Effective Use Of Evaporative Cooling For Industrial And Institutional/Office Facilities

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What Does It Take To Get You To Do That Which You Ought To Do?

- The fact is, there are really only two reasons why people make changes in the way they do things:
  - They are ***forced*** to change
  - It costs/hurts more ***not*** to change than to change

External Forces Affect The Way You Design/Operate Your Facilities

- Executive Order 13123
- ASHRAE Standard 62 .1- 2004
- ASHRAE Standard 90.1 - 2004
- LEED™ Certification and Green Building
- Indoor Air/Environmental Quality Concerns
- Escalating Energy Costs
- Chemical/Biological Warfare
- Global Climate Change Treaty

High Performance HVAC Benefits

- Innovative engineering and design can:
  - Improve system performance
  - Reduce first costs
  - Reduce operating costs
  - Reduce energy use
  - Reduce life cycle costs
  - Improve IAQ and IEQ
  - Minimize CBW concerns

What Is A "High Performance" HVAC System?

- Combines energy efficiency and indoor environmental quality
- Energy efficiency
  - Minimizes use of virgin/raw energy sources
- Indoor environmental quality (IEQ)
  - Optimizes indoor air quality (IAQ)
  - Provides stable thermal comfort
- New construction offers greater opportunities, but retrofits of existing buildings can be easily achieved to provide significant benefits for both the owner/operator and the occupants

IEQ/IAQ
Why Are They More Important Than Ever?

- Findings from many studies indicate that:
  - Many health problems are linked to poor IAQ
  - Inadequate ventilation is a major cause
  - Mold, germs and contaminants spread by mechanical recirculation systems are a major cause
  - Poor humidity control is a contributing factor
  - Poor building pressurization is a contributing factor
  - Improved IEQ/IAQ results in:
    - lower absentee rates
    - reduced worker turnover
    - increased productivity

Is There A Conflict Between Energy Efficiency And IEQ/IAQ?

- NO!
- High performance hybrid HVAC equipment and designs can eliminate the outdoor air penalty and thus eliminate any potential conflict between energy efficiency and indoor air quality.

High Performance Hybrid HVAC
Some Design Strategies

- Dual Path Ventilation
  - Separate ventilation from heating /cooling
  - Eliminate terminal reheat
- Energy Recovery
  - Recycle cooling/heating energy
  - Reduce the use of new energy resources
- Displacement Ventilation
  - Permits smaller 100% OSA systems
  - Increased ventilation effectiveness
  - Reduces energy use

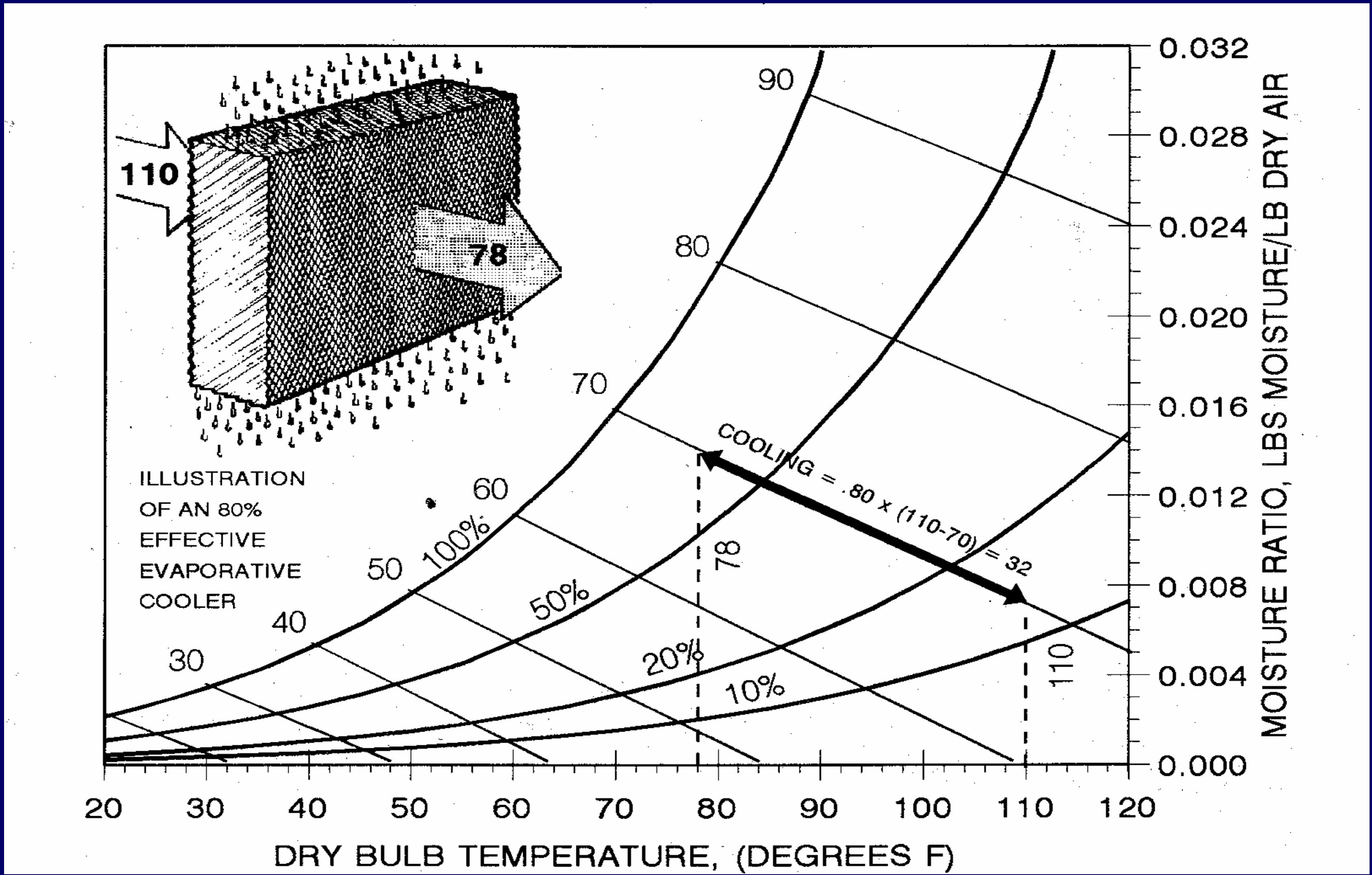
...More Design Strategies

- Process Synergy
- Multi-Functional Use
  - Use individual components for multiple tasks
  - Reduces parasitic losses
- Evaporative Cooling
  - Reduces (or eliminates) mechanical cooling ***and*** heating plants
  - Provides low cost humidification
- Thermal Storage
  - Reduces mechanical cooling plant
  - Reduces energy costs

Evaporative Cooling
A Very Powerful Tool

- Evaporative cooling technologies form the backbone of energy efficient high performance hybrid HVAC systems
- There are **2** forms of evaporative cooling
  - **Direct**
    - Draws warm air through a wetted media
  - **Indirect**
    - Utilizes an air-to-air plate heat exchanger to separate the supply air from the water used for evaporation
    - Uses a secondary air stream to reject heat from the evaporation process

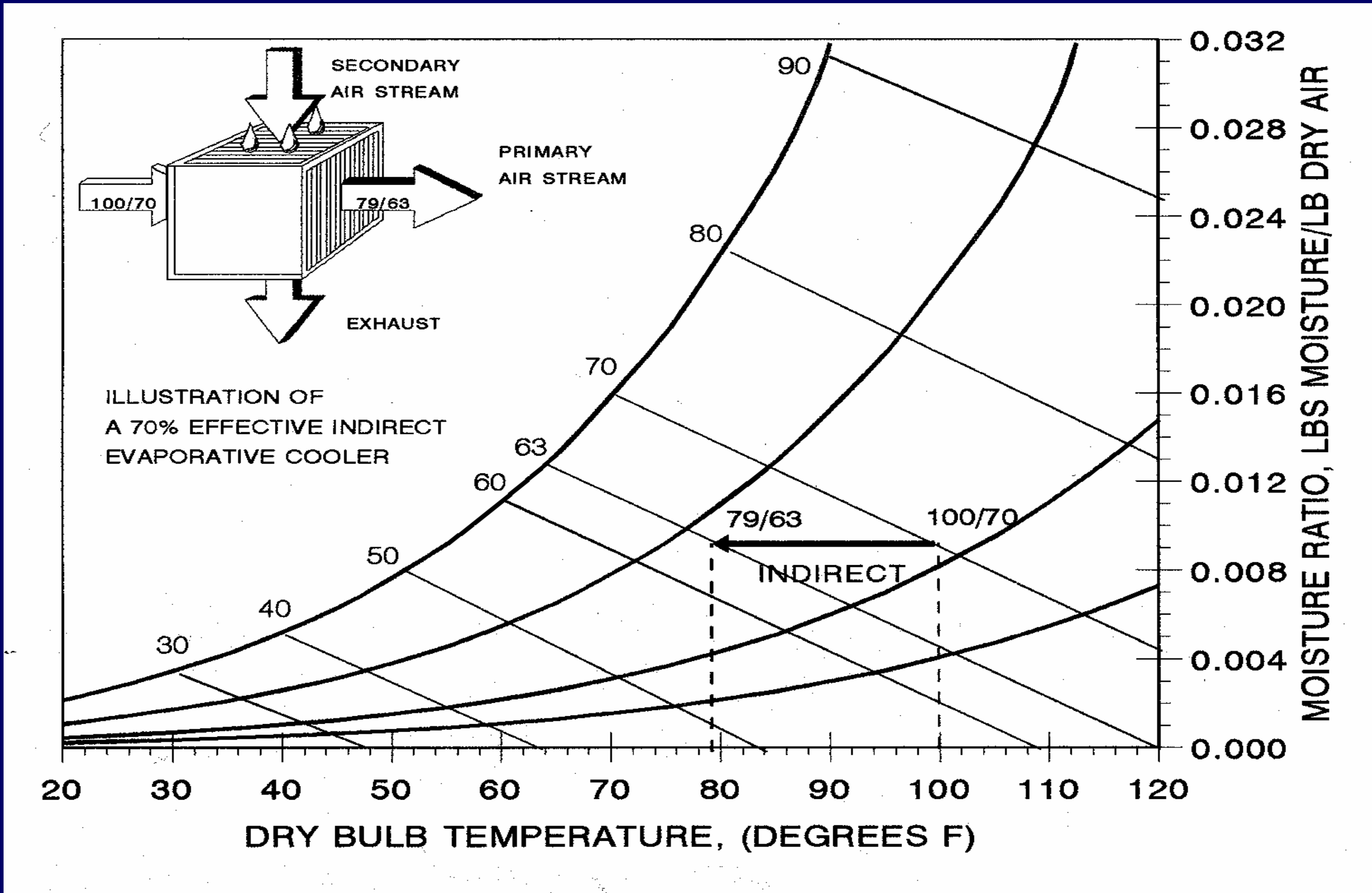
Direct Evaporative Cooling



Direct Evaporative Cooling

- ***Effectiveness*** is defined by the following equation:
  - * $\mathbf{E = (TI_{db} - TD_{db}) \div (TI_{db} - TI_{wb})}$
- ***Discharge Temperature*** can be determined by the following equation:
  - * $\mathbf{TD_{db} = TI_{db} - [E \times (TI_{db} - TI_{wb})]}$
- Factors affecting effectiveness are:
  - * type of media
  - * depth of media
  - * face velocity

