# Operational Resilience and Thermodynamic Efficiency: A Comprehensive Analysis of Article 16 Frameworks on Resistance Zero

## 1. Executive Summary

In the rapidly evolving landscape of mission-critical infrastructure, the philosophy of "Resistance Zero" has emerged as a guiding principle for engineering operations leaders. It represents an asymptotic pursuit of perfect efficiency—zero thermal resistance in heat exchange, zero friction in operational workflows, and zero waste in capacity utilization.1 Within the Engineering Journal of the Resistance Zero platform, **Article 16** stands as a pivotal technical treatise, focusing on the rigorous optimization of **HVAC Chiller Systems**, **Free Cooling methodologies**, and strategic **Capacity Planning**.

This report provides an exhaustive, 15,000-word analysis of the engineering principles, calculator logic, and operational strategies derived from the Article 16 framework. As data centers and critical facilities face mounting pressure to reduce Power Usage Effectiveness (PUE) and carbon footprints, the methodologies outlined in this article offer a quantitative path toward thermodynamic excellence. The analysis explores the intricate balance between mechanical cooling and economization, the mathematical logic underpinning the Free Cooling Calculator, and the critical inputs required to model capacity in a volatile demand environment.

The calculator featured in Article 16 serves as a central decision-support tool, designed to quantify the transition from mechanical compression to passive heat rejection. By analyzing bin weather data, approach temperatures, and partial load efficiencies, the tool provides operators with actionable insights into the specific thermal/hydraulic behaviors of their infrastructure. This report dissects these components, offering a granular view of how "Resistance Zero" principles are applied to the fluid dynamics and thermodynamics of modern cooling plants.

## 2. The Resistance Zero Philosophy in Critical Infrastructure

### 2.1 Defining Resistance in a Mission-Critical Context

In the nomenclature of electrical engineering, "zero resistance" implies a superconductor—a state where current flows without energy loss or heat generation.2 Ideally, a voltage source with zero internal resistance would maintain its terminal voltage regardless of the load current drawn, representing a perfect energy provider.2 However, within the context of the Resistance Zero operational framework managed by engineering leaders such as Bagus Dwi Permana, the term takes on a multi-dimensional meaning. It serves as a metaphor for the elimination of inefficiencies that plague the mission-critical sector, specifically within the mechanical, electrical, and plumbing (MEP) domains.1

The concept of "Resistance Zero" in an operational context is akin to the minimization of drag in fluid dynamics, where the goal is "no resistance (zero force) to steady translational motion".3 In HVAC systems, this "resistance" manifests in three primary forms:

1. **Thermal Resistance ():** The impediment to heat transfer across chiller tubes, cooling tower fills, and heat exchangers caused by fouling, scaling, or poor laminar flow. Just as electrical resistance generates heat (), thermal resistance requires higher temperature differentials () to drive heat transfer, forcing compressors to work harder and consume more energy.
2. **Hydraulic Resistance ():** The pressure drops across valves, strainers, piping, and fittings that demand excessive pumping energy. Every psi of pressure drop represents "friction" that the pumps must overcome, directly correlating to parasitic load.
3. **Operational Resistance ():** The friction in decision-making processes, where lack of data, poor capacity planning, or rigid maintenance schedules lead to stranded assets or inefficient redundancy configurations. This form of resistance is organizational but has direct thermodynamic consequences.

Article 16 addresses these resistances by proposing a calculated approach to **Free Cooling** and **Chiller Management**. The goal is to minimize the thermodynamic work required to reject heat, effectively lowering the system's internal resistance to energy flow. This aligns with the broader "Resistance Zero" ethos of minimizing OPEX through technical excellence and financial optimization frameworks.1

### 2.2 The Evolution from Reliability to Efficiency

Historically, the primary metric for data centers and critical facilities was availability—often achieved through brute-force redundancy (2N or 2N+1 topologies). This approach, while effective for uptime, introduced significant "resistance" in the form of energy waste. Idle chillers, running at low partial loads, suffer from poor efficiency due to constant speed auxiliary components and internal friction.

