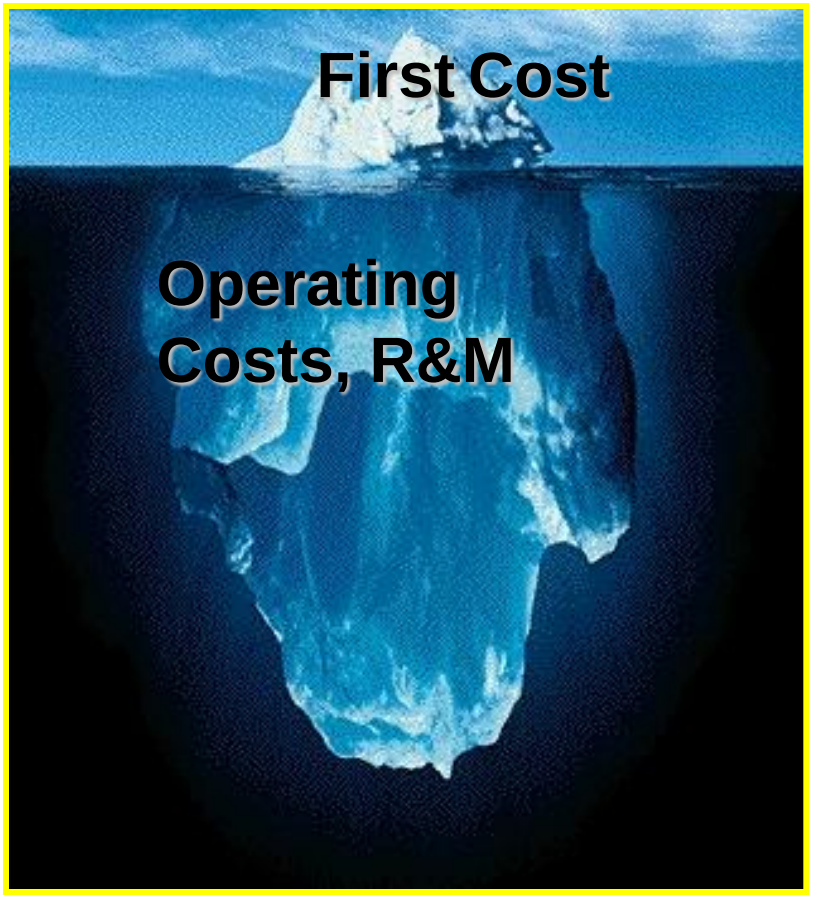
ENERGY EFFICIENCY: FORCING A NEW BUSINESS MODEL IN CHILLERS AND CHILLED WATER PLANTS

Progressive Energy Summit,
Weston FL 2010

Roger Richmond-Smith
Chairman
Smardt Chiller Group Inc

SMARDT

Chiller life cycle costs



Key aspects of the problem

- Traditional “iceberg” model stresses lowest first cost for chillers
- Major costs arise for owners after labor warranty expires - a problem for owners while chiller companies make 150% annual EBITDA from high-margin service and replacement parts
- Certification, legislation and utility incentives have institutionalized the problem

SMARDT

Key aspects of the problem

- Traditional chiller efficiencies calculated at 100% load (only relevant less than 4% of annual operating hours)
- Traditional capacity over-sized by 20%, as safety margin
- Traditional chiller condemned to operate inefficiently 100% of the time
- Net result: traditional chiller specification and business model is obsolete
- New chiller business model required

SMARDT

Buildings – a large business sector, traditionally slow to change

- *Construction of buildings contributes over 800 billion (now 1.8 trillion) to the US economy, and over 10 million jobs. The industry is large, fragmented and energy-indifferent.*
- *Over 50% of the total energy consumed by this sector, primarily in HVAC, is wasted*