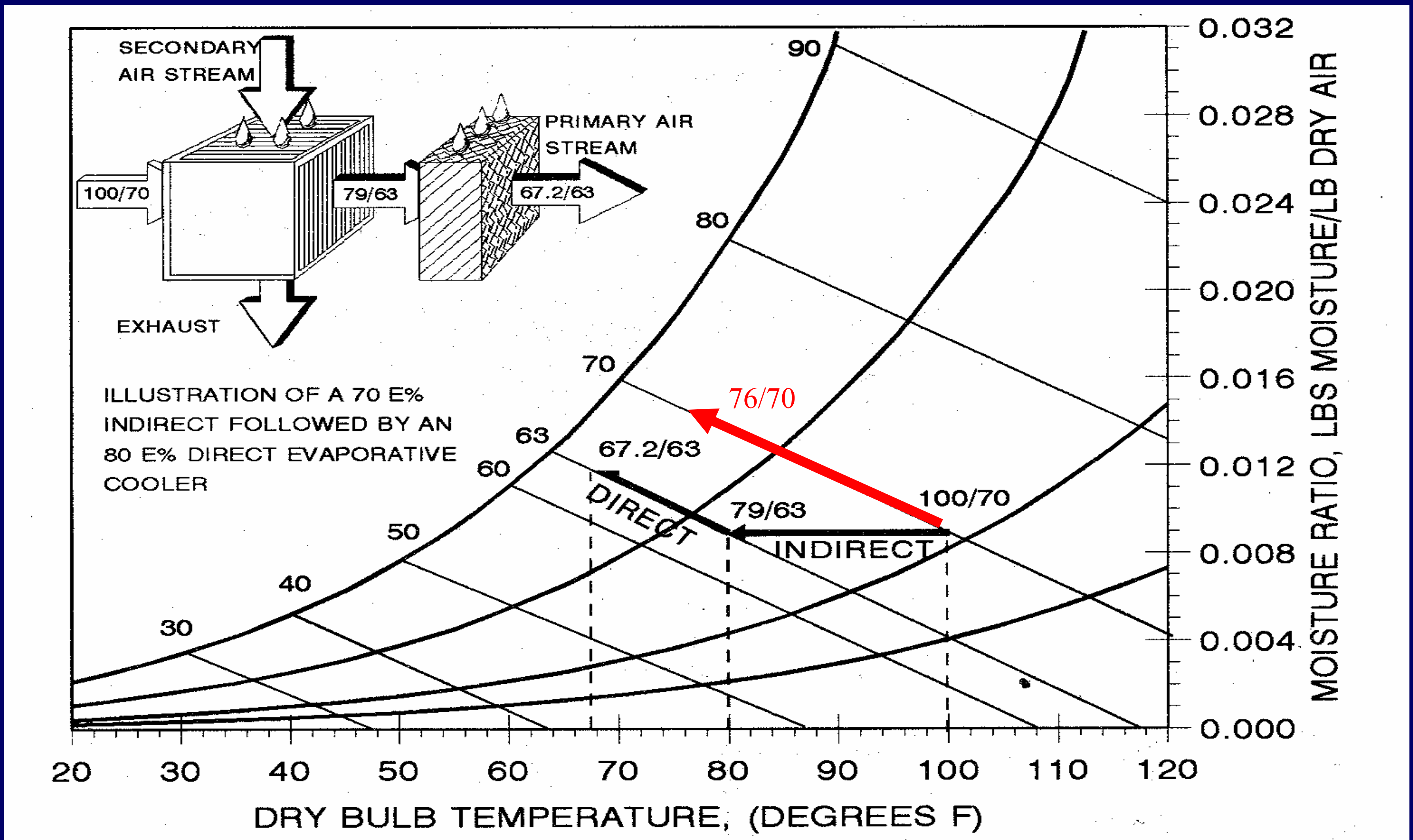
Indirect Evaporative Cooling



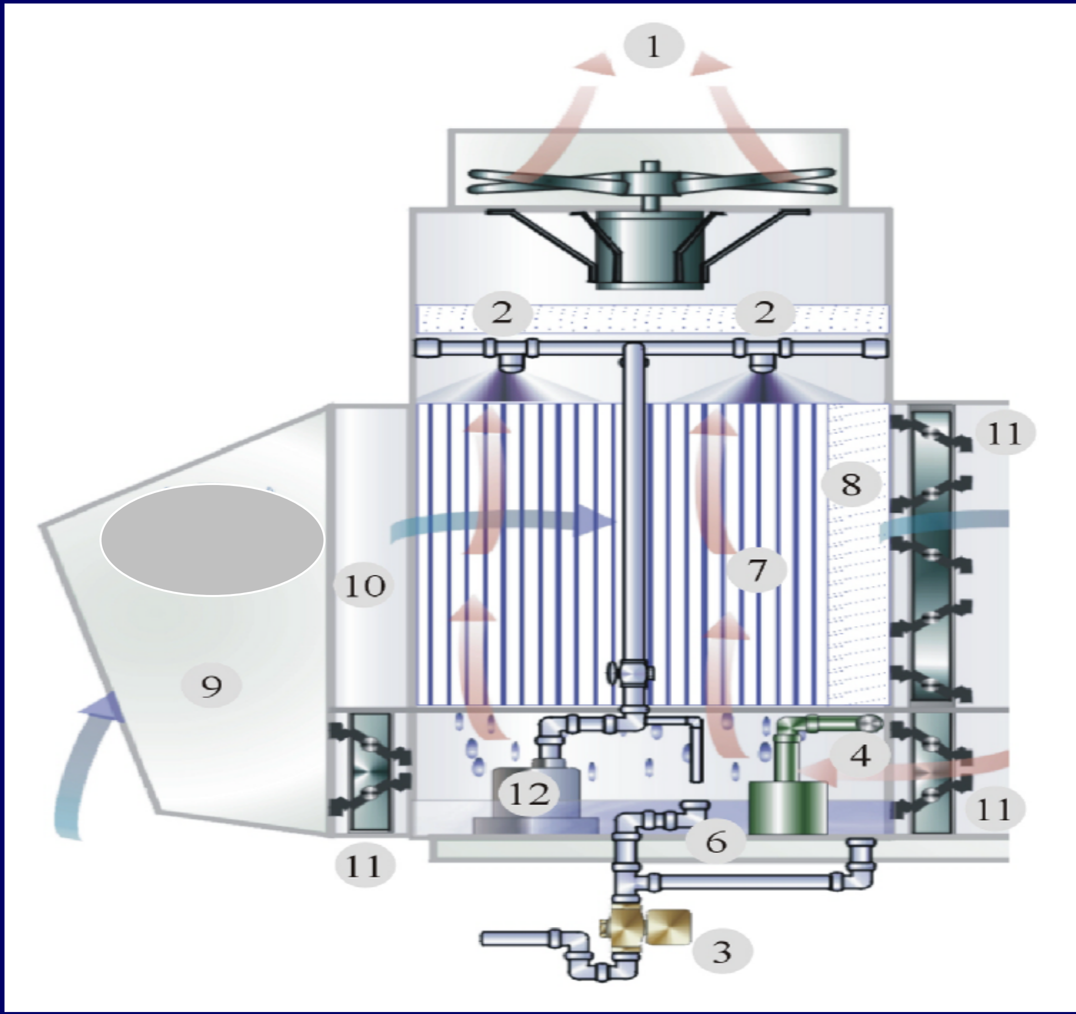
Indirect Evaporative Cooling

- ***Effectiveness*** is defined by the following equation:
  - * $E = (TI_{db} - TD_{db}) \div (TI_{db} - TIS_{wb})$
- ***Discharge Temperature*** can be determined by the following equation:
  - * $TD_{db} = TI_{db} - [E \times (TI_{db} - TIS_{wb})]$
- Factors affecting effectiveness are:
  - * type of heat exchanger
  - * supply and secondary air mass flow ratios
  - * use of outside air vs. building exhaust as the secondary/scavenger air source

Indirect/Direct (Two-Stage) Evaporative Cooling



Typical Indirect Module



1) SECONDARY FAN

2) NOZZLE SPRAY HEADER

3) DRAIN SOLENOID

4) SUPPLY WATER VALVE

6) OVERFLOW DRAIN

7) INDIRECT HEAT EXCHANGER

8) DIRECT SECTION (Optional)

9) INLET HOOD (Optional)

10) INLET FILTER (Optional)