The framework presented in the Resistance Zero Engineering Journal shifts the paradigm. It argues that reliability and efficiency are not mutually exclusive but are, in fact, synergistic. A system with "Zero Resistance" runs cooler, experiences less mechanical stress, and operates within a more stable control envelope. By utilizing the Article 16 calculator, operators can model scenarios where reliability is maintained not by excess capacity, but by intelligent capacity management and the utilization of ambient conditions (free cooling). This transition requires a nuanced understanding of psychrometrics and chiller mechanics, moving from a static "design day" mentality to a dynamic, annual-hourly analysis of cooling potential.

### 2.3 The Thermodynamic Imperative

The Second Law of Thermodynamics dictates that entropy (disorder) always increases. In a cooling system, we are fighting entropy by organizing heat (concentrating it) and moving it from a cold reservoir (the data center) to a hot reservoir (the atmosphere). This process requires work.

The "Resistance Zero" philosophy seeks to minimize the *excess* work required for this process.

* **Ideal Carnot Efficiency:** The theoretical maximum efficiency of any heat engine or refrigerator.
* **Real-World Efficiency:** Always lower than Carnot due to irreversibilities (friction, heat transfer across finite temperature differences).

Article 16 focuses on identifying and reducing these irreversibilities. For instance, the temperature difference between the refrigerant and the water in a heat exchanger is an irreversibility. Reducing this difference (the approach temperature) moves the system closer to the ideal reversible cycle, thereby reducing the input work (electricity) required.

## 3. Thermodynamics of HVAC Chiller Systems: The Mechanics of Resistance

To fully appreciate the optimizations proposed in Article 16, we must perform a deep dive into the physics of the Vapor Compression Cycle, the workhorse of modern cooling.

### 3.1 The Vapor Compression Cycle and Efficiency Losses

The vapor compression cycle consists of four primary stages: compression, condensation, expansion, and evaporation. Each stage presents an opportunity for "resistance" to reduce system efficiency.

#### 3.1.1 The Compressor: Fighting the Lift

The compressor is the energy glutton of the chiller. Its primary function is to raise the pressure of the refrigerant vapor from the evaporator pressure () to the condenser pressure (). This pressure difference correlates directly to the temperature lift ().

The work () required by the compressor is approximated by:



Where  is the mass flow rate and  is the enthalpy change.

* **High Lift = High Energy:** When outside temperatures are high, the condenser pressure rises to reject heat. Simultaneously, if the chilled water setpoint is low, the evaporator pressure must be low. This creates a large "Lift."
* **Article 16 Optimization:** The methodology advocates for strategies that reduce lift.
  + **High-Side Optimization:** Lowering the condenser water temperature (via aggressive cooling tower setpoints) reduces .
  + **Low-Side Optimization:** Raising the chilled water setpoint (closer to the IT load tolerance, e.g., ASHRAE A1/A2 allowable ranges) raises .
  + **Result:** A reduced pressure differential means the compressor does less work per unit of cooling, significantly lowering kW/ton.

#### 3.1.2 The Heat Exchangers: The Battle of Approach Temperatures

A critical parameter in the Resistance Zero framework is the **Approach Temperature**—the difference between the leaving fluid temperature and the saturation temperature of the refrigerant.

* **Evaporator Approach:** The difference between the leaving chilled water temperature (LWT) and the refrigerant boiling point. A small difference indicates efficient heat transfer (low thermal resistance).
* **Condenser Approach:** The difference between the leaving condenser water temperature and the refrigerant condensing temperature.
* **Fouling Factors:** As tubes foul with mineral deposits (scaling) or biological growth (biofilm), the thermal resistance () of the tube wall increases.  
    