- Laurence Berkeley Laboratory, 1998

State energy incentives rarely used*

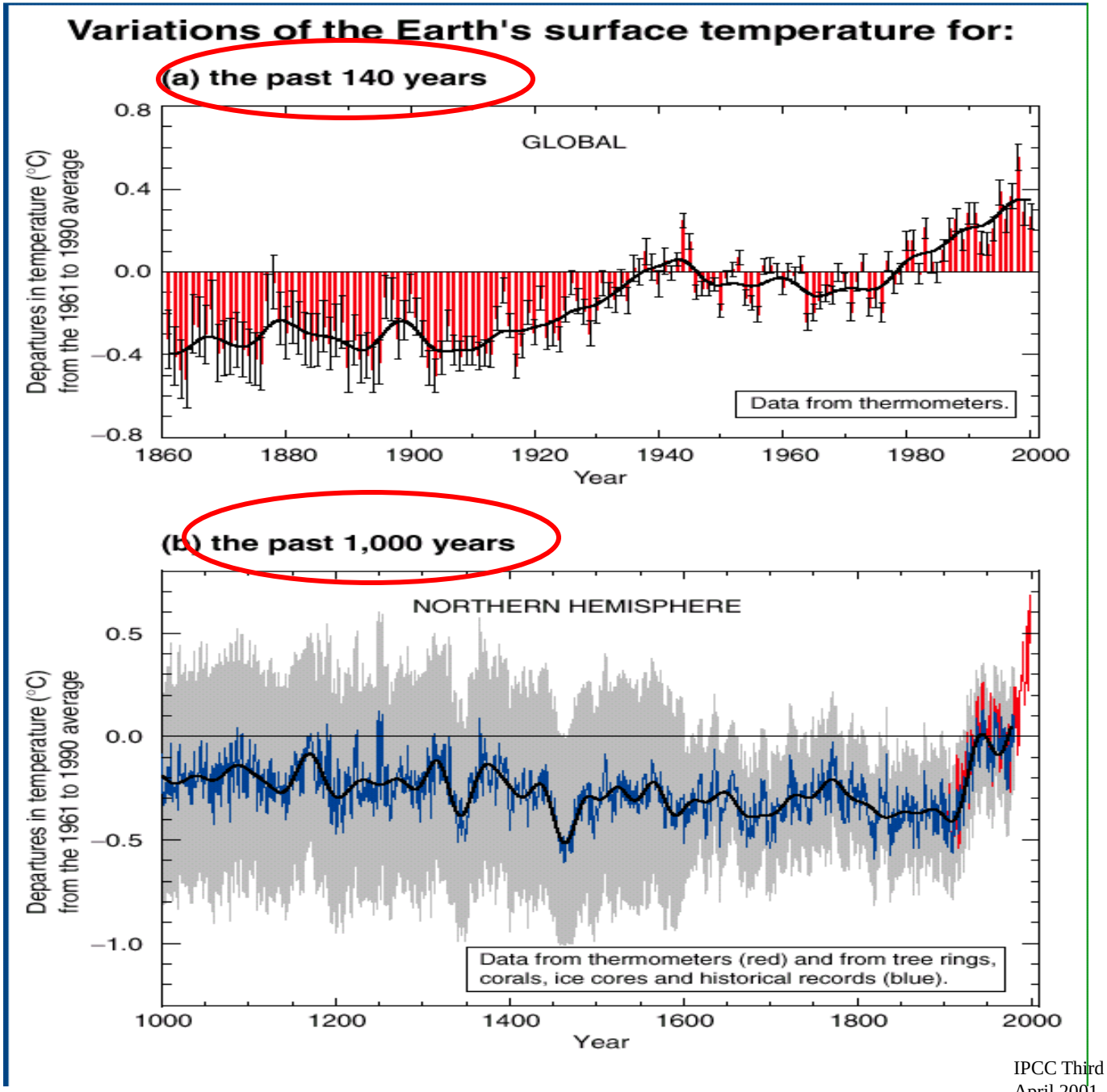
- Many states offer rich incentives for energy efficiency, but they are rarely used. A May 2009 study by the University of California Energy Institute* reported a participation rate of less than 0.1%.
- BOMA reports that 85% of commercial and institutional building owners currently find ESCO's "too complex to deal with".
- Major opportunities (proprietary market research) exist in funding EE upgrades over 10 years with simplified processing.

Major, irreversible market change imminent

- World chiller market USD 6.7 B (BSRIA 2009)
- Climate change and carbon footprints driving rapid expansion of its energy efficiency segment (now 30%+)
- Energy efficiency, energy pricing, sustainability now fixed on corporate and government agendas
- New technology (e.g. oil-free centrifugal compression) increasingly recognized as market-changing