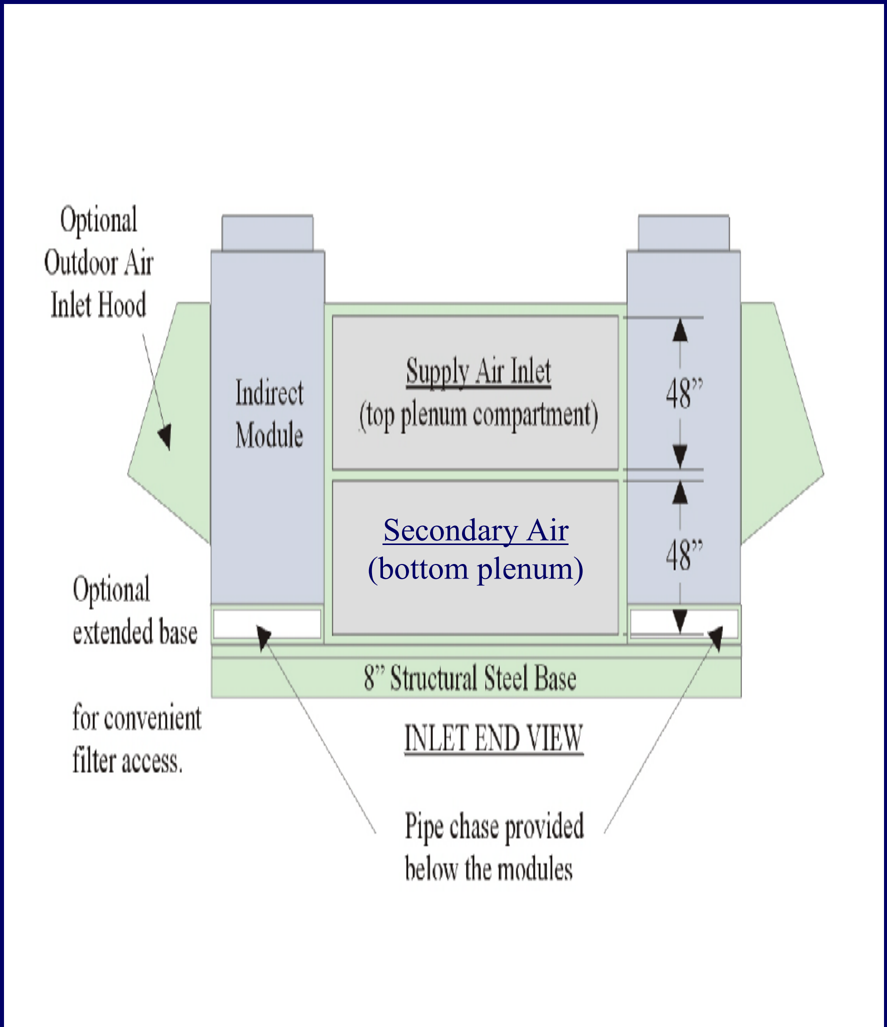
11) CONTROL DAMPERS (Optional - used to allow either building exhaust or outdoor air to be used as secondary air)

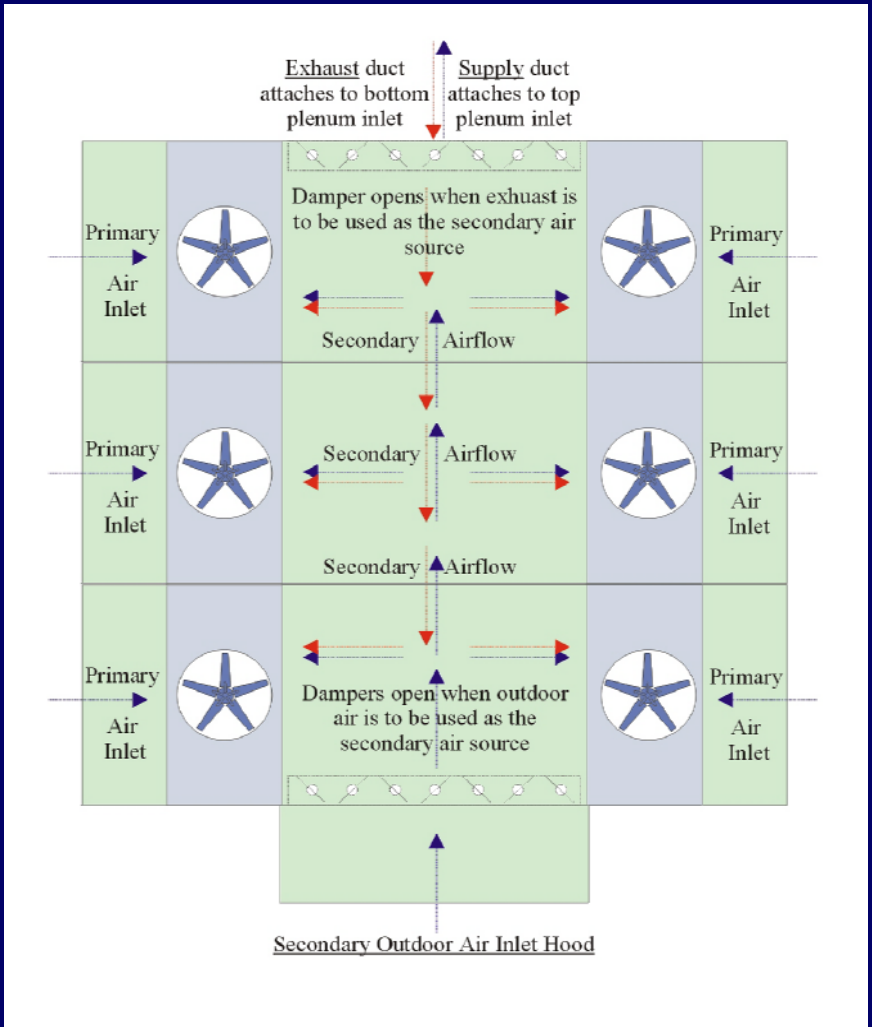
12) RECIRCULATING PUMP

Typical Indirect Module

1,000 - 15,000 CFM

Multiple Indirect Modules





Up To 90,000 CFM

Multi-Module Unit

45,000 CFM Unit

Evaporative Cooling Performance

- Low Wet Bulb Climate
  - OSA 97/68
  - Direct 71/68
  - Indirect (OSA) 75/61
  - Indirect/Direct 62/61
  - Indirect (BESA) 72/60
- High Wet Bulb Climate
  - OSA 97/76
  - Direct 78/76
  - Indirect (OSA) 81/71
  - Indirect/Direct 72/71
  - Indirect (BESA) 72/69

Performance Chart (Low Wet Bulb Area)

SACRAMENTO, CALIFORNIA

Performance of Evaporative Cooling and Heat Recovery Technologies

Ambient OSA DB/WB	Hours/ Year	DIRECT	INDIRECT OSA as Secondary Air	INDIRECT Bldg. Exhaust as Secondary Air	INDIRECT /DIRECT OSA as Secondary Air
107/70 (34.1)	7	74/70	79/61 (27.2)	74/59 (25.9)	63/61
102/70 (43.1)	59	73/70	78/63 (28.7)	73/61 (27.2)	65/63
97/68 (32.5)	144	71/68	75/61 (27.2)	72/60 (26.5)	62/61
92/66 (30.9)	242	69/66	72/60 (26.5)	70/59 (25.9)	61/60
87/65 (30.1)	301	67/65	70/59 (25.9)	69/59 (25.9)	60/59
82/63 (27.3)	397	65/63	68/58 (25.2)	68/58 (25.2)	59/58
77/61 (27.2)	497	63/61	65/57 (24.7)		58/57
72/59 (25.9)	641	60/59	62/55 (23.4)		56/55
67/57 (24.7)	821	58/57	60/54 (22.7)		55/54
62/54 (22.7)	1086	55/54	56/52 (21.5)		53/52

The above discharge temperatures (°F) are based on the following:

1. 75% Indirect Evaporative Effectiveness
2. 90% Direct Evaporative Effectiveness
3. 60% Heat Recovery Effectiveness
4. 75°F Building Exhaust Dry Bulb Temperature (Heat Recovery)
5. 63°F Building Exhaust Wet Bulb Temperature (Cooling)
6. DB = Dry Bulb Temperature
7. WB = Wet Bulb Temperature
8. OSA = Outside Air
9. ( ) Indicates Enthalpy Of Air

Performance Chart (High Wet Bulb Area)

CHICAGO, ILLINOIS

Performance of Evaporative Cooling and Heat Recovery Technologies

Ambient OSA DB/WB	Hours/ Year	DIRECT	INDIRECT OSA as Secondary Air	INDIRECT Bldg. Exhaust as Secondary Air	INDIRECT /DIRECT OSA as Secondary Air	HEAT RECOVERY
97/76 (39.5)	6	78/76	81/71 (35.0)	71/69 (33.3)	72/71	
92/74 (37.7)	58	76/74	78/70 (34.1)	70/68 (32.5)	71/70	
87/72 (35.9)	165	73/72	76/69 (33.3)	69/67 (31.7)	70/69	
82/70 (34.1)	324	71/70	73/67 (31.7)	68/66 (30.9)	68/67	
77/67 (31.7)	487	68/67	70/65 (30.1)	67/64 (29.4)	66/65	
72/64 (29.5)	681	65/64	66/62 (27.9)	65/6227.9)	63/62	
67/61 (27.2)	759	62/61	63/59 (25.9)	64/60 (26.5)	60/59	
62/57 (24.7)	700	58/57	60/56 (24.0)		57/56	
57/52 (21.5)	604	53/52	53/50 (20.3)		51/50	
52/47 (18.8)	581	48/47	48/45 17.7)		46/45	66
47/43	565					64
42/38	572					62
37/34	725					60
32/30	869					58
27/25	589					56
22/21	371					54
17/16	231					52
12/11	164					50
7/6	115					48
2/1	89					46
-3	53					44
-8	27					42
-13	11					40
-17	2					38

Performance Chart (Very High Wet Bulb Area)

BATON ROUGE, LOUISIANA

Performance of Evaporative Cooling and Heat Recovery Technologies

Ambient OSA DB/WB	Hours/ Year	DIRECT	INDIRECT OSA as Secondary Air	INDIRECT Bldg. Exhaust as Secondary Air	INDIRECT /DIRECT OSA as Secondary Air	HEAT RECOVERY
97/78 (41.7)	13	80/78	83/74 (37.7)	72/71 (35.0)	75/74	
92/76 (39.5)	211	78/76	80/73 (36.8)	70/69 (33.3)	74/73	
87/75 (38.6)	464	76/75	78/72 (35.9)	69/69 (33.3)	73/72	
82/72 (35.9)	984	73/72	75/70 (34.1)	68/68 (32.5)	71/70	
77/70 (34.1)	1214	71/70	72/68 (32.5)	67/67 (31.7)	69/68	
72/67 (31.7)	1517	68/67	68/66 (30.9)	65/65 (30.1)	66/65	
67/62 (27.9)	916	63/62	63/61 (27.3)		62/61	
62/58 (25.2)	878	59/58	59/57 (24.7)		58/57	
57/52 (21.5)	677	53/52	53/50 (20.3)		51/50	
52/47 (18.8)	601	48/47	48/45 (17.7)		46/45	66
47/43	543					64
42/39	296					62
37/34	249					60
32/30	171					58
27/25	22					56
22/23	4					54

Industrial Spaces

- Industrial facilities are particularly susceptible to problems related to heat and IAQ during extended periods of the year
  - Heat stress
  - Increased down time
  - Increased accidents and absenteeism
  - Quality control problems
  - Reduced productivity

What Are The Adverse Affects Of Heat?

