant is evaporated to provide vapor to the compressor for outdoor coil defrosting. This design allows cycle reversing defrosting but without an indoor cold air draft and without the indoor resistance heaters being energized. The advantages of this defrosting scheme are

1. Cold blow is eliminated during the defrosting period because the indoor blower is shut off.
2. Defrosting is very efficient because the accumulator is close to the outdoor coil where the heat lost is at a minimum. Heat input to the accumulator will be in the order of 1 kW, while the conventional defrosting method requires 7 to 10 kW to energize the indoor resistance heating elements.
3. The power consumption by the indoor blower motor is avoided.

## Experimental Setup

A 2-ton split heat pump was selected for the test because it was considered the most popular model in the TVA region. Figure 1 shows the schematic of the frost-less heat pump. Figure 2 shows the new accumulator-heater assembly. The new accumulator costs less than $16, while the heater costs less than $13, which are now adopted for the frost-less heat pumps. Figures 3 and 4 show the real accumulator and heater used. The setup measures both the air-side and refrigerant-side performance. Pressure transducers and thermocouples were used for pressure and temperature measurements.

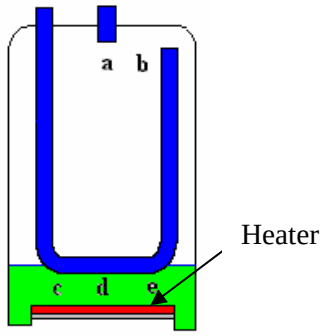


**Fig. 2. Flat bottom accumulator heater assembly design**

**Fig. 3. New flat-bottom accumulator by Parker-Hannifin**

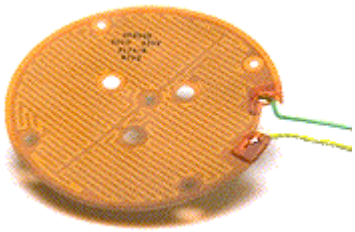

**Fig. 4. Thermofoil™ Mica heater from Minco**

However, air-side measurements were adopted because refrigerant-side mass flow rate measurement would not be accurate during transient operating periods, such as the start and the end of the defrost cycle.

## Laboratory and Field Test Data and Discussion

Laboratory tests have been performed with indoor conditions maintained at 21.1°C (70°F) and with wet bulb temperature at 15.6°C (60°F) maximum. The test unit was an Amena SEER 10.5 split heat pump system. The outdoor conditions vary from 4.4 to 0°C (40 to 32°F). The power input to the heater at the bottom of the accumulator was set at 1 kW. Figure 5 showed a typical test results at 1.7°C (35°F) ambient for both frost-less and baseline operations. The results indicated that the outdoor unit was almost completely covered with frost for baseline unit after 100 minute continuous operation. On the other hand, the frost-less heat pump had only a trace of frost at 100 minute operation mark. It continued to operate for another 100 minutes before the frost covered the outdoor unit completely.

Figure 6 showed the limited field test data collected during the 2004 winter. The unit in the field was a Rheem SEER 13 unit. The heater was working as expected. Except, the ambient temperature sensor on the heater control board was located in the electrical box where the compressor relay and a 24 V power supply unit were located. The heat generated by the relay and power supply unit kept the temperature inside the box about 4.4°C (8°F) higher than the true ambient temperature. The temperature differential resulted in energizing the heater from -4.4 to 0°C (24 to 32°F) instead of the designed temperature range of 0 to 4.4°C (32 to 40°F). This observation was delegated to the manufacturer of the control board so that future units would have a temperature sensor leads extended outside the box so that it could sense the true ambient temperature. As for the defrosting scheme was concerned, the indoor fan was off during the defrosting period, and the accumulator heater was on, which worked as expected. The owner of

the house indicated that the unit was very quiet during the defrosting period. The field test data collection continues during the 2005 winter season. Because of the exceptional warm weather at the Knoxville, TN. region at the first part of 2005 winter, meaningful data will be collected when weather turns cold.

## Conclusions

The frost-less heat pump concept has addressed the two major concerns about the heat pump operation, cold blow and periodic outdoor coil defrosting, by increasing the heat pump supply air temperature and reducing the defrosting cycle frequencies.

