

Separating Cooling and Dehumidification: A Path to Greater Efficiency

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ABSTRACT

Conventional vapor-compression air conditioning systems suffer from a fundamental inefficiency: the coupled processes of sensible cooling and latent dehumidification. To remove moisture, the evaporator coil must operate at an excessively low temperature, often necessitating subsequent reheating of the overcooled air to maintain comfort. This cycle of overcooling and reheating constitutes a significant source of energy waste. This paper critiques the limitations of this traditional approach and proposes a transformative alternative: the decoupling of dehumidification and sensible cooling. By employing dedicated systems, such as desiccant dehumidifiers for latent load and high-temperature cooling units for sensible load, this method eliminates the need for reheat and allows each system to operate at its peak efficiency. The decoupled system demonstrates the potential for energy savings of up to 35%, while also providing superior independent control over temperature and humidity, enhanced adaptability to part-load conditions, and improved indoor air quality. This approach represents a promising paradigm shift for enhancing energy efficiency in modern air conditioning.

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Introduction:

The Fundamental Challenge of Traditional AC

Traditional air conditioning systems (vapor compression cycle) are designed to achieve two main goals in a single process: sensible cooling (lowering dry-bulb temperature) and dehumidification (lowering humidity ratio and relative humidity). This is achieved by passing air over a cold evaporator coil below its dew point, causing water vapor to condense on the coil's surface. While this approach seems effective, it harbors a flaw that leads to significant energy waste.

1. Traditional Air Conditioning (Vapor Compression Cycle)

The Traditional Vapor Compression Cycle is the fundamental refrigeration process used in most standard air conditioners and heat pumps. It works by circulating a refrigerant through a closed loop, alternately compressing and expanding it to absorb heat from one area (indoors) and reject it to another (outdoors).

2. Sensible Cooling

Sensible Cooling is the process of lowering the dry-bulb temperature of the air—the temperature measured by a standard thermometer. It involves removing sensible heat, which is the heat associated with a change in temperature but not a change in the state

(e.g., from vapor to liquid) of the water vapor in the air. This is what we commonly perceive as "cooling." When you feel the air become cooler, you are experiencing the effect of sensible cooling. It is the removal of heat energy that directly changes the air temperature without altering the moisture content (the humidity ratio) of the air.

3. Dehumidification (Latent Cooling)

Dehumidification, or Latent Cooling, is the process of removing moisture (water vapor) from the air. This involves removing latent heat, which is the heat associated with a change of state of the water vapor, specifically its condensation from a gas to a liquid. This process is crucial for comfort as it reduces humidity. In a traditional AC system, dehumidification occurs as a byproduct. When warm, humid air passes over the cold evaporator coil, the air is cooled (sensible cooling). If the coil's surface temperature is below the air's dew point, the water vapor in the air condenses on the coil and drips away. This removes moisture, making the air feel less "sticky" or "muggy."

Relationship in a Traditional AC System in a Traditional Vapor Compression Cycle, the Evaporator Coil is responsible for achieving both Sensible Cooling and Dehumidification simultaneously. This forced coupling is the root cause of inefficiency, as the coil must be made cold enough to condense water (for

dehumidification), often resulting in the air being cooled more than is necessary for temperature control alone.

The Inherent Flaw in Traditional Systems;

Overcooling and Reheat overcooling is the process of cooling the indoor air to a temperature lower than what is required for comfort solely to achieve adequate dehumidification. IN a traditional AC system, the only way to remove moisture (dehumidify) is to run the evaporator coil so cold that water condenses on it. Often, the temperature needed to pull enough moisture from the air (e.g., to get from 60% RH to 50% RH) is much lower than the temperature needed to make the space comfortable (e.g., 24°C). Therefore, the system must overcool the air—sending it out at, for example, 12°C—just to remove the humidity, even though this makes the air unnecessarily cold. This is a fundamental inefficiency, as energy is wasted to create this excessive cooling.

This is the engine behind nearly all conventional AC units. The cycle consists of four main components:

1. Compressor pumps and pressurizes the refrigerant gas, raising its temperature.
2. Condenser the hot, pressurized gas releases heat to the outside air and condenses into a liquid.
3. Expansion Valve rapidly reduces the pressure of the liquid refrigerant, causing it to cool drastically.
4. Evaporator the cold liquid refrigerant absorbs heat from the indoor air, causing it to evaporate back into a gas. This process cools the indoor air, which is then blown back into the room.