NASA Report CR-1205-1 (Heat Stress)

Effective Temperature	75	80	85	90	95	100	105
Loss in Work Output	3%	8%	18%	29%	45%	62%	79%
Loss in Accuracy	-	5%	40%	300%	700%	-	-

So, What Is The Usual Solution?

- Use make-up air units to increase ventilation and make up for process exhaust (most of these units do not cool the outside air)
- Open up the doors and windows
- Bring out the floor fans

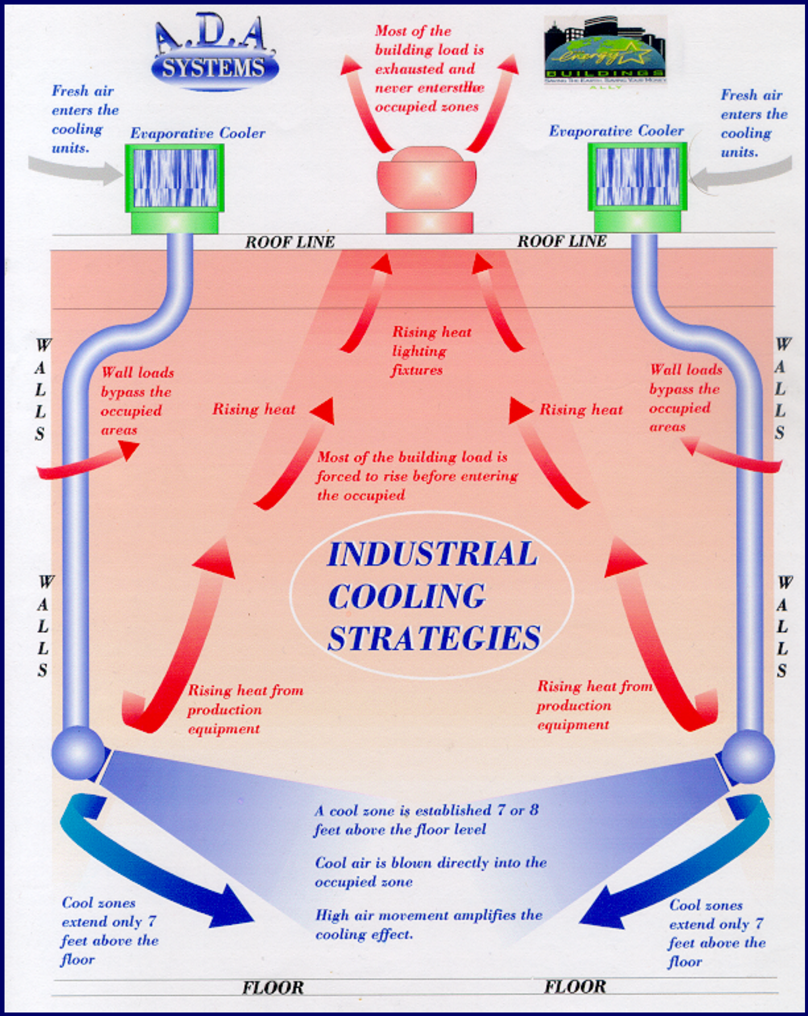
- This may help…but does not effectively address heat stress!

And, The Best Solution Is...

- ACGIH has established guidelines for reducing heat stress, including:
  - Increased rates of ventilation
  - **<u>Evaporative cooling of ventilation air</u>**
  - Displacement ventilation with stratification
  - Increased fluid intake

Industrial Cooling Strategies

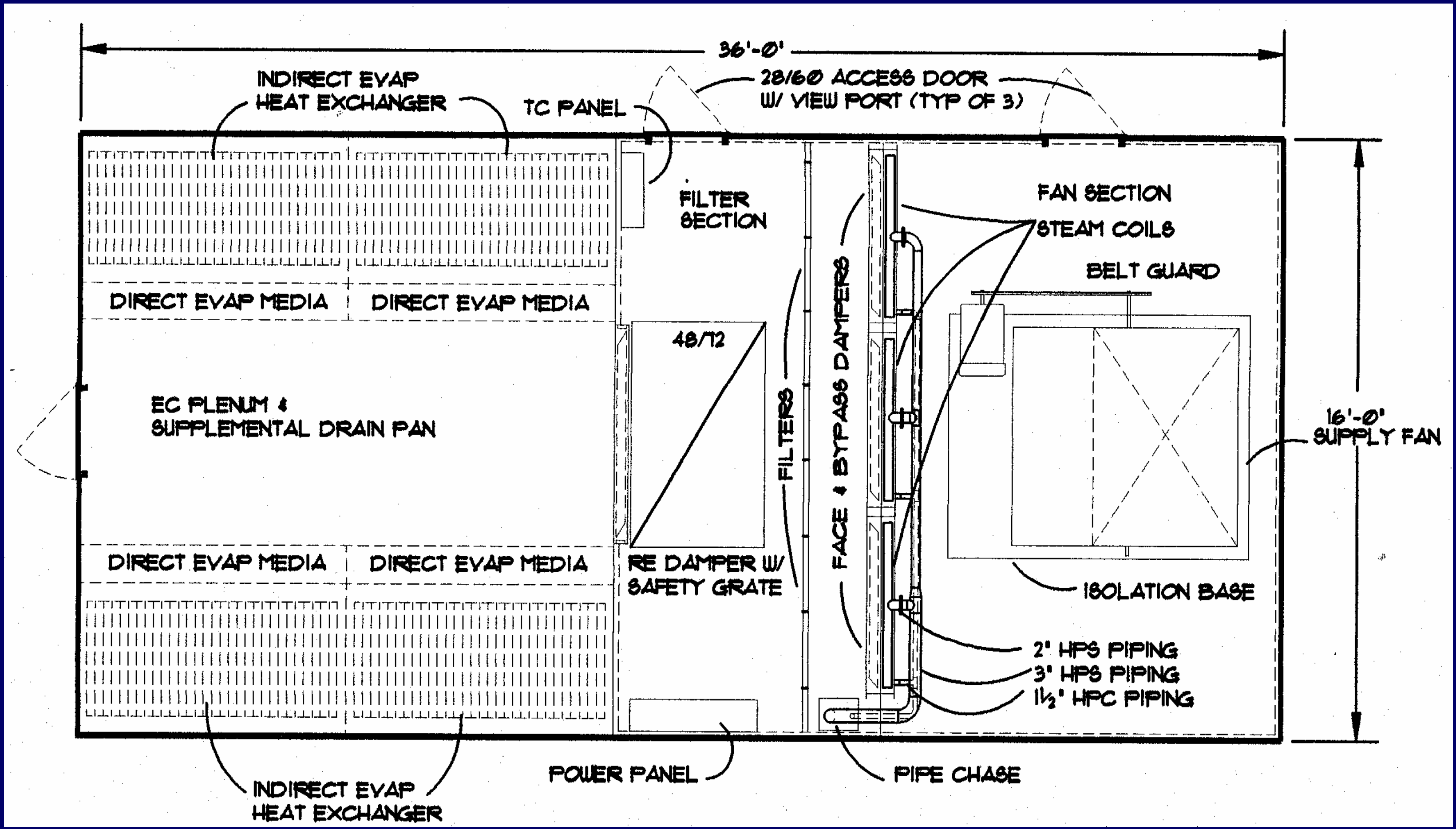
- Strategies to increase the effectiveness of evaporative cooling:
  - Displacement Ventilation
  - Stratification
  - Spot Cooling
  - Adjustable Diffusers



Industrial Cooling
Case Study 1

- CLIENT: Indianapolis Wood Veneer Manufacturer
- PROBLEM: Excessive Heat (>100^{o}F)
- GOAL: Low Cost Relief Cooling
- SOLUTION:
  - Indirect/Direct Evaporative Cooling
  - Eliminated The Proposed 1,800-Ton Chilled Water System
  - $2M vs $4.5M First Cost