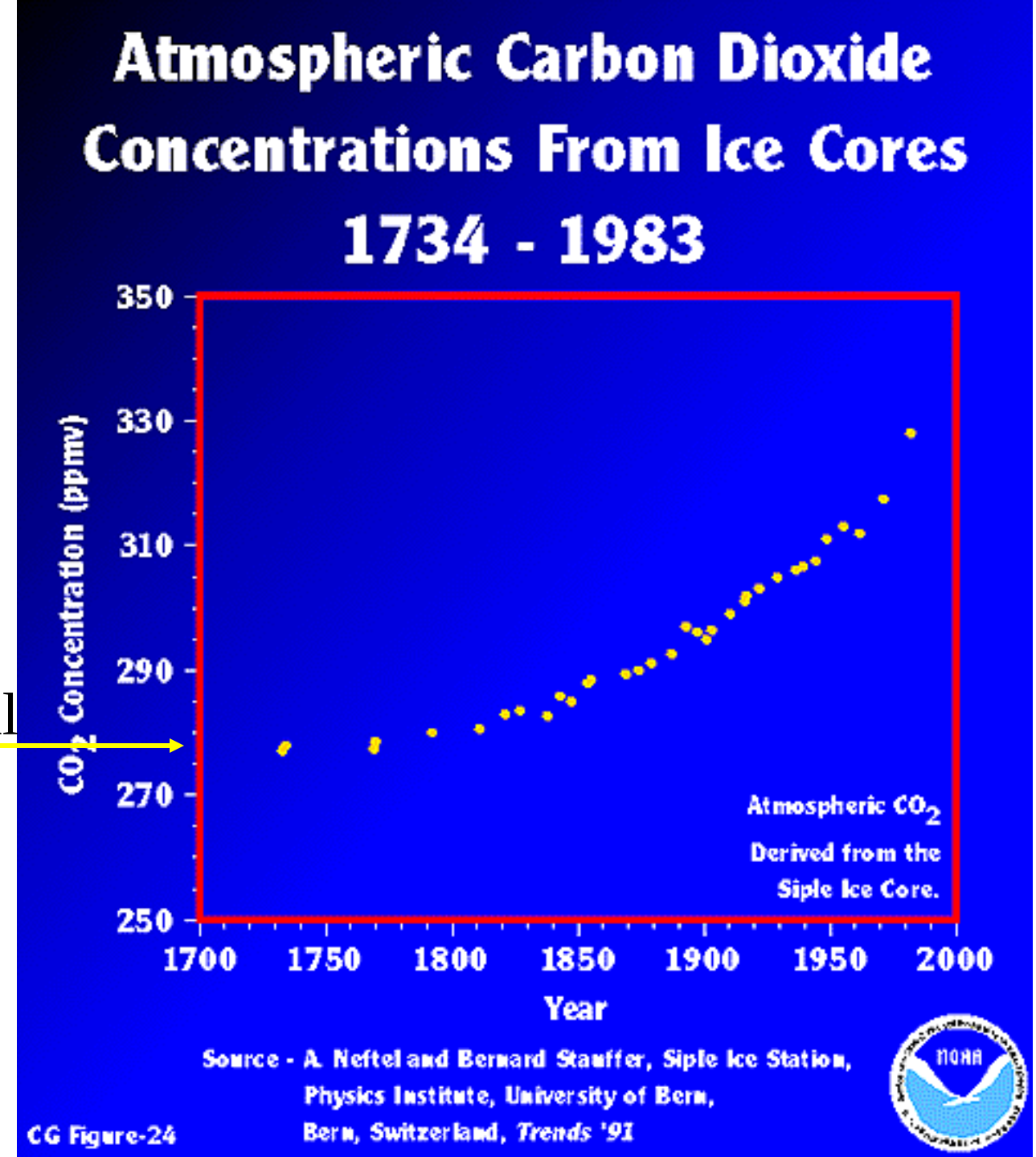
Paradigm shift driven by climate change, energy concerns and technology change

- Large heating, ventilation and air conditioning (HVAC) applications use 30% of total electric power
- Large chillers (over 50 tr) are the category's major power user
- Increased uptake of variable-speed drives
- Oil-free centrifugal chillers (with inbuilt VSD and PFC electronics) offer annual chiller energy savings well over 30%
- Annual maintenance costs well over 50% lower
- Total cost of ownership much lower than traditional business model



IPCC Third Assessment Report
April 2001
Summary For Policymakers

natural levels



Global perspective: Buildings HVAC consumes 38% of all energy produced worldwide; 8.4 billion tonnes of CO2

Market transformation opportunity with new business model

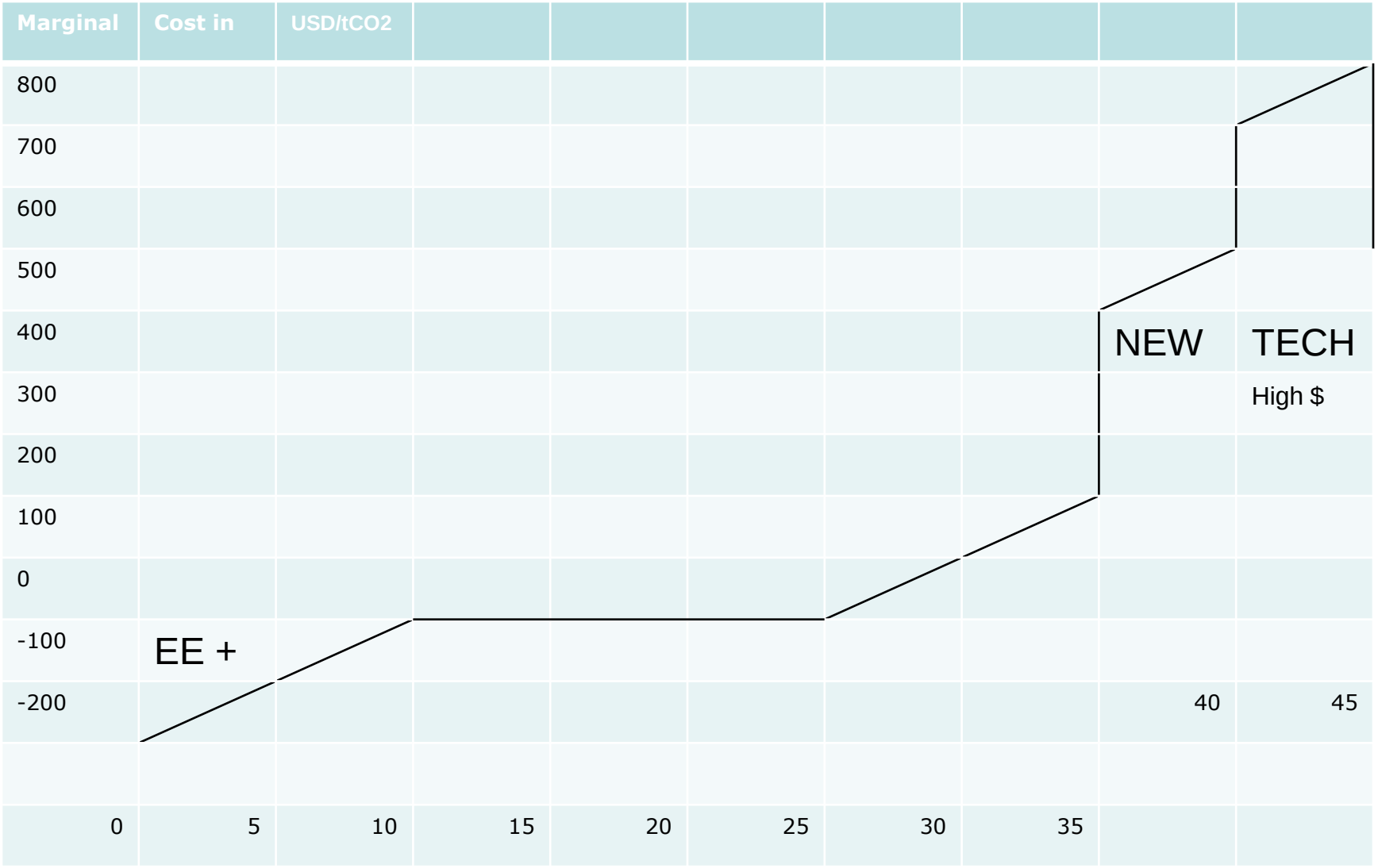
Energy Efficiency has "triple-bottom-line" benefits

