COMPARISON OF REHEAT STRATEGIES FOR CONSTANT VOLUME ROOFTOP UNITS

The Humidi-MiZer™ Adaptive Dehumidification System versus Alternate Methods

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INTRODUCTION

The air-conditioning industry's focus on humidity issues, including new indoor air quality standards and ventilation codes, has elevated the importance of dehumidification. This white paper evaluates the conceptual design of the Humidi-MiZer™ adaptive dehumidification system by Carrier, which utilizes a two-phase refrigerant mixture. The Humidi-MiZer adaptive dehumidification system is compared to alternative reheat dehumidification strategies for constant volume rooftop air-conditioning and heat pump applications. Additional information regarding the Humidi-MiZer adaptive dehumidification system can be found in the Humidi-MiZer Application Data manual, catalog number 514-80022.

Application requirements are the first among many essential issues to be addressed when selecting the proper mechanical dehumidification system using primary refrigerant. The system design strongly depends upon a range of indoor and outdoor environments, or stated differently, upon the relative significance of sensible and latent load components over an array of operating conditions. Although a universal solution is desired, most systems are geared towards one end of the design spectrum or the other. The Humidi-MiZer adaptive dehumidification system eliminates this limitation.

This paper is based on an article written by Michael Taras and published in ASHRAE Journal in December 2004. Mr. Taras is a Principal Engineer at Carrier Corporation and the original article from ASHRAE Journal has been modified to include information specific to Carrier Corporation's Humidi-MiZer™ system. ASHRAE does not endorse the products or technology of any specific manufacturer, including the Humidi-MiZer system described herein. Humidi-MiZer™ is a trademark of Carrier Corporation.

REHEAT CONCEPTS

Warm Liquid Refrigerant

One of the most popular and efficient dehumidification designs for hot and humid environments is the scheme using warm liquid refrigerant exiting the condenser coil (Fig. 1 and 2). This system delivers both sensible and latent components of system capacity. When the system is operating in dehumidification mode, the refrigerant exiting the condenser is rerouted to a reheat coil connected serially with the condenser and located behind the evaporator, on the way to the indoor air stream supplied to the conditioned space. Thus, cooled and dehumidified air exiting the evaporator coil is reheated. During this heat transfer interaction, the liquid refrigerant circulating through the reheat coil is sub-cooled. As a result, the refrigerant enthalpy difference in the evaporator and the evaporator capacity are increased. The augmented subcooling is responsible for the evaporation temperature reduction and the system latent capacity boost. Since the system sensible capacity loss in the reheat coil is somewhat compensated for by the enhanced evaporator performance, the overall system cooling potential remains adequate. At the same time, a significant enhancement of the evaporator latent capacity is achieved.

Since the system sub-cooling is only limited by the reheat coil size and air temperature leaving the evaporator (and not by the normally much higher outdoor air temperature, as in other systems), the warm liquid refrigerant method becomes one of the most efficient techniques of increasing system dehumidification capability without compromising system cooling performance. Additionally, one of the major concerns with multiple coil systems is refrigerant charge migration. This occurs when some of the refrigerant coils are inactive. Since refrigerant naturally migrates to the coldest region in the system, it could migrate to the inactive coil at certain operating modes and environmental conditions. The warm liquid reheat cycle offers a significant advantage because it is free of charge migration problems, since the reheat coil is always filled with liquid refrigerant, regardless of the operating mode.