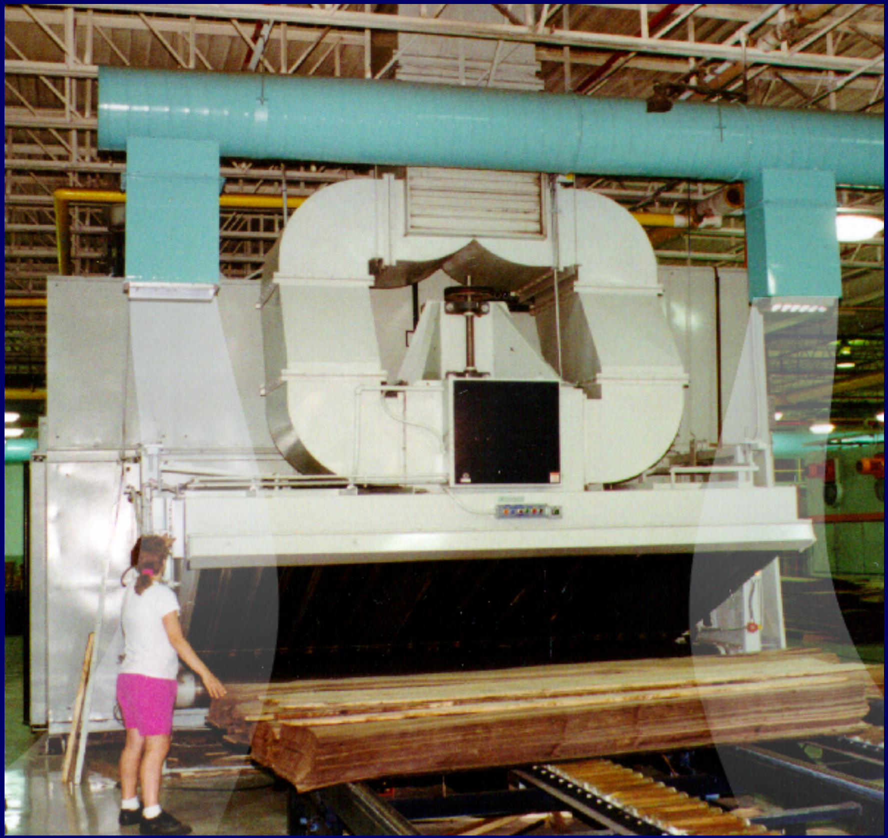
Industrial Cooling
Case Study 1



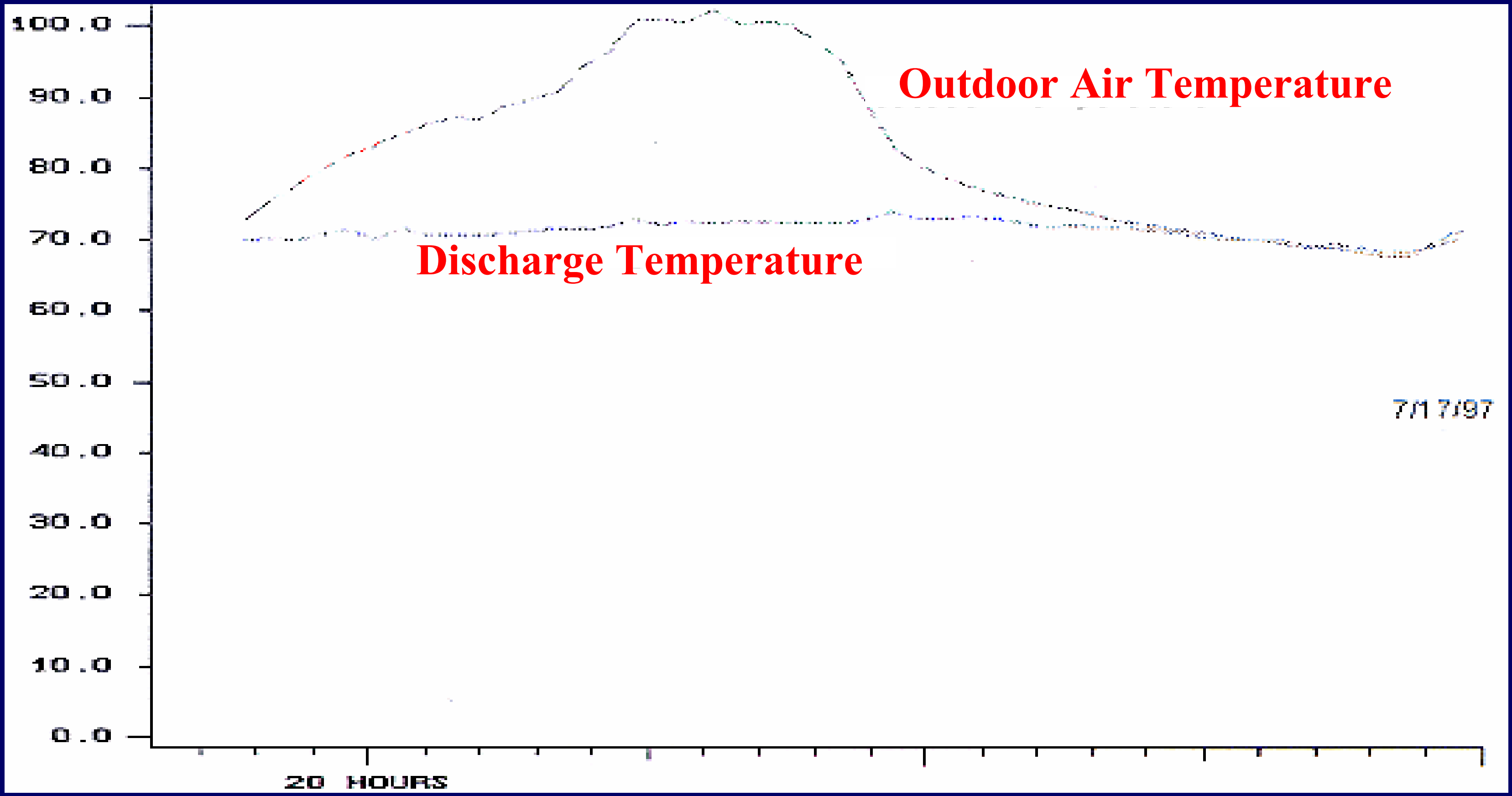
62,000 CFM Air Handler (1 of 4)

Industrial Cooling
Case Study 1

- Displacement Ventilation
- Spot Cooling
  - Establishes a cool zone
  - ***Feels*** like air conditioning
- Adjustable Diffusers



Industrial Cooling
Case Study 1



Field Temperature Recording

Industrial Cooling
Indirect With Chiller And Heat Recovery

- An Indirect evaporative pre-cooler can be used to reduce the size of a new chilled water system, or can be used to reduce the outside air load on an existing system.
- When used for energy (heat) recovery in winter operations, that same indirect unit can pre-heat the outside air.

Industrial Cooling
Case Study 2

- CLIENT: Chicago Printing Company
- PROBLEM: Undercapacity Chilled Water Plant
- GOAL: Avoid Increasing Chiller Plant
- SOLUTION:
  - Indirect Evaporative Pre-Cooler
  - Avoided Doubling The Chilled Water Plant Size
  - Desired Space Conditions Regained

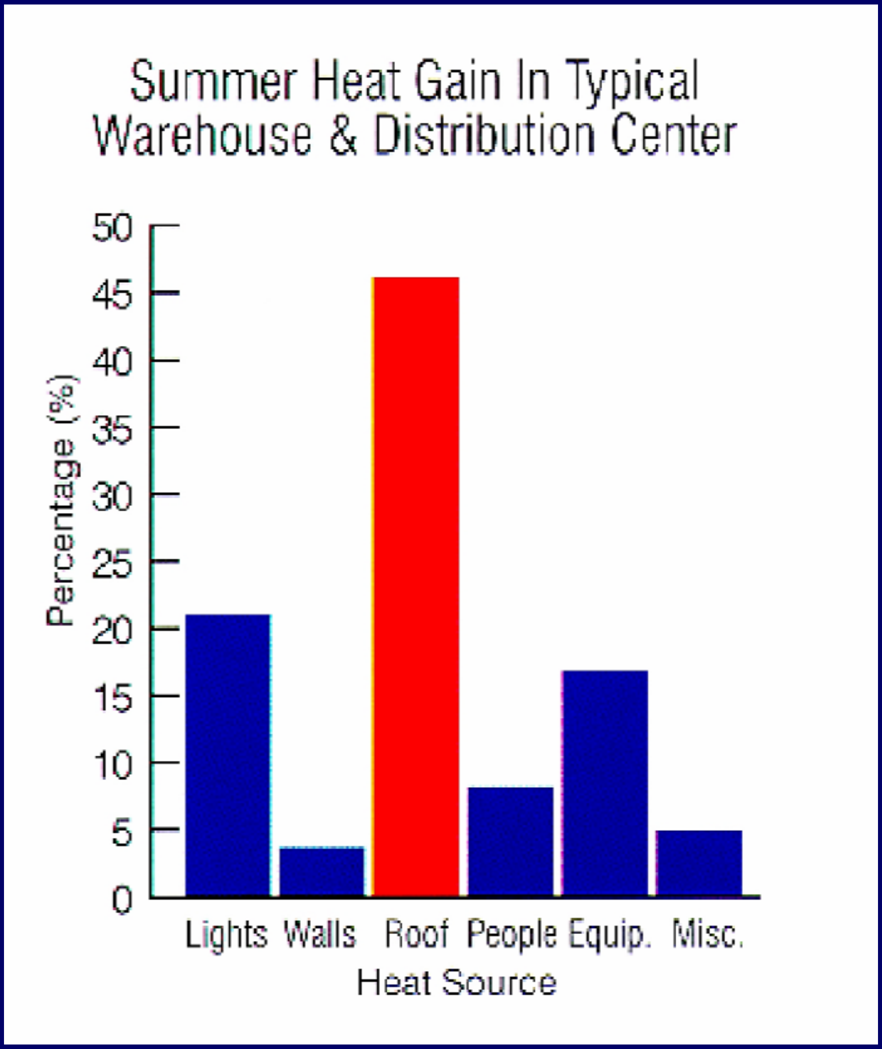
Industrial Cooling
Case Study 2

Before: 18,000 CFM OSA Intake

After: 18,000 CFM Indirect Evaporative Pre-Cooler

Industrial Cooling: Roof Misting

- Roof load heat gains are substantial
- Internal heat gains rise dramatically
- **Roof Misting** can drop the roof temperature up to 50°F
- Every 1.5 gallons of water that is evaporated absorbs more than 12,000 BTUs (a **ton** of cooling)



Industrial Cooling: Roof Misting

- **Roof Misting** can virtually eliminate the roof load
- Non-air conditioned buildings can lower space conditions **8^{o}F to 12^{o}F**
- Air conditioned buildings will reduce the load on the roof-top units and increase their performance
- Can extend the roof life by up to 50%

Institutional/Office Applications High Performance Hybrid HVAC

- The **Regenerative Double Duct™** is a hybrid, multi-component/function design that is proving to be one of the most energy efficient HVAC systems available. Its major components are:
  - **Indirect Evaporative Cooler (IDEC)**
    - First stage cooling
    - First stage heating
    - Limited capacity to act as a cooling tower
  - **Direct Evaporative Cooler (DEC)**
    - Direct evaporative cooling (when conditions permit)
    - Air filtration/scrubbing
    - Humidification