Reheat is the process of actively heating air that has just been cooled by the air conditioning system. Reheat is the paradoxical—and highly inefficient—solution to the problem of Overcooling. After air has been overcooled to remove moisture, it would cause discomfort and drafts if supplied directly to a room. Therefore, a reheat coil (typically using electricity, hot gas, or hot water) warms the cold, dry air back up to a suitable temperature (e.g., 15-18°C) before supplying it to the space.

The Core Inefficiency The system first consumes energy (electricity) to remove heat from the air, and then consumes more energy (electricity or gas) to add heat back into the same airstream. This "cool and heat" contradiction makes reheat one of the most significant sources of energy waste in traditional HVAC systems, particularly in applications requiring precise humidity control.

The core problem lies in the mandatory coupling of the two processes. To handle the latent load (especially in humid climates), the evaporator must operate at a very low temperature (often between 5-7°C) to condense moisture. However, the sensible heat load often requires a higher supply air temperature (around 12-15°C). This creates the following challenges:

1. Overcooling air is cooled to a temperature lower than required solely to remove moisture, wasting extra energy.

2. Need for Reheat in many applications (e.g., hospitals, laboratories, spaces requiring precise humidity control), this cold, dry air cannot be supplied directly as it would cause uncomfortable drafts. Therefore, the air is often reheated using an electric heater or hot water coil—a paradoxical process that consumes double the energy for overcooling, then energy to cancel that overcooling!
3. Reduced Evaporator Efficiency operating the evaporator at consistently low temperatures reduces its efficiency (Coefficient of Performance - COP), as it requires higher compressor pressure, disproportionately increasing energy consumption.
4. Inability to Adapt to Part-Load Conditions and Changing Weather traditional systems struggle outside of peak design conditions. On a humid but cool day, the system must cycle on and off (short cycling) to meet the sensible load, but doesn't run long enough to effectively remove moisture, leading to a cold, clammy feeling and potential mold growth.

This flaw not only signifies energy waste but also limits the ability of traditional systems to achieve optimal thermal comfort with independent control of temperature and humidity.

The coupled process of sensible cooling and dehumidification in traditional vapor-compression systems creates a fundamental and inefficient cycle of overcooling and reheat.

This flaw is not a minor drawback but a critical design limitation that forces the system to work against itself. The compressor consumes significant energy to overcool the air for humidity control, only for a separate energy source to be used to reheat that same air to a comfortable temperature. This paradoxical "cool and heat" process represents a profound waste of energy, drastically reducing overall system efficiency and increasing operational costs.

Therefore, the practice of reheat—a direct consequence of the coupled cooling and dehumidification process—stands as a clear indicator that traditional HVAC design is fundamentally misaligned with the goal of energy efficiency. Overcoming this flaw requires a paradigm shift away from this coupled approach, moving towards decoupled systems that handle temperature and humidity control independently, thus eliminating the energy penalty at its source.

Advantages and Disadvantages of Traditional Air Conditioning Systems

Table 1

Advantages	Disadvantages
1. Simplicity & Familiarity the technology is well-understood, with straightforward design, installation, and	1. Inefficient Dehumidification (Overcooling & Reheat) the fundamental flaw. The system must cool air below

<p>maintenance procedures. Most technicians are trained to service them.</p>	<p>its dew point to remove moisture, often leading to excessive cooling (energy waste) and a frequent need for energy-intensive reheat.</p>
<p>2. Lower Initial Cost the components (compressor, coil, etc.) are mass-produced, leading to a generally lower upfront cost compared to more complex decoupled systems.</p>	<p>2. Poor Humidity Control at Part Load when the sensible load is low but humidity is high (e.g., spring/fall), the system short-cycles, failing to run long enough to remove moisture effectively, leading to a clammy, uncomfortable environment.</p>
<p>3. Proven Reliability As a mature technology, these systems have a long track record of reliable operation when properly maintained.</p>	<p>3. Coupled Control inability to independently control temperature and humidity. Achieving precise humidity control is difficult and comes at a significant energy penalty.</p>
<p>4. All-in-One solution Provides both cooling and dehumidification in a single packaged unit, simplifying the initial system selection and layout.</p>	<p>4. Lower Overall Energy Efficiency the energy wasted on the overcooling/reheat cycle and operation at low evaporator temperatures results in a lower COP and higher long-term operating costs.</p>
<p>5. Widespread Compatibility easily integrates with standard thermostats and conventional building control systems.</p>	<p>5. Compromised Indoor Air Quality (IAQ) to save energy, systems may reduce the intake of humid outdoor air, leading to inadequate ventilation and poor IAQ.</p>