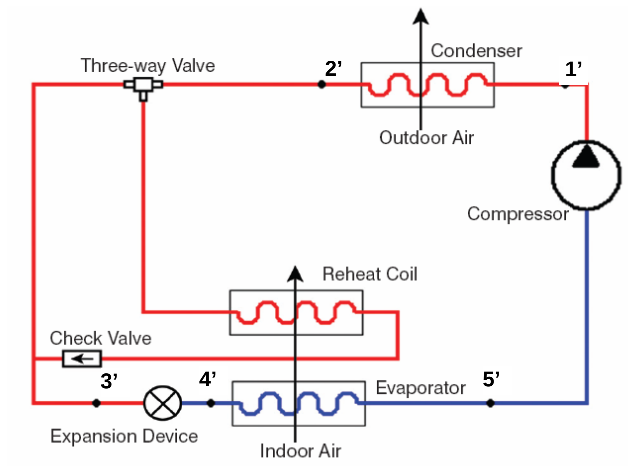

Fig. 1. Warm Liquid Reheat Cycle

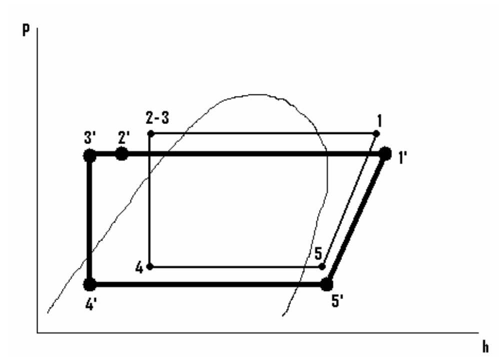

Fig. 2. Pressure/Enthalpy Diagram for Warm Liquid Reheat Cycle

Hot Refrigerant Gas

The hot refrigerant gas reheat cycle has been developed for applications that require that no sensible capacity be delivered by the system. In such cases, the sensible portion of the evaporator capacity must be significantly reduced by reheating the indoor air stream.

Sequential Configuration

The most popular approach to the hot gas reheat cycle uses compressor discharge gas rerouted to the reheat coil through a 3-way valve and a check valve similarly placed in the indoor section behind the evaporator and connected sequentially with the main condenser. This concept allows reheating of the indoor air stream and considerable reduction of the system sensible capacity (Fig. 3 and 4). However, a major limitation of this system is that the sensible capacity can be entirely eliminated only at a single design operating point. At all other off-design conditions the system will deliver either some sensible cooling or heating to the conditioned space. This can easily result in overcooling or overheating the conditioned space.

Although the main condenser and reheat coil jointly act as a much larger condenser coil when in the dehumidification mode and the condensing temperature is noticeably reduced, the system subcooling is still limited by the outdoor air temperature. This constraint, in turn, limits the evaporator latent capacity, especially in cases when the main condenser coil is already large and its temperature approach is small in order to satisfy continually increasing system efficiency requirements. As a result, the system latent capacity cannot be appreciably increased over the evaporator performance of the conventional cooling cycle.

As mentioned before, refrigerant migrates between the condenser and the reheat coil, depending on the operating mode and environmental conditions. In the dehumidification mode, the reheat coil primarily contains a two-phase refrigerant mixture, in comparison to the conventional cooling mode when it is not operational and is filled with liquid refrigerant. On the other hand, the condenser coil holds predominantly a two-phase refrigerant, but during the dehumidification mode this refrigerant mixture is contained at lower pressure and density. As a result, the refrigerant charge rebalances, and alternating between the operational modes should not cause any major charge migration issues. The reheat coil isolation methods are incorporated into some design configurations, but commonly employed flow control devices tend to leak over time and cannot be relied upon to permanently solve the charge migration problems. Refrigerant "bleed circuits" are typically used to assist in charge migration prevention.