High Performance Hybrid HVAC

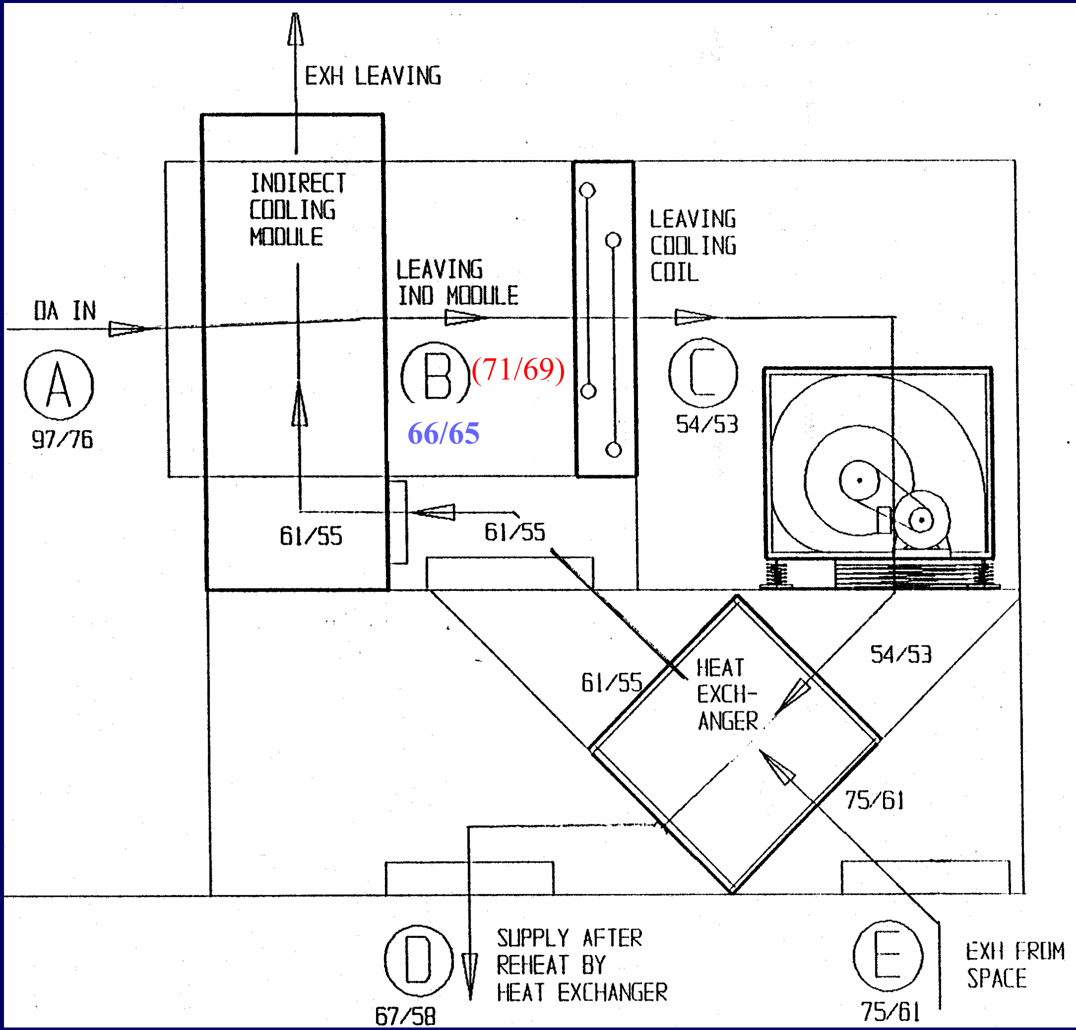
- **Secondary Plate-And-Frame Heat Exchanger (HX)**
  - Provides heating for the hot deck
  - Sub-cools building exhaust
- **Thermal Energy Storage**
  - Makes ice during less expensive time of day
  - Flattens out the demand curve
  - Downsizes the chilled water plant
- **Chilled Water**
  - Supplemental cooling
  - Supplemental dehumidification
- **Boilers**
  - Perimeter heating
  - Supplemental heating

High Performance Hybrid HVAC

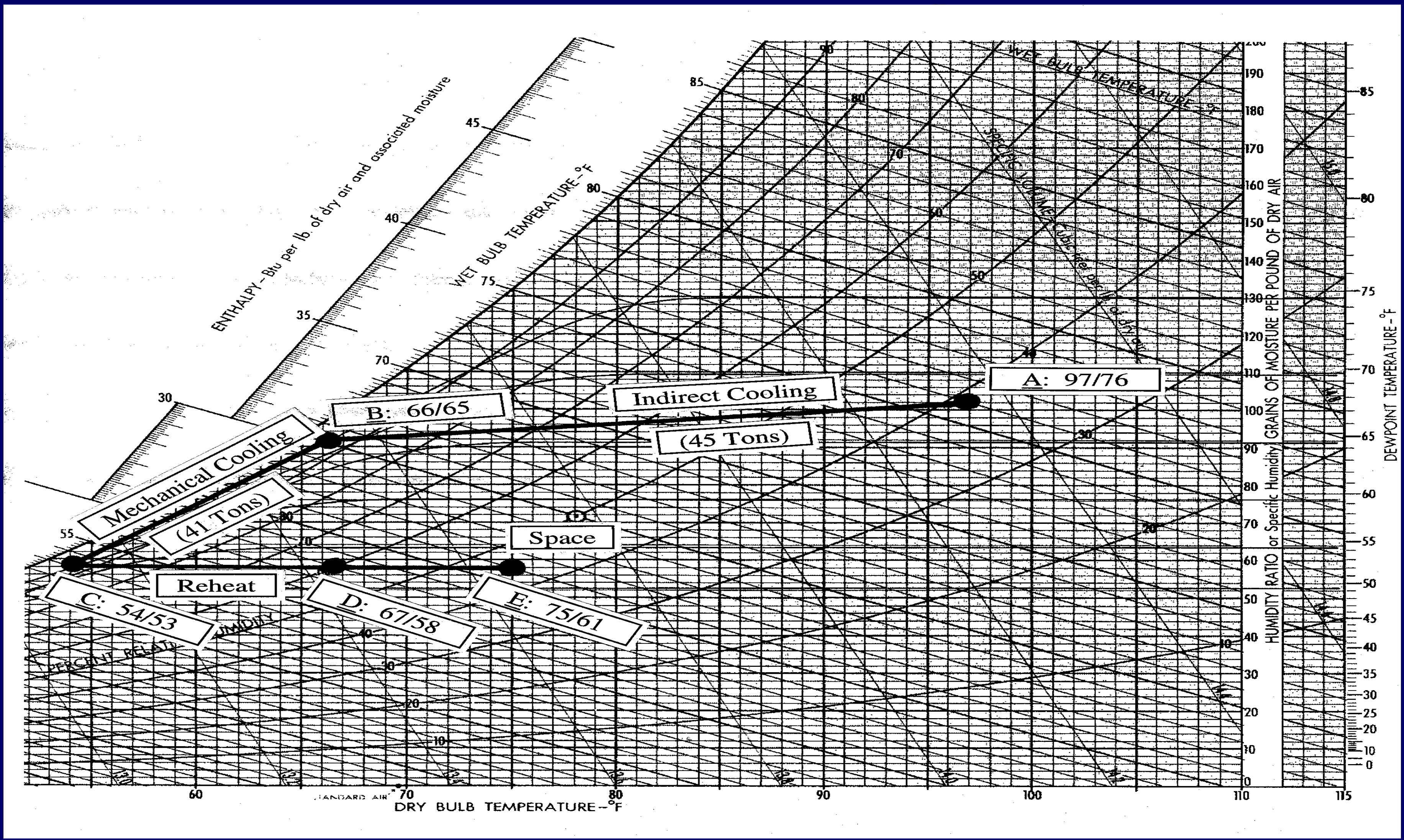
- **Heating Coil**
  - Pre-heat (on building exhaust)
  - Supplemental heat
  - Defrost (for IDEC)
- **Filtration**
  - Supply
  - Exhaust
- **Water Treatment**
  - Ozonation
  - Mechanical (non-chemical)
  - Filtration
- **Building Automation System (Controls)**

High Performance HVAC
Low Energy Reheat

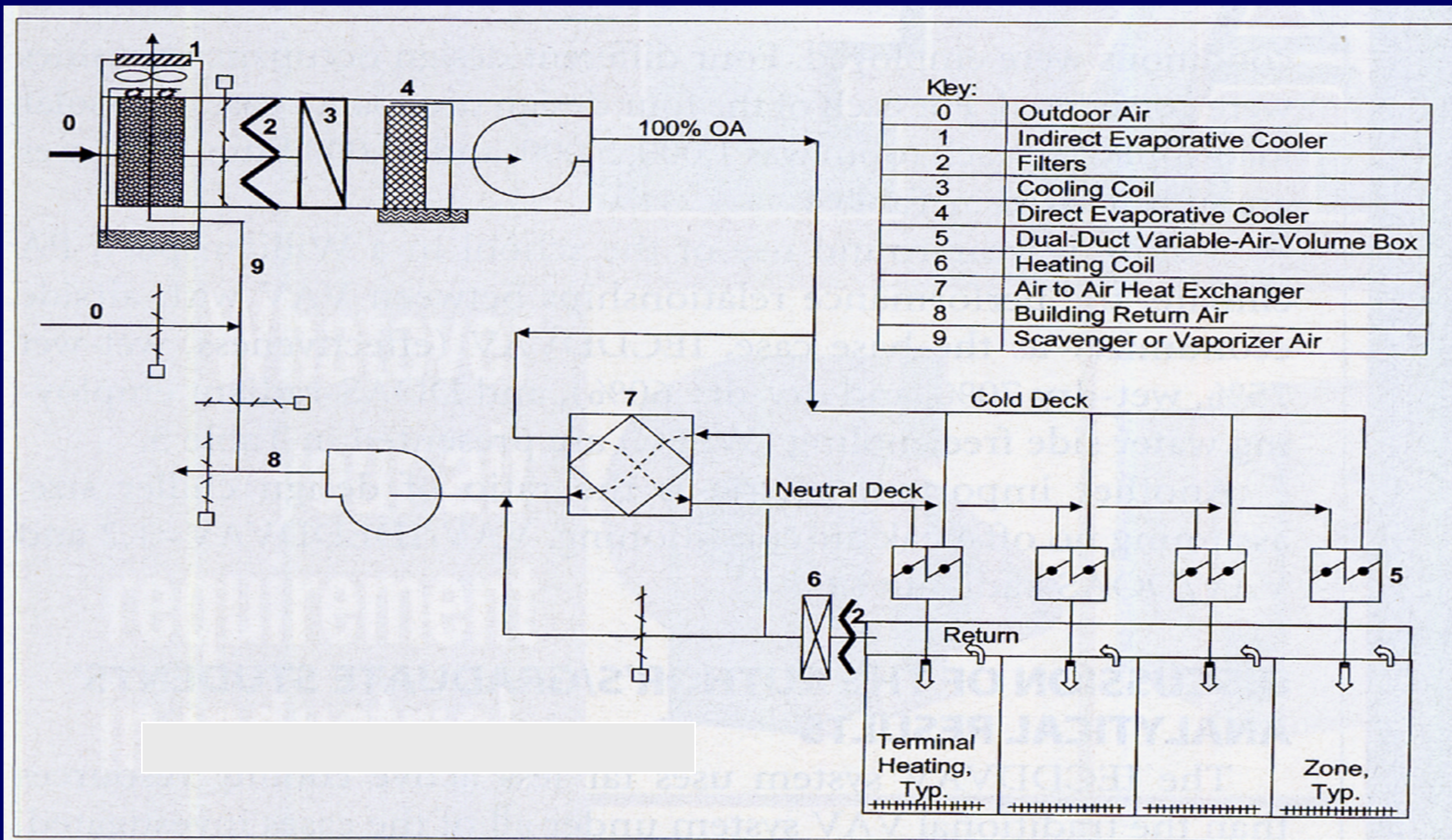
- Facilities with high OSA needs often require expensive reheat
- Components of a low energy reheat system:
  - Indirect evaporative pre-cooler
  - Mechanical cooling coil
  - Secondary heat exchanger