- Advantages: Easier maintenance (all components in one place), saves indoor space.
- Disadvantages: Slightly less efficient in some cases, no individual room control.

Visual Summary of the Refrigeration Cycle:

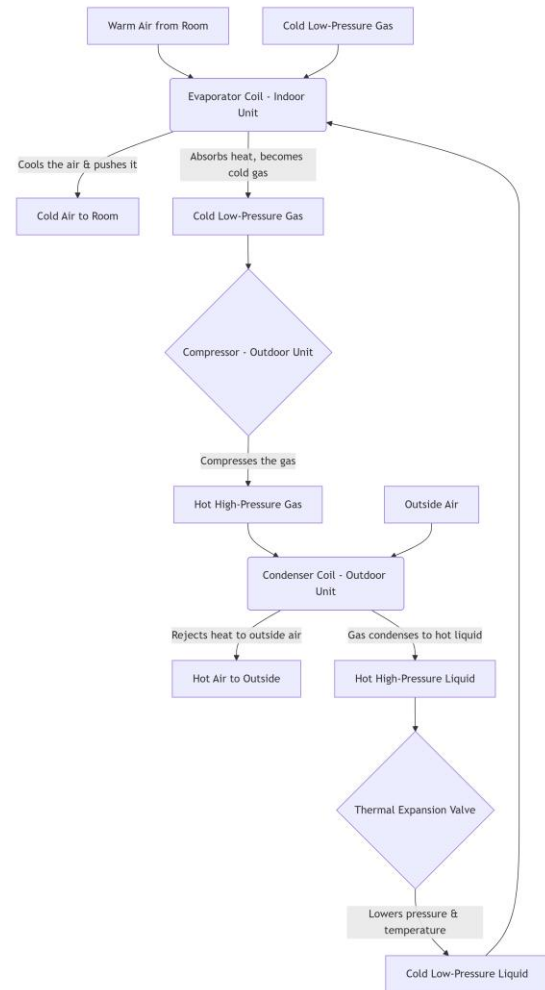


Fig.1

Separating Dehumidification and Cooling (Dedicated Outdoor Air Systems - DOAS)

A Dedicated Outdoor Air System (DOAS) is an HVAC approach that uses a separate system to precondition 100% of the outdoor ventilation air required for a building. Its primary role is to decouple the handling of the latent (moisture) load from the sensible (temperature) load.

Unlike traditional systems that mix return and outdoor air, a DOAS treats the outdoor air centrally. It is specifically designed to:

1. Provide Ventilation deliver the required fresh air according to building codes and occupancy.
2. Control Humidity actively and independently remove the latent load (dehumidify) from the outdoor air before it is supplied to the space. This is its core function.
3. Provide Sensible Cooling/Heating pre-condition the air's temperature as needed.

Common Types of Traditional AC Systems

- Single-Split System:
 - One outdoor unit serves one indoor unit.
 - Ideal for single rooms or small spaces.
 - Advantages: Individual control for each room, simple installation.
 - Disadvantages: Impractical for large buildings (requires multiple outdoor units).
- Multi-Split System:
 - One outdoor unit (or more) serves multiple indoor units.
 - Ideal for apartments or houses with several rooms.
 - Advantages: Saves outdoor space, individual control for each room.
 - Disadvantages: Higher cost; if the outdoor unit fails, all indoor units are affected.
- Packaged System:
 - All components (compressor, condenser, evaporator) are housed in one large unit, typically placed on the roof or beside the building.
 - Used for medium-sized commercial buildings or large homes where space for separate units is not available.