- Financial return: energy bill savings
- Social return: "green collar" retrofitting jobs
- Environmental return: reduces greenhouse gas emissions
- Increasingly recognized in new programs – e.g. Property Assessed Clean Energy (PACE) program announced Sep 2009 by Clinton Global Initiative, creates municipal finance districts for energy-efficiency loans with 15-20 year duration – paid-back through surcharge on property taxes

Change in market environment: AEE Member Survey 2008

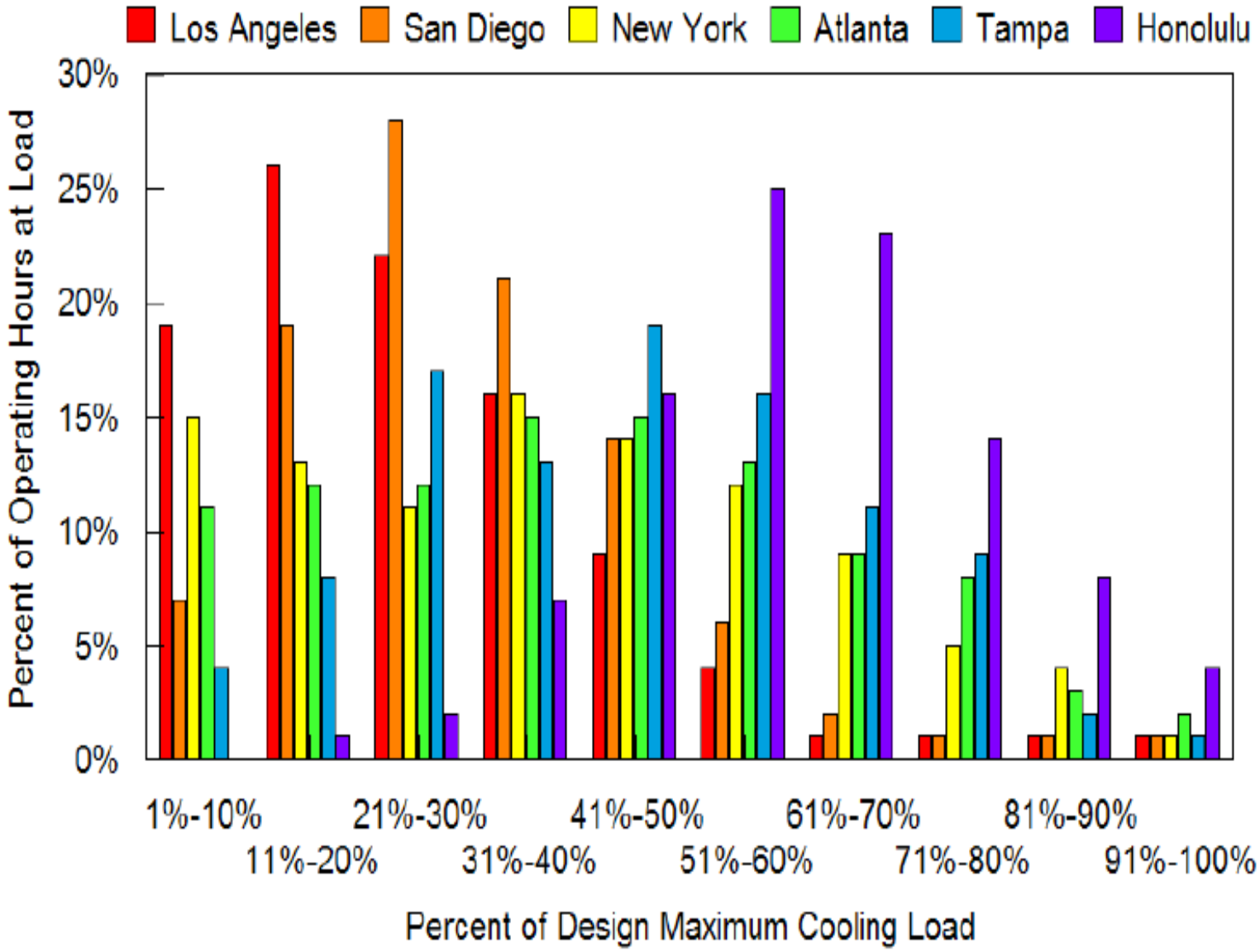
- Energy efficiency the most important plank of National Energy Policy (NEP) 46%
- Energy efficiency codes to become more stringent 68%
- NEP needs to address global warming 81%
- Tax breaks should help high-efficiency technologies 94%
- Electricity costs up in past year 67%
- Energy efficiency program adopted 46%
- Will use an ESCO on energy projects 50%