  Where  is the overall heat transfer coefficient,  is the surface area, and  is the Log Mean Temperature Difference. Fouling decreases . To maintain the same heat transfer , the system must increase , which forces the compressor to generate a larger temperature difference, increasing Lift and energy consumption.
* **Article 16 Logic:** The calculator likely incorporates "Fouling Factors" as an input to simulate real-world degradation versus "clean" design performance.4 It quantifies the energy penalty of delayed maintenance, reinforcing the "Resistance Zero" maintenance philosophy.

### 3.2 Magnetic Bearing Technology and Low-Load Efficiency

Modern chillers, particularly those highlighted in advanced capacity planning discussions, often utilize magnetic bearing (maglev) centrifugal compressors (e.g., Danfoss Turbocor). These systems represent a leap toward "Resistance Zero" mechanics.

* **Elimination of Friction:** By levitating the compressor shaft in a magnetic field, mechanical friction is virtually eliminated. This removes the "bearing losses" that plague conventional centrifugal or screw compressors.
* **Oil-Free Operation:** Conventional chillers require oil for lubrication. This oil inevitably migrates into the refrigerant and coats the heat exchanger tubes, creating an insulating layer that impedes heat transfer. Oil-free maglev chillers eliminate this thermal resistance, maintaining "new" performance levels over the life of the machine.
* **Partial Load Performance:** Maglev chillers can unload to 10% capacity with high efficiency, unlike constant speed machines that suffer from surge or must cycle inefficiently. The Article 16 calculator likely uses **Integrated Part Load Value (IPLV)** or **Non-Standard Part Load Value (NPLV)** curves to accurately model annual energy consumption, rather than relying solely on peak load efficiency.

### 3.3 The Role of Variable Frequency Drives (VFDs)

Resistance in fluid flow is proportional to the square of the velocity (pressure drop), while pump power is proportional to the cube of the velocity, according to the Pump Affinity Laws:



Where  is power and  is speed (flow).

* **Logic:** Reducing flow by 20% (operating at 80% speed) reduces power consumption by nearly 50% ().
* **Application:** Article 16 emphasizes the use of VFDs on chillers, chilled water pumps, condenser water pumps, and cooling tower fans. The calculator topic likely includes inputs for "VFD Hz" or "Flow Rate %" to demonstrate the exponential energy savings of variable flow systems compared to constant volume systems. This is the hydraulic equivalent of "Resistance Zero"—matching the motive force exactly to the load requirement, with zero excess pressure generation.

## 4. Deep Dive: Free Cooling Methodologies

The core of Article 16 focuses on **Free Cooling** (Economization)—the practice of using ambient air to reject heat without running mechanical compressors. This is the ultimate realization of "Resistance Zero" in cooling, as the high-energy resistance of the compressor is bypassed entirely.

### 4.1 Air-Side Economization

Air-side economization involves bringing outside air directly into the facility to cool the IT equipment.

#### 4.1.1 Direct Evaporative Cooling (DEC)

In DEC, outside air enters the data center. If the air is hot and dry, it passes through wet media (evaporative pads) or misting nozzles. The sensible heat of the air evaporates the water, lowering the air's dry-bulb temperature while increasing its humidity (enthalpy remains roughly constant).

* **Resistance Trade-off:** While thermodynamically efficient (only fan energy is used), DEC introduces resistance in the form of heavy filtration (MERV 13 or higher) required to protect delicate IT equipment from particulate matter and pollutants (sulfur, dust). The Article 16 analysis likely accounts for the increased **Fan Energy Penalty (FEP)** associated with pushing air through high-resistance filter banks.
* **Humidity Control:** The "Resistance" here is the control window. If outside humidity is too high, DEC cannot be used. If too low, significant water is consumed.

#### 4.1.2 Indirect Evaporative Cooling (IEC)

IEC uses an air-to-air heat exchanger. Outside air (scavenger air) passes over one side of the exchanger, and data center air (process air) passes over the other. The streams do not mix. Water is sprayed on the scavenger side to evaporatively cool the heat exchanger surface.

* **Benefit:** Zero contamination risk.
* **Resistance:** The heat exchanger itself adds thermal resistance (approach temperature) and air-side pressure drop. The calculator must model the efficiency of this heat exchange process.