The DOAS delivers this conditioned, dry outdoor air to various zones in the building. Within each zone, local, parallel terminal units—such as Fan Coil Units (FCUs), Water-Source Heat Pumps, or Radiant Ceiling Panels—handle the space-specific sensible heating and cooling loads. Since the DOAS has already removed all the humidity, these local units only need to adjust the temperature and can operate at higher, more efficient temperatures without any risk of condensation. In essence, a DOAS acts as a specialized humidity manager for the entire building, enabling simpler and more efficient temperature control in each room. The modern and more efficient approach is to decouple the tasks of dehumidification and sensible cooling into two or more independent systems, each optimized for its specific function with maximum efficiency. This concept is based on handling the entire latent load from the outdoor air separately from the internal sensible heat load.

Decoupled Systems:

Decoupled Systems (also known as Split-Core Systems) represent an advanced approach to HVAC design where the processes of sensible cooling (temperature control) and latent cooling (dehumidification) are handled by separate, specialized systems. This approach fundamentally reorganizes the traditional coupled methodology by assigning each thermodynamic function to a system optimized for that specific task.

Traditional air conditioning systems combine temperature control and dehumidification in a single process, creating inherent inefficiencies. Decoupled systems revolutionize this approach by separating these two functions:

Core Components:

1. Dedicated Dehumidification System

Desiccant Dehumidifier uses a rotating wheel containing hygroscopic material (e.g., silica gel). Outdoor air passes through one section of the wheel, where moisture is adsorbed. The desiccant is regenerated using a heat source (e.g., solar thermal energy, waste heat from the system, or natural gas), offering significant energy savings compared to electrical cooling.

Dedicated Outdoor Air Cooler A traditional refrigeration cycle can be used, but it is dedicated *only* to dehumidifying the outdoor air before it is mixed with return air, often with energy recovery to cool the air after it's dried.

- Typically uses technologies like desiccant dehumidifiers or specialized cooling coils
- Handles all latent (moisture) loads independently
- Can utilize alternative energy sources (solar thermal, waste heat) for regeneration

Visual Summary of the Cycle

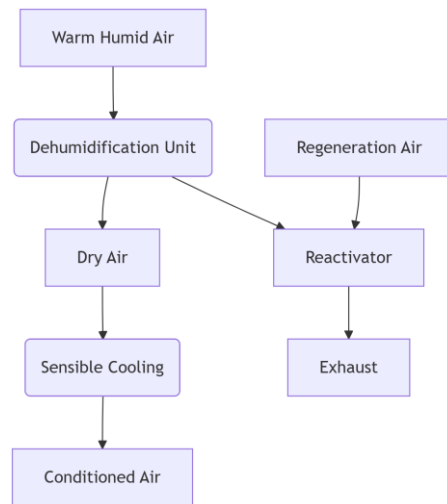


Fig.2

Advantages and Disadvantages of Dedicated Dehumidifiers

Table2

Advantages	Disadvantages
Effective Moisture Control: Superior at maintaining a specific humidity level regardless of temperature.	Adds Heat to the Room: The process is net-additive of heat, which can increase the cooling load on an AC in summer.
Operates in Cool Conditions: Can dehumidify effectively even in cool, damp weather (e.g., basements, spring/fall) when running an AC for dehumidification alone is inefficient or uncomfortable.	Energy Consumption: Runs on electricity, adding to energy bills.
Standalone Solution: Does not require a full HVAC system to operate. Portable and easy to install.	Noise: Contains a compressor and fan, which generate noise similar to an AC unit.
Prevents Overcooling: The reheat function ensures the space is dehumidified without becoming too cold.	Maintenance: Requires regular cleaning of filters and emptying of the water bucket (if not connected to a drain).

1. Separate Sensible Cooling System

After the air is dried, it is cooled to the desired temperature using high-efficiency cooling units that operate at higher temperatures (e.g., 15-18°C), significantly increasing their COP.

Local terminal units (e.g., Fan Coil Units, Active Chilled Beams, Radiant Cooling Panels) handle the internal sensible heat load in each zone. These units operate with high efficiency because they are not burdened with dehumidification.