McKinsey & Co., 2009: emission-abatement cost curve. EE far more cost-effective than renewables and new technologies

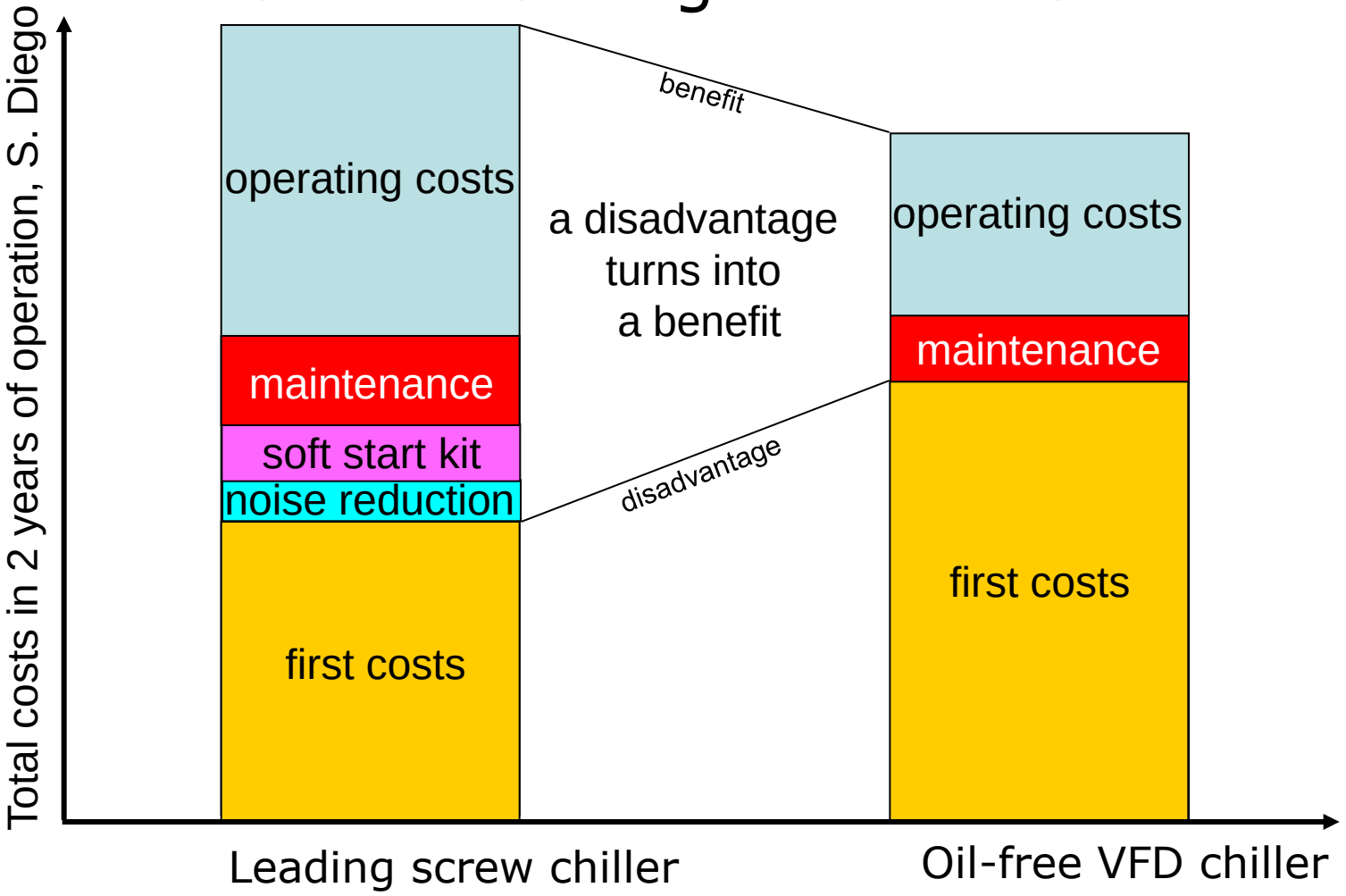


Moves to new market paradigm

- Strong move to IPLV rather than full load as comparative chiller metric (IPLV standard is 1% @ 100%, 42% @ 75%, 45% @ 50%, 12% @ 25% load)
- Noticeable movement away from first cost to whole of life costing of chiller purchase, not only among younger engineers