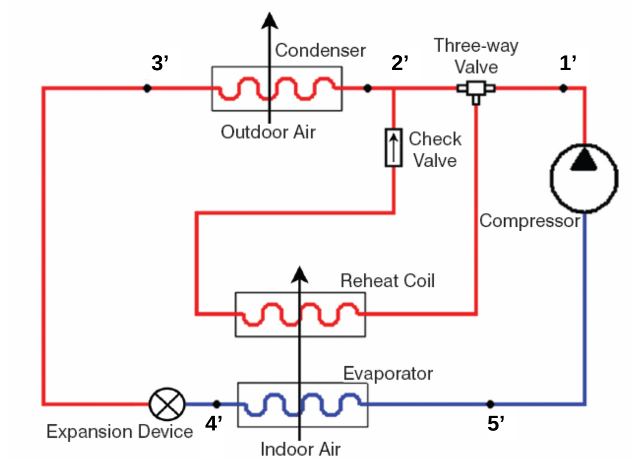

Fig. 3. Sequential Hot Gas Reheat Cycle

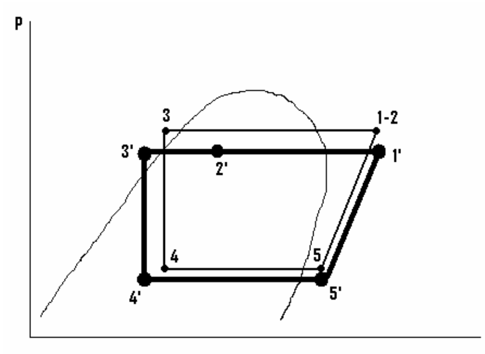

Fig. 4. Pressure/Enthalpy Diagram for Hot Gas Reheat Cycle

Parallel Configuration

An alternate and relatively popular approach to the sequential hot refrigerant gas reheat concept uses compressor discharge gas in a similar fashion, with the exception that the reheat coil is positioned in a parallel arrangement with the main condenser, and the latter is taken out of the circuit in the dehumidification mode of operation (Fig. 5 and 6). Although the performance of such a design is not thoroughly investigated in this paper, several features of the system operation are discussed below.

First, the reheat coil, which solely performs the condensation function in the dehumidification mode, is much smaller than the combined condenser/reheat coil in the previous arrangements. This may affect system performance and life-cycle cost of the equipment. Additionally, when the reheat cycle is activated, the parallel hot gas configuration will always deliver heat (at least for a single-circuit system), since the heat rejected into the conditioned space (comprised of the condenser heat flux and indoor fan power) exceeds the evaporator sensible capacity. As a result, the controls constantly alternate between the cooling and dehumidification modes of operation in order to maintain the design point of the time-averaged neutral (zero) sensible capacity. Such alternating can introduce additional instability, reliability and control issues into the system design and operation.

Another drawback of this type of system is that the airflow cannot be used as a head pressure control parameter, since the reheat coil and the evaporator are coupled by the indoor air stream. Also, since the main condenser and reheat coil are functionally separated, the system design is more susceptible to refrigerant charge migration. As was mentioned previously, the flow control devices such as a conventional solenoid valve, a three-way valve and a liquid line check valve may be introduced to isolate the reheat circuit, but they can leak over time, often causing the refrigerant charge to migrate to the condenser in the dehumidification mode of operation. To protect against the charge imbalance and migration, a small bleed line with a solenoid valve and/or a hot gas bypass circuit often are integrated into the system design.