- Employs technologies like chilled beams, fan coil units, or radiant panels
- Operates at higher temperatures (typically 15-18°C/58-65°F)
- Focuses exclusively on temperature control

Visual Summary of the Cycle

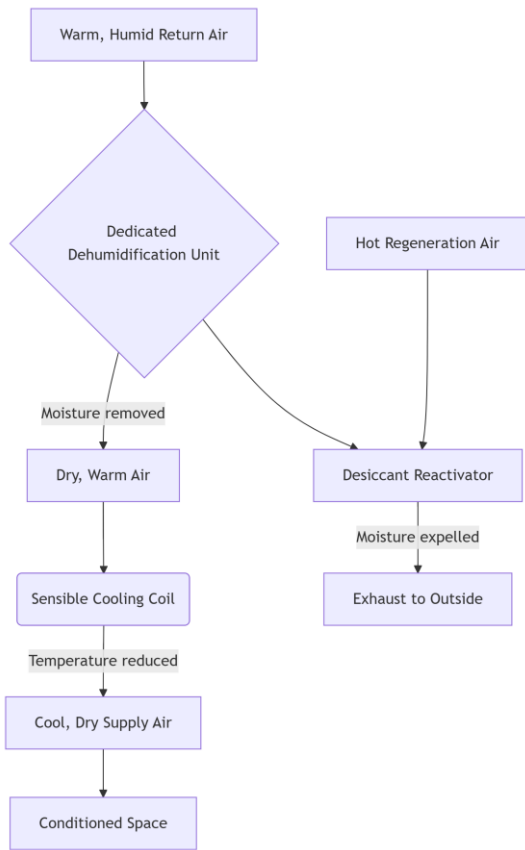


Fig.3 Advantages and Disadvantages Table3

Advantages	Disadvantages
Superior Humidity Control: Precise independent control of temperature and humidity	Higher Initial Cost: More complex system with multiple components
Energy Efficiency: Eliminates overcooling and reheating energy waste	Complex Control System: Requires sophisticated building automation
Improved Indoor Air Quality: Better moisture control prevents mold and mildew	Larger Space Requirements: Multiple units need more mechanical space
Flexibility: Each system can be optimized for its specific function	Higher Maintenance: Multiple systems to maintain and service
Reduced Cooling Capacity: Sensible-only coils can use higher temperature chilled water	Design Complexity: Requires careful load calculations and system integration

How It Works:

The system first treats ventilation air separately, removing moisture through the dedicated dehumidification system. This dry, conditioned air is then supplied to spaces where local sensible cooling units handle only the temperature control. Since the air is already dry, the cooling units can operate at higher temperatures and don't need to handle moisture removal.

By separating these functions, each subsystem operates at its optimal efficiency point. The sensible cooling system doesn't waste energy by overcooling, and the dehumidification system doesn't compromise temperature control. This separation enables:

- Significant energy savings (typically 25-35%)
- Superior humidity control
- Enhanced comfort conditions
- Flexible system operation across varying load conditions

Decoupled systems represent the next evolutionary step in HVAC design, particularly suited for applications requiring precise environmental control, high energy efficiency, and superior indoor air quality.

Case Study: Office Building in a Hot-Humid Climate example:

A 10,000 sq. ft. single-story office building with 50 occupants. The design conditions are:

- Outdoor: 91°F DB / 78°F WB (33°C / 26°C)
- Indoor Setpoint: 75°F DB / 50% RH (24°C)
- Ventilation Requirement: 500 CFM of outdoor air (per ASHRAE 62.1)
- Total Cooling Load: 30 Tons (360,000 BTU/hr), of which 8 Tons (30%) is latent load from outdoor air and occupants.

1. Traditional VAV System with Reheat

- Process All air is cooled to ~55°F (13°C) at the central air handler to condense moisture. To avoid dumping 55°F air into the space, most zones require reheating the air back up to ~60-65°F (16-18°C) using electric resistance or hot water coils.
- Key Energy Penalty, Energy is used twice—first to cool below the necessary temperature, then to reheat.