High Performance HVAC
Low Energy Reheat



High Performance Hybrid HVAC System Schematic

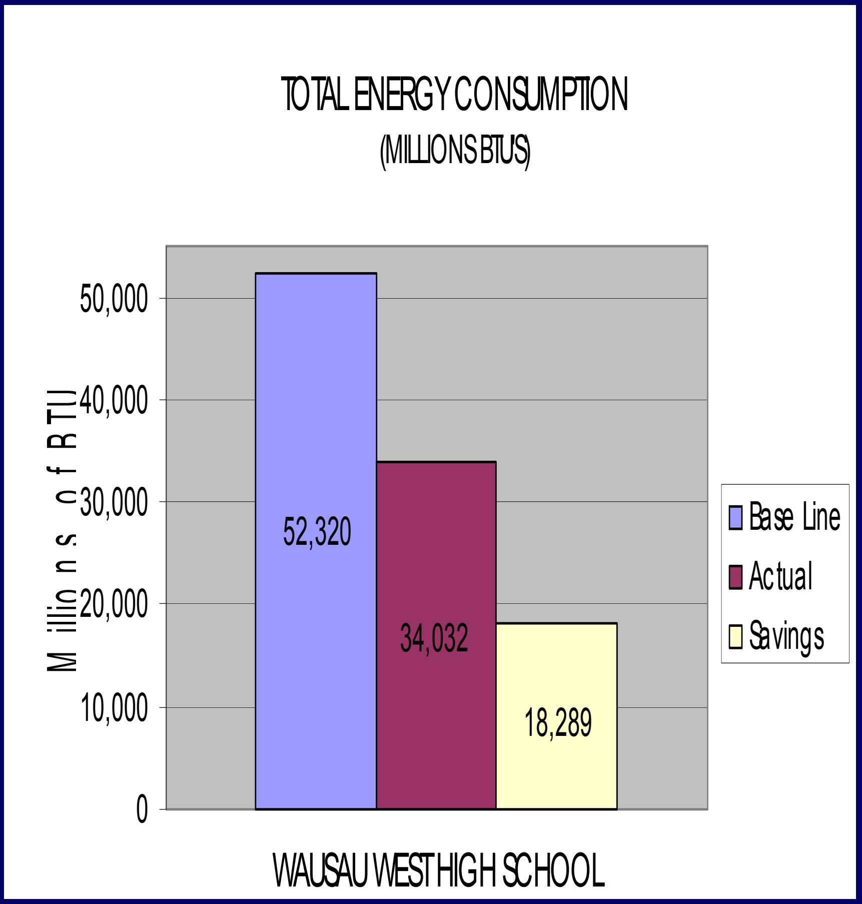


High Performance Hybrid HVAC Case Study 1

- Wausau West High School Wausau, WI
- Problems they were facing:
  - Expensive retrofit of existing chiller and boiler plants
  - Severe indoor air quality problems
  - Non-compliance with Standard 62
  - Rising energy costs

Eliminate The "Energy Penalty" For 100% OSA

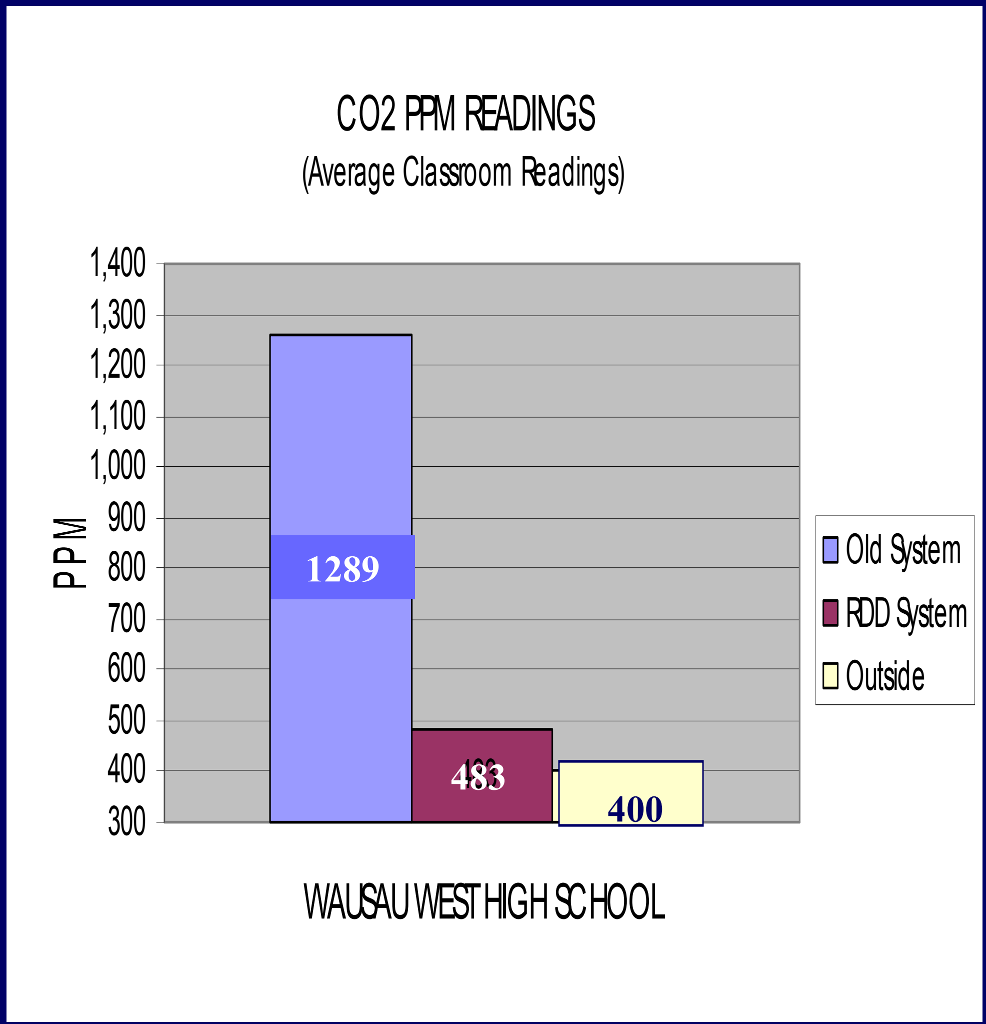
- "Base Line" energy consumption based on the former HVAC system that utilized **minimum outside air** and recirculated a majority of existing building air
- "Actual" energy consumption based on the new **100% outside air** HVAC system



29.3% Energy Cost Reduction

Good Things Happen When Bad Things Are Not Recirculated

- ASHRAE Standard 62.1-2004 uses an indoor to outdoor differential concentration not greater than 700 ppm of CO_2 as an indicator of acceptable indoor air quality
- Classroom CO_2 reduced by <u>**262%**</u>
- **What are the implications for CBW defensive HVAC designs?**



Wausau West High School Retrofit Profile

- 275,000 S/F
- 100% OSA (No Recirculation When Occupied)
- 100% Air Conditioned
- 70 Tons (Nominal) Chilled Water Plant
  - **91% Reduction From Proposed Retrofit**
- 7 MMBH Boiler Plant (100% Redundancy)
  - **60% Reduction From Old Boiler Plant**
- Total Building Energy Cost:
  - **29.3% Reduction**

Wausau West High School

IDEC Units

Wausau West High School

70-Ton Chiller

7MMBH Boiler Plant

Wausau West High School

DEC Unit

Ozone Water Treatment

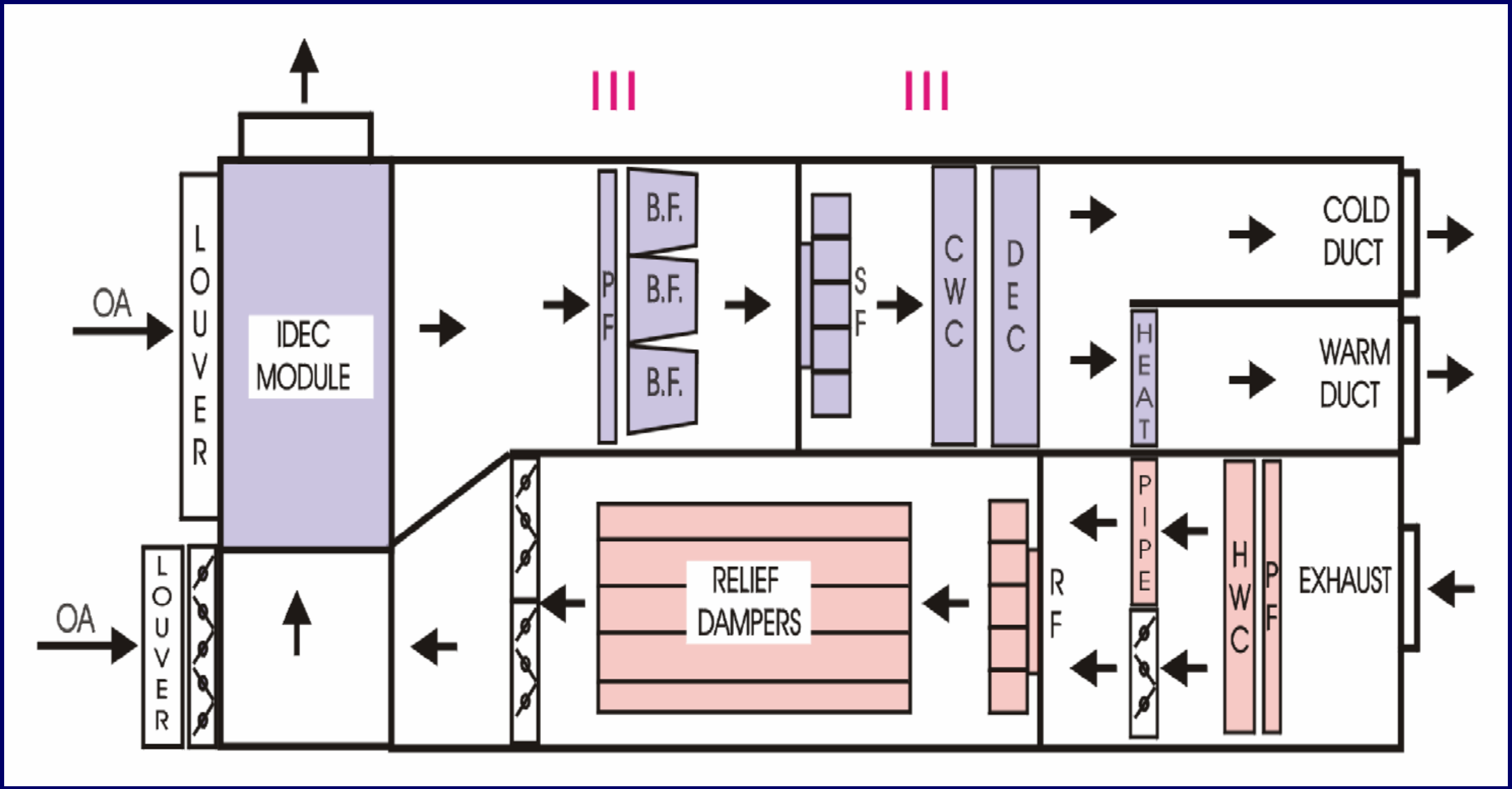
Wausau East High School
New Construction Profile