Laboratory test data showed the concept worked very well. It delays the frost accumulation on a 10.5 SEER heat pump unit so that it operated 200 minutes instead of the baseline operation that operated for 100 minutes before the defrosting cycle was initiated. The limited field test data on an SEER 13 heat pump also indicated that the accumulator heater worked as expected that during the defrosting cycle, the indoor blower was off and the accumulator heater was energized with 1 kW power input to the heater, which turned the accumulator to serve the function of the evaporator.

The indoor cold blow during the defrosting period was completely eliminated. What this means are that indoor thermal comfort was improved, and that energy saving was achieved, instead of 7 to 10 kW resistance heating, only 1 kW power input was needed during the defrosting period. Furthermore, this technology enables the heat pumps at regions above the TVA region to save more energy during the defrosting period, because those regions would require more frequent defrosting cycles.

**20 minutes** **40 minutes** **60 minutes** **80 minutes** **100 minutes**

**(a) Baseline operation at 35°F and 80%RH**

**20 minutes** **40 minutes** **60 minutes** **80 minutes** **100 minutes**

**120 minutes** **140 minutes** **160 minutes** **180 minutes** **200 minutes**

**(b) Frost-less operation at 35°F and 80%RH; 1kw accumulator heating**

**Fig. 5. Transient process of frost formed on the surface of outdoor coil**

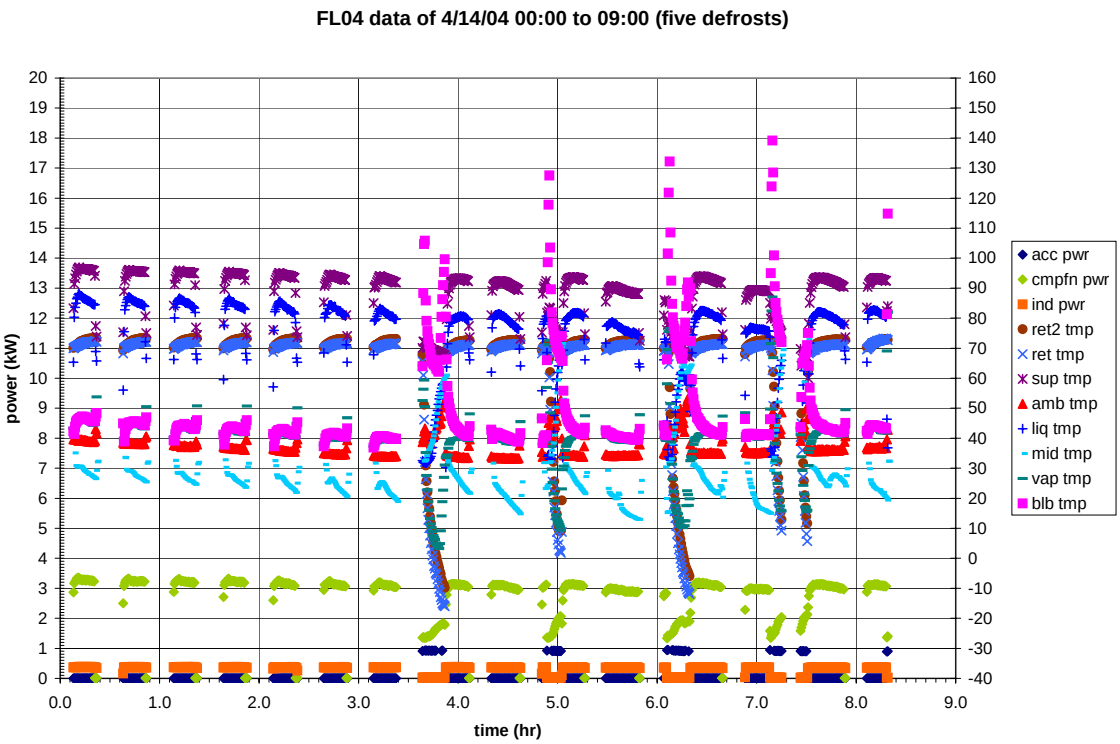


**Fig. 6. Defrosting Cycles at Honeycutt's House at Johnson City, TN.**

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