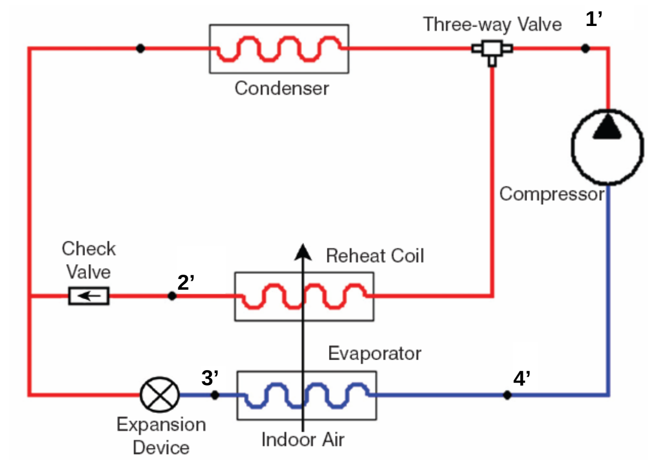

Fig. 5. Parallel Hot Gas Reheat Cycle

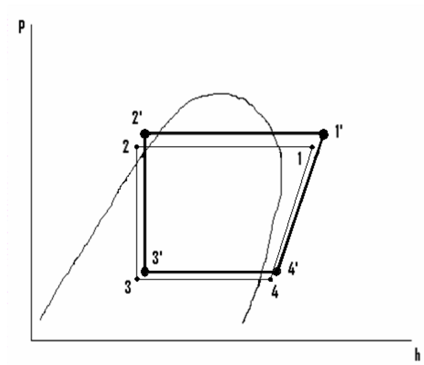

Fig. 6. Pressure/Enthalpy Diagram for Parallel Hot Gas Reheat Cycle

Two-Phase Refrigerant Mixture – Humidi-MiZer™ Adaptive Dehumidification System

The Humidi-MiZer adaptive dehumidification system uses a novel approach to humidity and part-load capability by using a mixture of hot compressor discharge gas and warm liquid exiting the condenser (Fig. 7 and 8). In this process, the refrigerant flow at the compressor exit splits into two streams: one stream completes the conventional path through the condenser and the other stream is rerouted around the condenser coil. These refrigerant streams rejoin at the condenser exit, forming a two-phase mixture. As in the warm liquid dehumidification concept, the refrigerant subsequently enters the reheat coil, but in an entirely different two-phase state, where it is further condensed and then sub-cooled (Fig. 7 and 8). During this heat transfer interaction, the air stream exiting the evaporator is reheated. Assuming that all other parameters remain the same, the amount of flow bypassing the condenser will determine the vapor quality in the refrigerant at the mixing point and will define the reheat coil capacity. The bypass refrigerant flow consequently establishes the evaporator performance (based on the amount of subcooling gained).

If the bypass refrigerant flow is increased, the mixing point shifts into the higher vapor quality region inside the two-phase dome, which in turn enhances the reheat coil capacity (Fig. 7 and 8). Since the system subcooling is concurrently reduced, the evaporator performance diminishes accordingly. Of course, the bypass flow reduction causes just the opposite effect. This design makes it possible to meet market requirements of both evaporator latent capacity and system sensible capacity by means of modulating or pulsating the condenser bypass flow, without changing any of the system components. If the conventional refrigerant path through the condenser is closed, the two-phase mixture system turns into the parallel hot gas reheat design. If the bypass around the condenser is closed, the system develops into the warm liquid design.

This discussion demonstrates that some flexibility could be achieved for all the previous designs if regulating or pulsating flow control devices are substituted for the fixed-position valves. Unfortunately, all of these methods offer significantly lower agility in system design and may encounter more complex control and reliability issues. However, the two-phase refrigerant system used by the Humidi-MiZer™ system offers at least three distinct modes of operation to satisfy a wide range of environmental conditions and thermal load demands. The system provides adequate operation for conventional cooling applications, for hot and humid environments, and for low sensible load cases, by alternating between these operating modes. Finally, although implementation of the considered design may require slightly larger reheat coil than in the sequential hot gas approach, the original evaporator airflow distribution will not be compromised, preventing a potential flooding problem in some of the evaporator circuits.