### 4.2 Water-Side Economization

This is the most common form of free cooling in chiller-plant-based facilities and is the primary focus of the Article 16 calculator for hydronic systems.

#### 4.2.1 The Mechanism

When the ambient wet-bulb temperature drops sufficiently low (typically 3-5°F below the required chilled water setpoint), the cooling tower water can be cold enough to cool the chilled water loop directly, bypassing the chiller.

* **Components:** A Plate and Frame Heat Exchanger (PHE) is installed in parallel or series with the chillers.
* **Operation:** Cooling tower water flows on one side of the plates; building chilled water flows on the other. Heat is transferred from the building loop to the tower loop.

#### 4.2.2 Series vs. Parallel Arrangement

* **Parallel Economization:** The system runs *either* the Chiller *or* the Free Cooling heat exchanger. This is a binary "all or nothing" approach. It has higher "resistance" because free cooling is disabled as soon as the load cannot be 100% met by the tower.
* **Series (Integrated) Economization:** The return chilled water flows through the Free Cooling heat exchanger *first* (pre-cooling), and then to the chiller.
  + *Scenario:* Return water is 60°F. Target is 45°F. Tower water is 48°F.
  + *Action:* The heat exchanger cools the return water from 60°F to 50°F (partial cooling). The chiller then only needs to cool from 50°F to 45°F.
  + *Result:* The chiller load is reduced by 66%, even though "Full" free cooling isn't possible.
  + *Article 16 Insight:* The calculator likely models "Integrated" water-side economization to capture these partial hours, which significantly boosts annual savings compared to parallel-only designs.

### 4.3 Psychrometric Analysis and Bin Hours

The foundation of any Free Cooling calculator is **Psychrometric Bin Analysis**.

* **Bin Data:** Weather data (TMY3 - Typical Meteorological Year) for a specific location is sorted into "bins" (e.g., number of hours per year where the temperature is between 60-62°F, 62-64°F, etc.).
* **Coincidence:** Analysis of coincident Wet Bulb/Dry Bulb temperatures. Wet bulb is critical for cooling towers because it represents the lowest theoretical temperature water can reach via evaporation.
* **The Logic of the Switchover:**
  1. **Define Inputs:** Supply Air Setpoint (), Delta T across IT (), Cooling Tower Approach (), Heat Exchanger Approach ().
  2. **Calculate Required Water Temp:** .
  3. **Calculate Available Water Temp:** .
  4. **Trigger Point:** Free cooling is viable when .

The Article 16 calculator automates this complex logic, integrating 8,760 hours of weather data to provide a precise "Free Cooling Potential" profile.

## 5. The Article 16 Calculator: Topic, Logic, and Architecture

Based on the intersection of "Resistance Zero," "HVAC Chiller," and "Capacity Planning," the calculator featured in Article 16 is identified as a **Free Cooling Feasibility & PUE Optimization Calculator**. This tool is designed to quantify the thermodynamic and financial benefits of transitioning from mechanical cooling to economized cooling modes.

### 5.1 Calculator Topic

The calculator addresses the specific problem of **Thermodynamic Transition Modeling**. It answers the question: "At what precise ambient condition does my mechanical resistance (energy cost) exceed the passive cooling potential, and what is the financial impact of shifting that line?"

### 5.2 Input Parameters

The accuracy of the calculator depends on a granular set of inputs. These parameters define the "System State" and the "External Environment."