- 334,000 S/F
- 100% OSA (No Recirculation When Occupied)
- 100% Air Conditioned
- 0.6 CFM Per S/F
- 220 Tons (Nominal) Chilled Water Plant
- 6 MMBH Boiler Plant (100% Redundancy)
- Total Building Energy Usage: $0.68 Per S/F
  - State Average: $1.34 Per S/F

High Performance Hybrid HVAC Unitary Systems

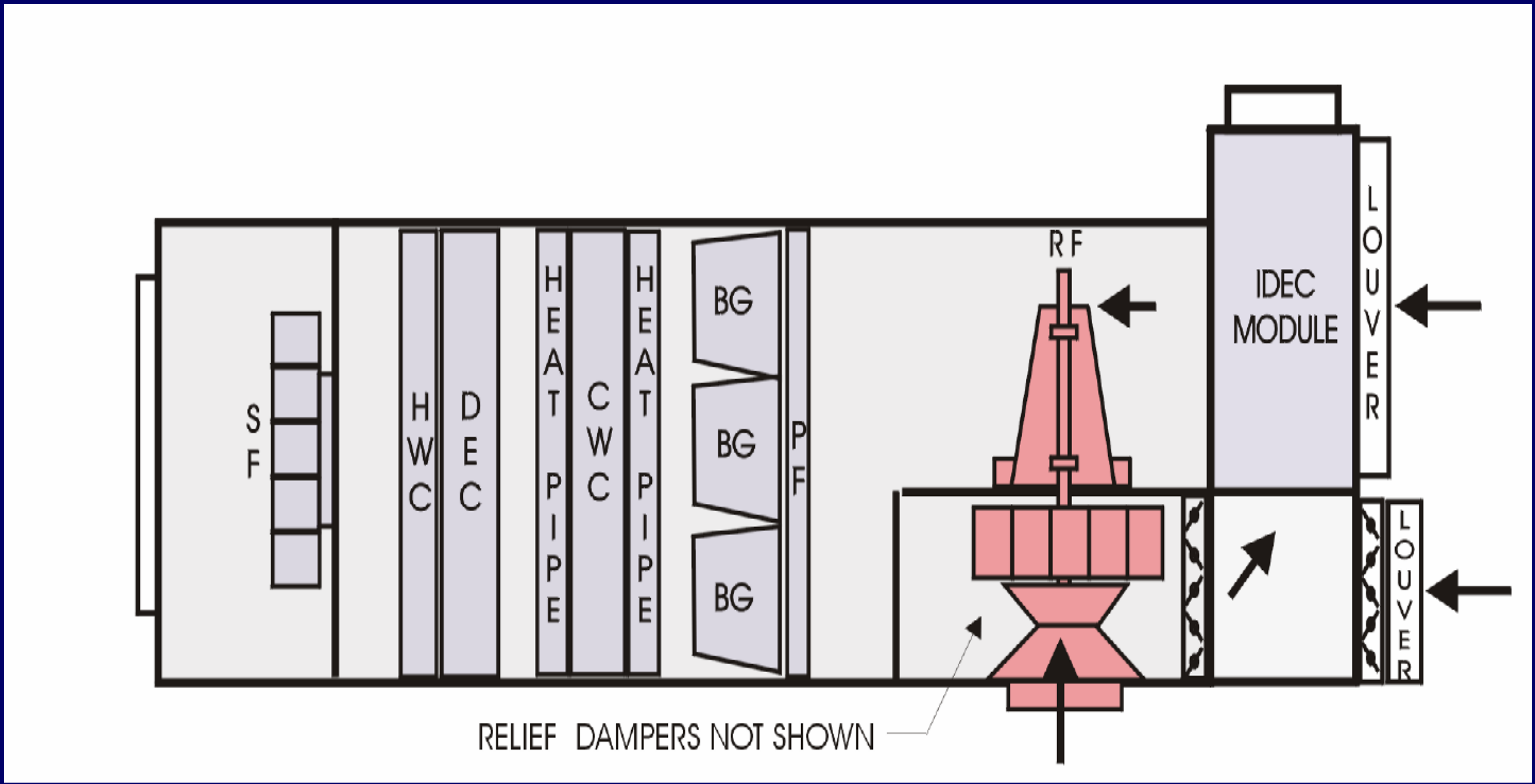
- Roof-top units can be designed with many of the same components and efficiencies of the built-up systems
  - Indirect evaporative precooling/preheating
  - Direct evaporative cooling/humidification
  - Evaporative condenser
  - Downsized centrifugal compressor and cooling coil
  - Downsized hot water coil or furnace
  - Dual duct and single duct configurations

High Performance Hybrid HVAC
Unitary Systems



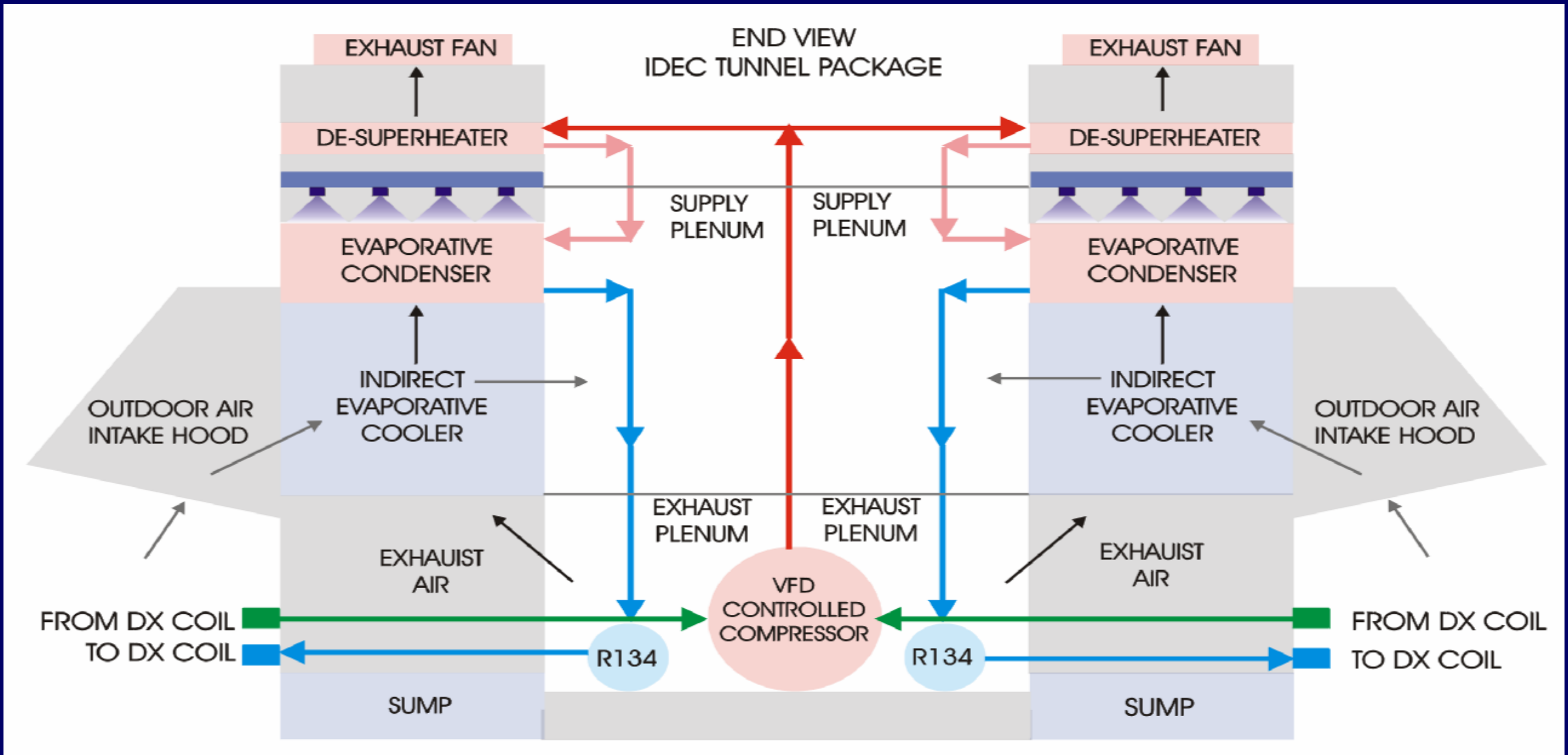
Dual Duct Unitary System

High Performance Hybrid HVAC
Unitary Systems



Single Duct Unitary System

High Performance Hybrid HVAC Unitary Systems



Refrigeration System EER's in the **20's**

Total System EER's in the **50's**

Evaporative Cooling
Does It Waste Water?

- So, everything sounds great, but…aren't we supposed to be conserving water for better sustainability?
- Absolutely…and evaporative cooling does!
- Evaporative based hybrid systems, when taking into account power plant point of production water usage:
  - Use about the same amount of water as an air cooled system
  - Use less water than a water cooled system
  - Use a lot less water than a ground source heat pump system

Conclusions

- Classical HVAC system strategies and equipment are not meeting your needs:
  - They are constructed around energy intensive processes
  - Recirculation compromises IAQ and energy efficiency
- In seeking a solution, avoid "one solution fits all" thinking. This leads to the "cookie cutter" approach to design so prevalent in the HVAC industry.
- Truly green HVAC systems are attainable with simple technologies that are readily available.

Conclusions

- Benefits of these green systems:
  - Competitive construction/first costs
  - Improved indoor air quality
  - ***Significantly*** reduced energy consumption/costs
  - Smaller heating/cooling plants
  - Easy to maintain
  - Economic solution for the CBW problem
- In short, a "win-win-win" solution for a tough problem!

Questions And Comments

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