Simplified Energy Calculation (Focus on Latent Load Handling):

- Energy to Dehumidify (Cooling + Reheat):
 1. Cooling to 55°F The system must remove the sensible + latent load. The latent load of 8 Tons requires the coil to be very cold.
 2. Reheat Energy after cooling to 55°F DB, the air is reheated to 62°F DB for supply.
 - Airflow (approx.): 30 Tons * 400 CFM/Ton = 12,000 CFM.
 - Reheat = 1.08 * CFM * ΔT = 1.08 * 12,000 * (62-55) = 90,720 BTU/hr of additional electric heat.
- Total Compressor Load The compressor must handle the full 30 Tons plus the added load from reheating the air it just cooled. The reheat energy (90,720 BTU/hr ≈ 7.6 Tons) ultimately becomes an additional sensible load on the system. This creates a feedback loop of inefficiency.

- Estimated Annual Energy Use (Cooling + Reheat Fans): ~150,000 kWh

2. Decoupled DOAS with High-Temperature Sensible Cooling

- Process:
 - DOAS Unit handles all 500 CFM of ventilation air. A desiccant wheel (regenerated by solar thermal collectors or a small gas heater) removes the 8-ton latent load without overcooling. It delivers dry, neutral-temperature air (~75°F) directly to the zones.
 - Sensible Cooling fan Coil Units (FCUs) or a Chilled Beam system handle only the 22-ton sensible load. They circulate chilled water at a high temperature of 58°F (14°C), which is much more efficient to produce than 44°F water.

Simplified Energy Calculation:

- DOAS Energy (Desiccant): Latent load is handled by thermal energy (e.g., natural gas or waste heat). If using a high-efficiency gas-fired regenerator:
 - Gas Consumption for 8 Tons Latent ≈ 0.8 Therm/hr (vs. 8 kW/ton for electric cooling).
- Chiller Energy for Sensible Cooling producing 58°F water instead of 44°F water significantly improves chiller efficiency.
 - Traditional Chiller COP (44°F water): ~4.0
 - High-Temp Chiller COP (58°F water): ~6.0 (50% more efficient)
 - Energy for 22 Tons Sensible: $(22 \text{ Tons} * 12,000 \text{ BTU/hr/Ton}) / (\text{COP } 6.0 * 3,412 \text{ BTU/kW}) = 12.9 \text{ kW}$
- Eliminated Energy: No reheat energy is required (saving 90,720 BTU/hr), and the chiller avoids the inefficient low-temperature operation for dehumidification.
- Estimated Annual Energy Use: ~95,000 kWh + 800 Therms of gas.

Chiller Efficiency (COP)	4.0	6.0	+50%
Reheat Energy	Required (Major Penalty)	Eliminated	100%
Control	Coupled, Poor Humidity Control at Part Load	Independent, Precise Temp & Humidity Control	Superior Comfort & IAQ

This simplified example illustrates the dual energy penalty of the traditional system: (1) the chiller runs inefficiently at low temperatures, and (2) it must power a reheat coil to correct its own overcooling. The decoupled system avoids both penalties. By assigning the latent load to a thermally-driven DOAS and allowing the chiller to produce high-temperature water for sensible cooling only, the system achieves estimated total site energy savings of 30-40%. The savings are most dramatic in humid climates where the latent load is significant and persistent. This makes the decoupled approach not only an energy-saving strategy but also a critical one for achieving resilient, comfortable, and cost-effective building operation.

Advantages and Benefits of the Decoupled System

1. Energy Savings of up to 35% numerous studies and practical applications indicate that decoupled systems can achieve energy savings ranging from 25% to 35% compared to traditional systems. This saving comes from:
 - Eliminating the reheat process.
 - Operating sensible cooling systems at higher, more efficient temperatures.
 - Using low-grade energy sources (e.g., waste heat or solar thermal) for regenerating desiccant dehumidifiers.
2. Superior and Independent Control of Humidity and Temperature the system provides exceptional precision in controlling humidity levels regardless of the sensible cooling load, which is critical for industrial, healthcare, and archival applications.
3. Improved Indoor Air Quality (IAQ) by treating outdoor air separately and dedicatedly, the system guarantees the required ventilation rates without compromising the performance of the internal cooling units.
4. Design and Operational Flexibility these systems can be seamlessly integrated with other sustainable technologies like radiant cooling or energy recovery ventilators.
5. Enhanced Flexibility and Adaptation to Variable Loads and Climates decoupled systems are inherently designed to handle changes IN sensible and latent loads independently.