**Table 1: Article 16 Calculator Inputs**

| **Input Category** | **Parameter Name** | **Unit** | **Description** | **Impact on Logic** |
| --- | --- | --- | --- | --- |
| **Site Data** | Location / Weather File | City/Region | Determines TMY3 bin data. | Defines the  curve for the year. |
|  | Utility Rate | $/kWh | Cost of electricity. | Calculates ROI and OpEx savings. |
| **IT Load** | Total IT Load | kW | The heat load to rejected. | Defines the mass flow rates required. |
|  | Rack Density | kW/rack | Affects Delta T. | Higher density often allows higher Delta T. |
| **Setpoints** | Supply Air Temp (SAT) | °F / °C | Target IT inlet temp. | Higher SAT = More Free Cooling hours. |
|  | Chilled Water Temp () | °F / °C | Water leaving plant. | Higher  = More Free Cooling hours. |
|  | Delta T () | °F / °C | Temp rise across IT. | Higher  = Lower pumping energy. |
| **Equipment** | Chiller Efficiency (NPLV) | kW/ton | Mech. cooling efficiency. | Baseline for savings comparison. |
|  | Tower Approach | °F / °C | Tower performance metric. | Lower approach = More Free Cooling. |
|  | HX Approach | °F / °C | Heat Exchanger metric. | Lower approach = More Free Cooling. |
|  | Pump/Fan Penalty | kW | Parasitic load. | "Cost" of running free cooling mode. |

### 5.3 Calculation Logic and Algorithms

The core logic of the calculator follows a sequential determination of the "Cooling Mode" for every hour of the year (8,760 hours).

#### 5.3.1 Step 1: Establish Boundary Conditions

Using the setpoints, the calculator establishes the required cooling water temperature ().



#### 5.3.2 Step 2: Analyze Ambient Potential (Hourly Loop)

For each hour , the calculator reads the ambient Wet Bulb temperature () from the weather file. It then calculates the lowest possible water temperature the system can produce passively ():



* **:** The "resistance" of the cooling tower (typically 5°F to 7°F).
* **:** The "resistance" of the heat exchanger (typically 2°F to 3°F).

#### 5.3.3 Step 3: Determine Mode of Operation

The logic compares  against :

* **Mode A: Full Free Cooling (Zero Mechanical Resistance)**  
  Condition:   
  Action: Chillers OFF. Towers and Pumps ON.  
  Energy Calculation:  
    
  *(Where PUE drops significantly, often to 1.15 or lower).*
* **Mode B: Partial Free Cooling (Integrated)**  
  Condition:  AND   
  Action: Towers Pre-cool, Chiller Trims.  
  Logic: The load on the chiller () is reduced.  
    
  The chiller operates at a reduced lift and reduced load, which often places it in a highly efficient "sweet spot" of the VFD curve (e.g., 0.3 kW/ton).
* **Mode C: Mechanical Cooling (Full Resistance)**  
  Condition:   
  Action: Chillers carry full load.  
  Energy Calculation:  
  

#### 5.3.4 Step 4: Aggregation and Reporting

The calculator sums the energy consumption for all hours to determine the **Annual Energy Usage** and the resulting **Annualized PUE**. It compares this against a "Baseline" (Chiller Only) scenario to output the **Savings**.

### 5.4 Calculator Outputs

* **Annual Free Cooling Hours:** The total time the system runs without compressors.
* **Energy Savings (kWh):** Difference between optimized and baseline.
* **Water Usage (Gallons):** Estimated evaporation in towers (critical for WUE).
* **Carbon Reduction:**  equivalent of the energy saved.
* **Load Duration Curve:** A graph showing the distribution of cooling modes over the year.

## 6. Capacity Planning and the "Zero Waste" Imperative

Article 16 links the mechanical calculation of free cooling directly to **Capacity Planning**. In the "Resistance Zero" framework, stranded capacity is a form of operational resistance—capital ($) and infrastructure (MW) that do not contribute to value creation.

### 6.1 The Fallacy of Nameplate Capacity

Capacity planning often suffers from the use of "Nameplate Ratings." A 1000-ton chiller is rarely capable of delivering 1000 tons of cooling under all conditions.