Los Angeles
San Diego
New York
Atlanta
Tampa
Honolulu
30%
25%
20%
15%
10%
5%
0%
Percent of Operating Hours at Load
1%-10%
11%-20%
21%-30%
31%-40%
41%-50%
51%-60%
61%-70%
71%-80%
81%-90%
91%-100%
Percent of Design Maximum Cooling Load

Whole of life costing model: lower lifetime costs mean higher first costs



Whole life cost analysis – chiller plant. Comparing the icebergs

- Hospital operating cost (maintenance and energy) exceeds first cost by 1200%
- Office building operating cost (maintenance and energy) exceeds first cost by 400%
- School operating cost (maintenance and energy) exceeds first cost by 600%

Royal Academy of Engineering 1998 (et al): 25 year building lifespan is assumed.

Whole life cost analysis – chiller plants

Cost elements required include:

- Equipment life (economic life, technological life, useful life?)
- Energy consumption
- Utility costs
- Maintenance program
- Occupation patterns
- Taxation, tax credits, borrowing costs

Ref: New York, McGraw-Hill 1995. Kirk & Dell'Isola. *Life cycle costing for design professionals.*

Whole life cost analysis – chiller plants

Barriers to adoption include:

- Developer greed
- Owner ignorance
- Tenant masochism
- Competition between building stakeholders
- Artificial separation of capex and opex – planning, management and reporting
- Lack of framework and GAAP standards
- Building and systems complexity

New stress on measurement and verification

- Increasingly required by all stakeholders in energy-efficiency equations
- M&V puts increased pressure on maintenance and commissioning standards
- Failure to embrace M&V as part of WLCA model risks losing over 20% of savings won

Performance standards start to reflect the new market paradigm

- ASHRAE 90.1 – 2010: finally shifts some emphasis away from the traditional "full load" paradigm with Path A (full load) and Path B (slightly lower full load with substantially higher IPLV) – at minimum level delivers 30% energy savings over 90-1-2007.
- BUT strong resistance from numerous old-school engineers. 90.1-2010 not yet implemented.
- New whole-building standard ASHRAE 189 – in public draft Sep 2009 – reflects design approach aligned with LEED. But process is slow.

New technology paradigm

- Oil-free variable-speed chillers offer 30+% saving on annual energy costs
- Lifetime maintenance costs cut by 50+%
- Higher first cost
- New focus on lifetime ownership cost
- BUT, oil-free chillers still a disruptive new technology, so market flux and uncertainty to be expected

Change in technology: oil-free VSD compressors move up- industry consensus

- Turbocor – first oil-free patent 1993
- Carrier/UTRC/USAF/SBIR project with hydrostatic bearings 1995
- York Millennium series with mag bearings from 1998
- Trane oil-free with ceramic bearings 2002
- Mitsubishi Heavy with mag bearings in lab 2002
- Turbocor takes market lead with launch of TT300 at AHR Expo Chicago 2003

Trane S-Series EarthWise CentraVac oil-free chiller

- 40% fewer parts than conventional CentraVacs
- Ceramic hybrid bearings, lubricated by refrigerant R123
- High efficiency, low maintenance operation expected
- Still low-profile in market

Mitsubishi Heavy's Micro-Turbo

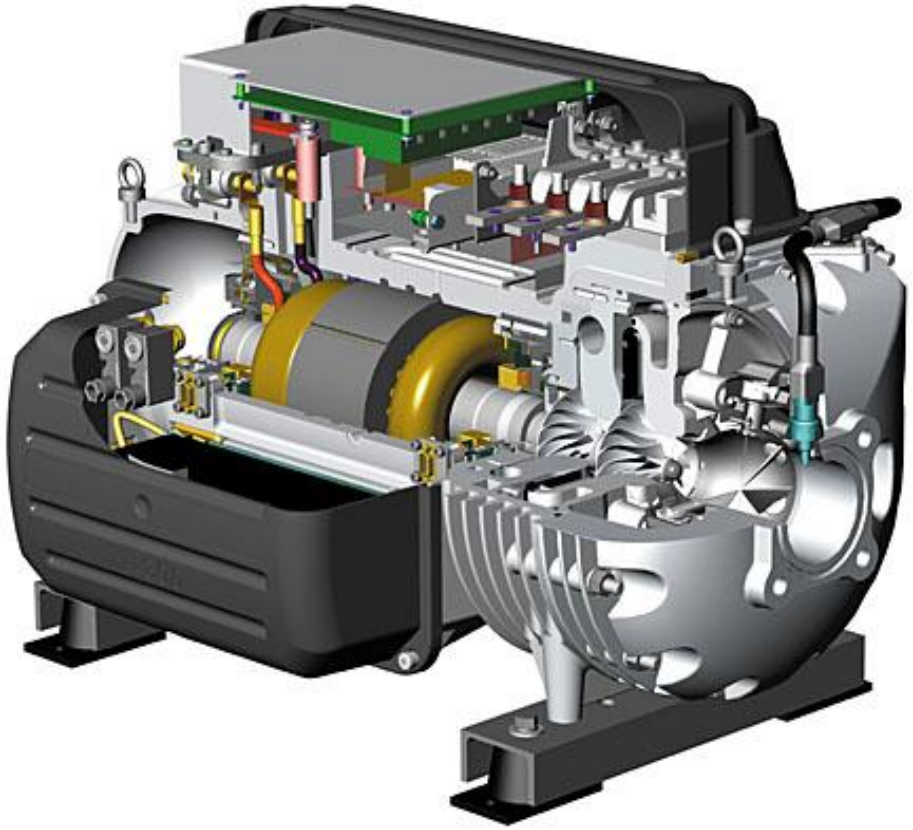
- Inverter-controlled speed
- Direct drive
- Speed up to 50,000 rpm (cf York 14000 rpm, Turbocor 21-48,000 rpm)
- Range starts at 50 tr
- Still low-profile in Japanese market only