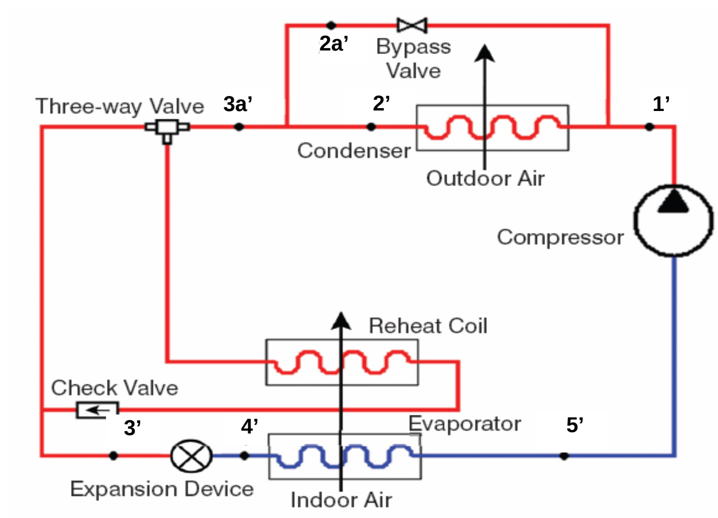

Fig. 7. Humidi-MiZer Two-Phase Reheat Cycle

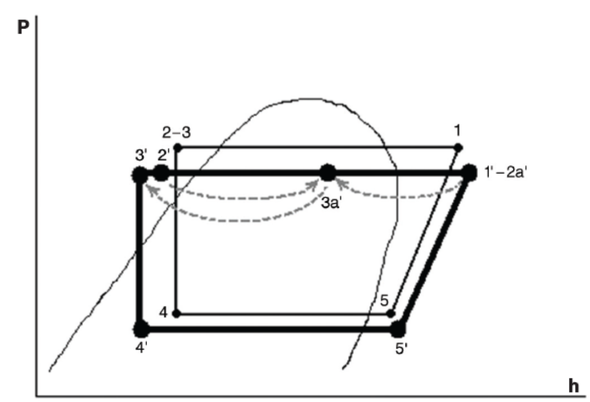

Fig. 8. Pressure/Enthalpy Diagram for Humidi-MiZer Two-Phase Reheat Cycle

OFF-DESIGN CONDITIONS

It is essential to analyze each design concept at off-design conditions in terms of system reaction and sensitivity to various environmental conditions and operational parameters. Issues such as performance degradation, potential system malfunctioning, reliability and required changes in the control logic must be evaluated carefully. The following parameters are considered the most critical for system operation: ambient temperature, indoor humidity, outdoor airflow, and indoor temperature and airflow. Below, the two-phase mixture design used by the Humidi-MiZer™ is compared to a sequential hot gas reheat concept.

Ambient Temperature

All air-conditioning systems must operate at various ambient conditions and should be able to sustain the desired performance in the dehumidification mode of operation. A significant advantage of the two-phase mixture reheat concept is that the system performance improves with the ambient temperature. Conversely, the system performance of the sequential hot gas reheat method diminishes at the conditions when dehumidification is needed most. At relatively high ambient temperatures, both sensible and latent components of the system capacity are required to satisfy, respectively, increased cooling and dehumidification demands. In such ambient conditions, the hot gas design would switch to the conventional cooling mode.

The two-phase mixture system, however, has the option to either naturally transition to the warm liquid mode (by completely closing the condenser bypass valve) or to operate in the conventional cooling mode. In the latter case, both systems perform identically. Although for the hot gas reheat design, the sensible system capacity is significantly enhanced while switching to the conventional cooling mode of operation, its latent performance drops in comparison to the dehumidification cycle. Conversely, for the two-phase mixture system, its latent performance improves when the transition to the warm liquid method occurs while the sensible capacity reaches reasonably high levels (~75%). Thus, it becomes clear that the two-phase mixture system inherently has a higher degree of flexibility in design and in satisfying various latent and sensible load demands.

Indoor Humidity

It is not uncommon for dehumidification systems to operate in environments with varying indoor humidity levels. Therefore, the system should be able to adequately respond to the humidity changes by removing sufficient amounts of moisture in order to keep the conditioned space within the comfort zone or recommended specification. Both the hot gas and two-phase mixture reheat designs react similarly to variations in indoor humidity and exhibit identical performance trends, providing an equal ability to remove moisture from the indoor air stream. The most noticeable enhancement in the latent performance, in comparison to the conventional system, is achieved at the lower end of the relative humidity spectrum, as a result of the improved reheat coil operation at lower evaporation temperatures.