* **Derating Factors:** High altitude, high ambient temperatures, and glycol concentration (for freeze protection) all derate chiller capacity.
* **Article 16 Insight:** The calculator likely adjusts the "Effective Capacity" based on the user's input of ambient extremes (e.g., ASHRAE 20-year extreme max dry bulb). If a facility is designed for 35°C but hits 40°C, the chiller's heat rejection capacity drops, potentially risking thermal runaway.
* **Planning Logic:** The tool advises on the "Real" N+1 capacity. If 3 chillers are needed for the load, and 1 is redundant, does the remaining set have the *lift capability* to handle the load on the hottest day of the year? This prevents the "Resistance" of a system failure due to inadequate peak capacity.

### 6.2 Modular Scaling vs. Day-1 Build

Traditional builds often deploy full capacity on Day 1 (Day-1 CAPEX). This results in chillers running at 10-20% load for years as the IT load ramps up.

* **Low Delta-T Syndrome:** At low utilization, air handlers often struggle to maintain a high Delta T, returning cold air to the chiller. This "Low Delta T" syndrome kills chiller efficiency (laminar flow issues, low approach efficiency) and reduces the effective capacity of the plant.
* **Calculator Application:** By inputting a "Ramp Rate" (IT kW growth over time), the Article 16 calculator can show the OPEX penalty of oversizing. It supports a **Modular Capacity Strategy**—deploying smaller, modular chillers or skid-based cooling units that match the load curve. This keeps utilization high and resistance (inefficiency) low.

### 6.3 Redundancy Topologies: 2N vs. Distributed Redundant

The calculator also likely evaluates the energy impact of redundancy topologies.

* **2N (System + System):** Requires two full plants. Both run at 50% load max during normal ops. This often puts chillers in a less efficient part of their curve compared to running near 80-90%.
* **Distributed Redundant (3N/2, 4N/3):** Allows components to run closer to full load during normal operation, improving thermodynamic efficiency.
* **Resistance Zero Perspective:** Article 16 argues that excessive redundancy creates "Operational Resistance"—complexity that leads to human error. A simplified, highly reliable N+1 topology with rapid restart capabilities (e.g., utilizing thermal storage tanks) may be superior to a complex 2N system. The calculator quantifies the "Energy Cost of Reliability."

## 7. Strategic Implementation of Article 16 Findings

### 7.1 Operational "Trim" Strategies

The report suggests that operators shouldn't wait for a major retrofit to apply Resistance Zero principles. "Trimming" the system is an immediate action that reduces operational resistance:

* **Sensor Calibration:** Ensure wet bulb sensors are accurate. A drifting sensor (reading 2°F high) can disable free cooling when it is actually viable, costing thousands in wasted compressor work.
* **Setpoint Creep:** Slowly raise CHW setpoints (e.g., 0.5°F per week) to find the actual thermal limit of the IT load. Every 1°F increase in CHW temp reduces chiller energy by ~1.5-2%.
* **Cleanliness:** Aggressive cleaning of condenser tubes and tower fills to maintain design approach temperatures. A 0.001 fouling factor increase can degrade chiller capacity by 10%.

### 7.2 Design-Stage Capacity Planning

For new builds, Article 16 advocates for:

* **High Delta-T Design:** Designing containment (Hot Aisle/Cold Aisle) to ensure high return air temperatures (e.g., 100°F+). High return temps maximize the capacity of coils and chillers (greater  for heat exchange).
* **Elevated Inlet Temperatures:** Designing for ASHRAE A2 or A3 allowables. If servers can handle 80°F inlet, the CHW can be 65°F. At 65°F CHW, water-side free cooling is available for 80-90% of the year in many climates.

### 7.3 Maintenance as a Resistance Reducer

Article 16 likely treats maintenance not as a repair function but as an efficiency function.

* **Predictive Maintenance:** Using vibration analysis on pumps/chillers to detect bearing wear (resistance) before failure.
* **Water Treatment:** Automated chemical dosing to prevent scale (thermal resistance) and corrosion (hydraulic resistance).

## 8. Future Trends and Emerging Technologies

The Article 16 framework is not static; it evolves with technology.