Turbocor's oil-free TT300 unveiled at ASHRAE Chicago 2003, steady growth since then

- Hailed as industry breakthrough (JARN)
- WC chiller IPLV .375 kW/tr
- 2 amp starting current – soft start
- 60 to 90 ton capacity range, now scaling up to 150 tons then higher
- R134a
- Homopolar magnetic bearings
- high speed synchronous permanent magnet direct drive motor
- much more compact than competitors
- very quiet (<70 dBa at 1.5 meters)
- fully integrated control system including bearing and inverter (VFD) control , with PFC
- weighs 112 kg, so 2 men can replace a crane

Revolutionary compressor technology

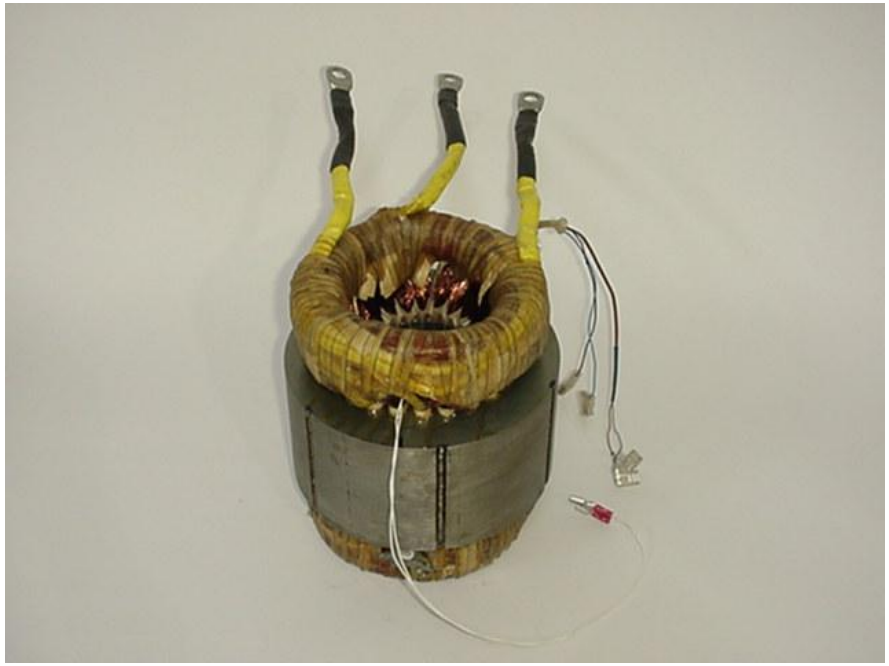
- The permanent magnet motor's speed varies with the load, from 18,000 to 48,000 RPM.
- The inverter is integrated with the power electronics and control systems.
- Very low starting current - ***2 amps*** rather than a conventional compressor's ***500 amps.***
- Magnetic bearings allow very high reliability
- Two-stage centrifugal design