Outdoor Airflow

Outdoor (condenser) airflow affects many of the system operational parameters and should be given special attention in the evaluation of the dehumidification system performance. Although the majority of air-conditioning systems are not yet configured for variable-speed operation, the goal of achieving higher efficiencies while reducing the lifetime cost of the equipment is becoming one of the most critical concerns in the industry. In addition, many applications use various methods of outdoor airflow adjustment to achieve the required head pressure control in order to avoid system malfunction or failure. Also, operating the system in dirty environments may vary condenser airside impedance, causing a change in the fan operating point and the amount of delivered airflow. Thus, it becomes important to analyze the effect of the outdoor airflow on dehumidification system performance.

When the effect of outdoor airflow is considered, a substantial advantage of the two-phase mixture reheat design is that it is more adaptable to the head pressure control by means of the condenser airflow adjustment through continuous modulation or fan cycling. The hot gas reheat schematics, however, are either insensitive to the previously mentioned control methods or such control techniques are not feasible due to the specific system configurations, such as in the case of the parallel hot gas system. The rates of change in essential performance characteristics for both dehumidification concepts are almost identical. The most significant improvement in the dehumidification capability, relative to the conventional system, can be achieved at the lower end of the airflow spectrum, since the reheat coil plays a more significant role in latent performance enhancement at higher condensation temperatures.

Indoor Temperature and Airflow

Since the conditioned space temperature is highly application dependent, it is practical to evaluate dehumidification system performance at various indoor dry-bulb temperatures. Similarly, indoor airflow can vary for a number of reasons. For instance, variable air volume (VAV) and variable volume temperature (VVT®) systems are found in multiple applications in the industry. In addition, plugged filters or customized ductwork may cause a shift in the indoor fan operating point, even for the preset airflow systems. Therefore, it is essential to evaluate the influence that the amount of supplied air and the temperature of the conditioned space have on the dehumidification system performance.

As expected, both two-phase mixture and hot gas reheat systems operate in a similar fashion, exhibit identical trends, reveal no malfunction problems and have no detrimental effect on the end customers.

DESIGN COMPARISONS

A selected dehumidification system design should be capable of handling the requirements of a particular application in terms of the cooling and heating needs and the moisture removal criterion. An investigation of the dehumidification methods described above shows that the two-phase mixture scheme provides the most adequate coverage for a wide spectrum of potential applications. This approach offers superior flexibility in satisfying a wide range of latent and sensible capacity demands. It also provides an essential advantage of minimizing or even reversing undesirable tendencies in system performance deviation for a majority of off-design conditions. The system functionality or component reliability is not compromised, since it can be adequately addressed through the appropriate control logic (i.e. activation of the head pressure control) and careful component design (reheat coil size selection, condenser circuiting, etc.). The essential results and conclusions of the analysis are summarized in Table A, which compares the two-phase mixture reheat design with the most popular hot gas reheat concepts.

To further improve system flexibility, all fixed-position two-way and three-way valves could potentially be replaced with controllable devices to regulate the amount of the refrigerant flowing through every branch of the dehumidification cycle. This creates a trade-off of cost versus system flexibility. For most applications, modulating valves are not necessary when using the Humidi-MiZer™ system, due to the high degree of system flexibility at a relatively low cost. Additionally, the reheat designs can be used within the multi-circuit systems where each circuit is controlled independently to provide adequate overall system performance.

Recently, several hybrid concepts have been developed in order to satisfy an even wider range of cooling, heating and dehumidification requirements. These systems are also affected by the trade-off in higher costs and the system complexity. If designed adequately, these systems can potentially operate in several of the dehumidification modes discussed previously, by opening and closing the appropriate flow control devices to reroute the refrigerant through a particular branch of the cycle.