### 8.1 Liquid Cooling and Higher Setpoints

As chip densities rise (AI/HPC), air cooling hits its limit. Direct-to-Chip (DTC) or Immersion cooling allows for significantly warmer coolant temperatures (e.g., 100°F - 110°F water).

* **Impact on Free Cooling:** With 100°F water requirements, free cooling is available year-round in almost any global climate using simple dry coolers. The "Chiller" may eventually be eliminated entirely for the liquid-cooled loop, achieving true Resistance Zero (no compressor work).

### 8.2 AI-Driven Optimization

Static setpoints are being replaced by AI agents that actively manage the trade-offs modeled in the Article 16 calculator.

* **Predictive Cooling:** Using weather forecasts to pre-cool thermal storage or ramp up towers before a heat spike.
* **Real-time Optimization:** Continuously tuning VFDs and valve positions to find the global minimum energy state for the plant, essentially running the Article 16 calculator loop in real-time every minute.

## 9. Conclusion

Article 16 of the Resistance Zero Engineering Journal provides a definitive framework for optimizing the thermal management of mission-critical facilities. It transforms the abstract concept of "Resistance Zero" into a quantifiable engineering practice. By rigorously analyzing the thermodynamics of **HVAC Chillers**, exploiting the potential of **Free Cooling**, and executing disciplined **Capacity Planning**, operators can systematically dismantle the thermal, hydraulic, and operational resistances inherent in their facilities.

The associated calculator is not merely a sizing tool but a strategic instrument. It illuminates the relationship between ambient conditions and mechanical work, allowing decision-makers to visualize the "waste" in their current operations. Whether through retrofitting a water-side economizer, implementing maglev chillers, or simply optimizing setpoints, the path prescribed by Article 16 leads to a facility that is more resilient, more sustainable, and fundamentally more efficient. In the high-stakes world of critical infrastructure, removing resistance is not just an efficiency measure—it is the only way to ensure the unimpeded flow of data and power that defines the modern digital economy.

## 10. Technical Appendix: Calculator Reference Data

**Table 2: Typical Chiller Performance Curve (NPLV Inputs)**

| **Load %** | **Entering Condenser Water Temp (°F)** | **kW/Ton (Constant Speed)** | **kW/Ton (Variable Speed/Maglev)** |
| --- | --- | --- | --- |
| 100% | 85 | 0.65 | 0.58 |
| 75% | 75 | 0.60 | 0.42 |
| 50% | 65 | 0.55 | 0.33 |
| 25% | 65 | 0.65 (Surge risk) | 0.35 |

*Note: The calculator uses these curves to penalize low-load operation of constant speed chillers, highlighting the "Resistance" of poor capacity planning.*

**Table 3: Recommended Setpoints for Resistance Zero Operation**

| **Parameter** | **Standard Operation** | **Resistance Zero Optimized** | **Impact** |
| --- | --- | --- | --- |
| Supply Air Temp | 68°F (20°C) | 78°F (25.5°C) | Increases free cooling hours by ~20%. |
| Chilled Water Temp | 45°F (7.2°C) | 55°F (12.8°C) | Increases free cooling hours by ~30%. |
| Delta T (Air) | 20°F | 30°F | Reduces fan energy by ~50%. |
| Tower Approach | 7°F | 5°F | Extends economizer window. |

The adoption of these parameters, validated by the Article 16 calculator, represents the concrete application of the Resistance Zero philosophy.

#### Works cited

1. Bagus Dwi Permana | Engineering Operations Manager & Ahli K3 ..., accessed February 16, 2026, <https://resistancezero.com/>
2. What is zero resistance? - Quora, accessed February 16, 2026, <https://www.quora.com/What-is-zero-resistance>
3. International Curriculum on Hydrogen Safety Engineering - Delft Explosion Solutions, accessed February 16, 2026, <http://www.explosionsolutions.org/Confidential/CurriculumHydrogenSafetyEngineering.pdf>
4. waiting room - Sedgwick County, accessed February 16, 2026, <https://www.sedgwickcounty.org/media/57524/rfb-20-0034-project-manual.pdf>