Comparison Summary
Table4

Metric	Traditional VAV with Reheat	Decoupled DOAS + High-Temp Cooling	Savings
Annual Cooling Elec. (kWh)	~150,000	~95,000	~37%
Dehumidification Method	Electric Compression (Low COP)	Thermal (Desiccant) / High-Efficiency	Shift to cheaper/free energy source

- Independent Control the dehumidification system (e.g., desiccant wheel) can operate independently of the sensible cooling system. On a humid but cool day, only the dehumidifier runs to maintain target humidity without any sensible cooling.
- Part-Load Performance each subsystem operates at its own optimal point. Fan coil units can modulate or turn off in unoccupied rooms, while the outdoor air dehumidifier continues to handle moisture, ensuring consistent comfort and IAQ throughout the building.

Conclusion:

The pursuit of energy efficiency and superior indoor environmental quality IN the HVAC industry necessitates a critical re-evaluation of conventional practices. The fundamental limitation of traditional vapor-compression systems lies IN their inherent coupling of sensible cooling and latent dehumidification. This forced marriage of two distinct thermodynamic processes creates a cycle of inefficiency, primarily manifested as overcooling and the frequent need for wasteful reheat. This paradigm, while simple and cost-effective initially, proves to be energetically unsound, leading to elevated operational costs, compromised comfort IN part-load conditions, and an inability to provide precise independent control over temperature and humidity.

The solution emerges IN the form of decoupled systems, with the Dedicated Outdoor Air System (DOAS) as a leading approach. By separating the tasks of dehumidification and sensible cooling, this innovative strategy assigns each function to a system specifically optimized for it.

- Dedicated Dehumidification, often using technologies like desiccant wheels, handles the latent load independently, potentially using low-grade thermal energy and eliminating the core reason for overcooling.
- Separate Sensible Cooling systems, such as fan coil units or radiant panels, can then operate at higher, more efficient temperatures, focusing solely on temperature control.

The advantages of this decoupled approach are transformative. It promises energy savings of up to 35% by eradicating the reheat penalty and optimizing the performance of each subsystem. Furthermore, it delivers unparalleled control over the indoor environment, ensuring both thermal and hygroscopic comfort, and offers superior flexibility to adapt to changing climatic conditions and partial loads.

References:

1. ASHRAE. (2021). ASHRAE Handbook—Fundamentals. American Society of Heating, Refrigerating and Air-Conditioning Engineers.
2. Zhang, L., & Niu, J. (2003). Energy Performance of Independent Humidity Control Air-Conditioning System with Desiccant Wheel. *Energy and Buildings*.
3. Gatley, D. P. (2000). The 100% Outdoor Air System: The Dehumidification Solution. *Heating/Piping/Air Conditioning Engineering (HPAC)*.
4. Khalid, A., Mahmood, M. H., Aslam, M., & ul Haq, I. (2019). A Comprehensive Review of Dedicated Outdoor Air Systems (DOAS): Advancements, Challenges, and Opportunities. *Energy and Buildings*.
5. Shan, K., Wang, X., & Sun, Y. (2016). Energy Saving Potential of a Desiccant-Assisted Separate Sensible and Latent Cooling System. *Applied Thermal Engineering*.
6. Coad, W. J. (1999). *Conditioning Ventilation Air for Improved Performance and Air Quality*. HPAC Engineering.
7. ASHRAE. (2019). *Standard 62.1-2019: Ventilation for Acceptable Indoor Air Quality*. American Society of Heating, Refrigerating and Air-Conditioning Engineers.
8. Harriman, L., Plager, D., & Kosar, D. (1997). *Dehumidification and Cooling Loads from Ventilation Air*.
9. Wang, S. K. (2000). *Handbook of Air Conditioning and Refrigeration (2nd ed.)*. McGraw-Hill.
10. Harriman, L., Brundrett, G., & Kittler, R. (2008). *Humidity Control Design Guide for Commercial and Institutional Buildings*. ASHRAE.