For example, Fig. 9 shows one such schematic where the two solenoid valves and two shutoff valves (replacing typical check valves) manage an appropriate refrigerant flow path in response to external sensible and latent load demands. Since the complexity in design and control logic for these systems increases proportionally, any subsystem of the hybrid design can be implemented and executed independently. As a result of this extra complexity and additional cost, the two-phase refrigerant mixture reheat strategy of the Humidi-MiZer adaptive dehumidification system is a much more effective and straightforward alternative for low cost constant volume airflow applications.

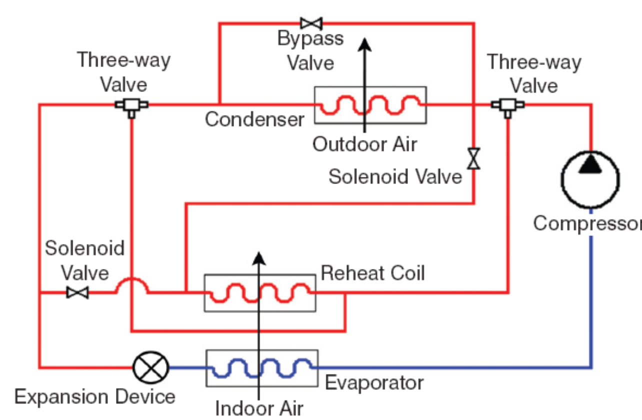

Fig. 9. Hybrid Reheat Schematic

Table A
Comparison of Hot Gas Reheat Concept with Two-Phase Mixture Reheat Concept

Characteristic	Hot Gas Reheat Concept	Humidi-MiZer™ Adaptive Dehumidification System Using Two-Phase Mixture Reheat Concept	Humidi-MiZer™ System Advantage
Modes of Operation	• Two modes of operation: — Conventional cooling — Dehumidification (hot gas)	• At least three modes of operation: — Conventional cooling — Dehumidification (two-phase mixture) — Cooling and enhanced dehumidification (warm liquid)	✓
Variable Performance	• It is not feasible to vary system performance at the design point without altering the system components	• System performance at the design point can be controlled by a variable (modulation) or preset (pulsation) restriction in the condenser bypass line	✓
Reliability	• Potential leakage through the three-way and check valve	• Potential leakage through the three-way valve and check valve • Flow change through the condenser (while switching between cooling and dehumidification modes of operation) is not a concern with the Humidi-MiZer™ System as a result of proper condenser circuiting design	No Difference
Charge Migration	• Design is less stable due to charge migration • System operation is more sensitive to charge migration	• Design is stable, minimal charge migration • System operation is not altered	✓
Latent Capacity Maximization	• Latent performance of the reheat cycle slightly exceeds latent capacity of the conventional system (ambient temperature limitation is more restrictive)	• Latent performance of the dehumidification cycle can significantly exceed latent capacity of the conventional system (indoor temperature limitation is less restrictive)	✓
Operation at High Ambient Temperature	• Switching to the conventional cooling mode of operation at high ambient temperature reduces dehumidification ability of the system	• Switching to the enhanced dehumidification mode of operation at high ambient temperatures enhances dehumidification ability of the system (at ~75% of sensible capacity) • Switching to the conventional cooling mode provides dehumidification capability equal to the hot gas reheat concept	✓
Ambient Temperature	• System performance degrades with the ambient temperature elevation: — Sensible capacity (↓) — Latent capacity (↓) — Latent efficiency (↓) • Head pressure control is activated at low ambient temperature	• System performance improves at high ambient temperatures — Sensible capacity is reduced at a lower rate (relative to the hot gas reheat concept) — Latent capacity is augmented — Latent efficiency is enhanced • Head pressure control is activated at low ambient temperature	✓
Outdoor Airflow	• Design is less adaptable to head pressure control	• Design is more adaptable to head pressure control	✓
Indoor Dry-Bulb Temperature, Humidity and Airflow	• Performance trends are similar to the two-phase mixture reheat concept	• Performance trends are similar to the hot gas reheat concept	No Difference

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