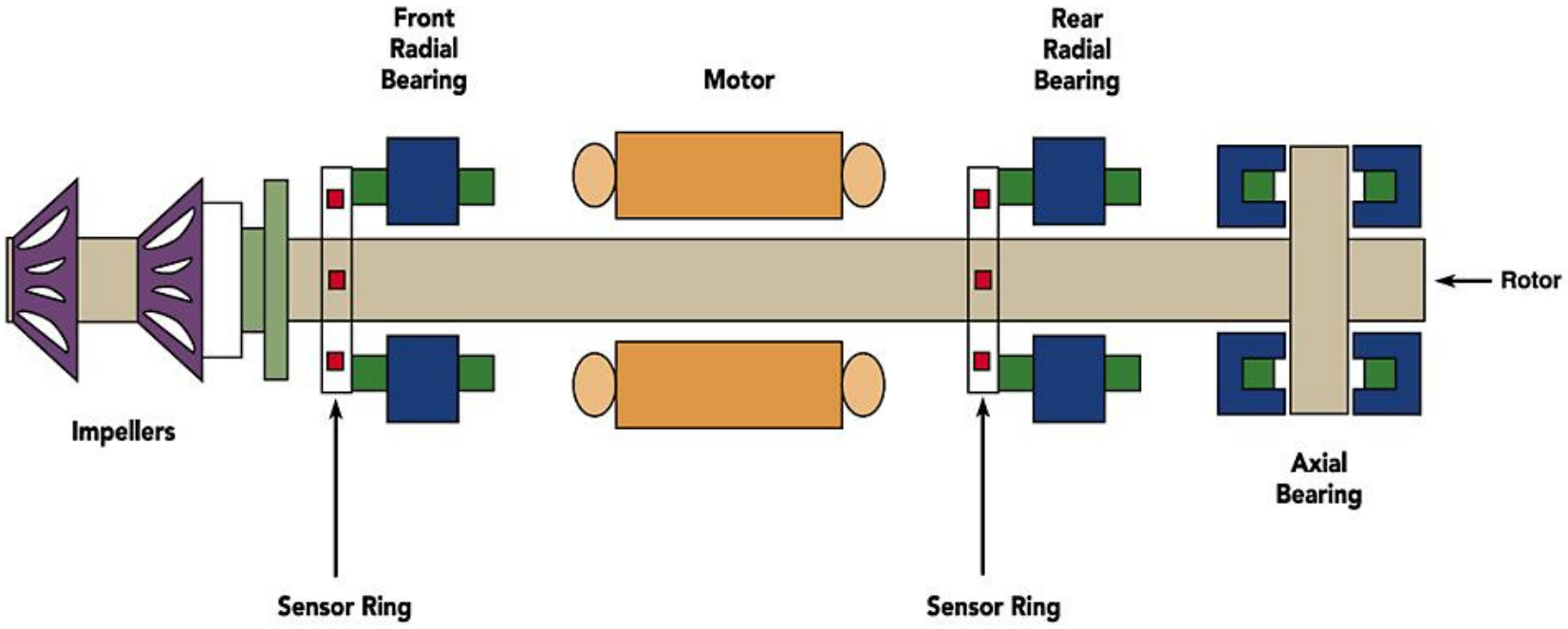
Permanent magnet motor

The permanent magnet motor uses neodymium iron boride; designed for high efficiency and very high reliability:

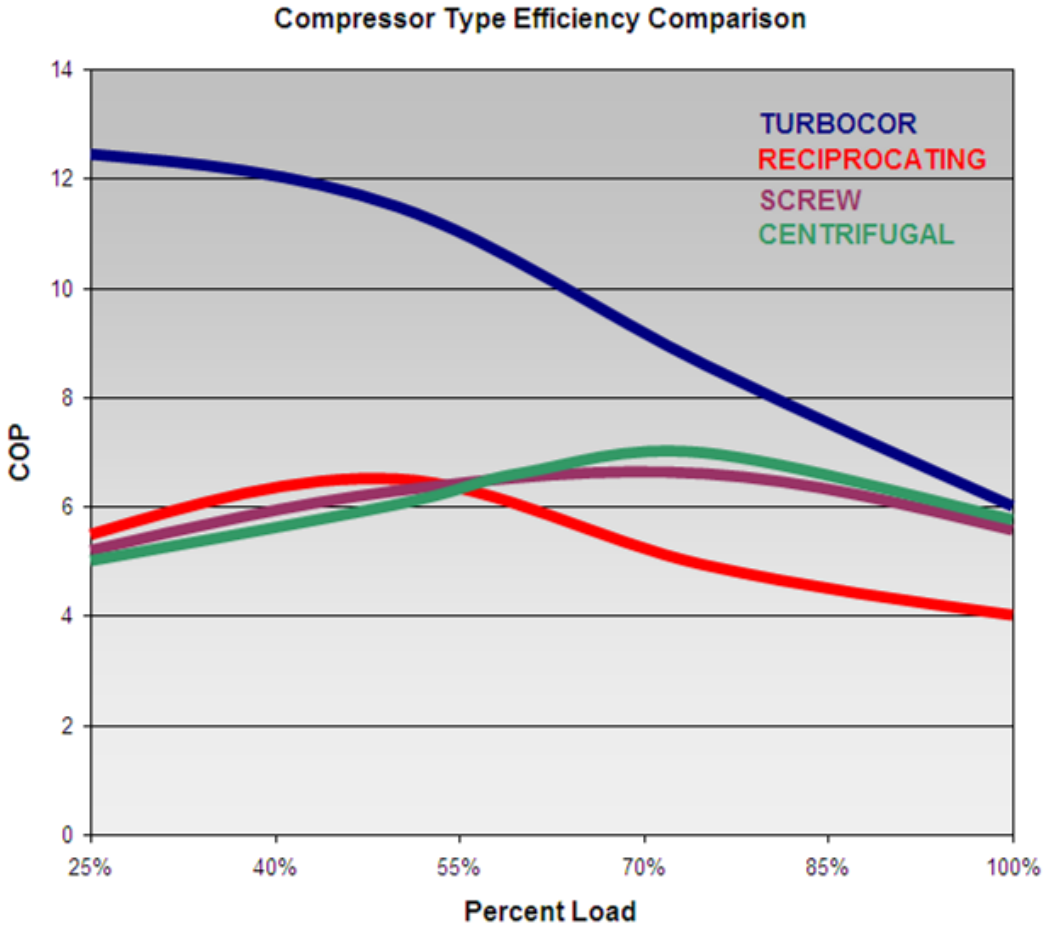
- 140hp motor is the size of a conventional 1hp induction motor.
- operates at high speed (18,000 to 48,000 RPM
- refrigerant-cooled, enhancing longevity.



Magnetic bearing system



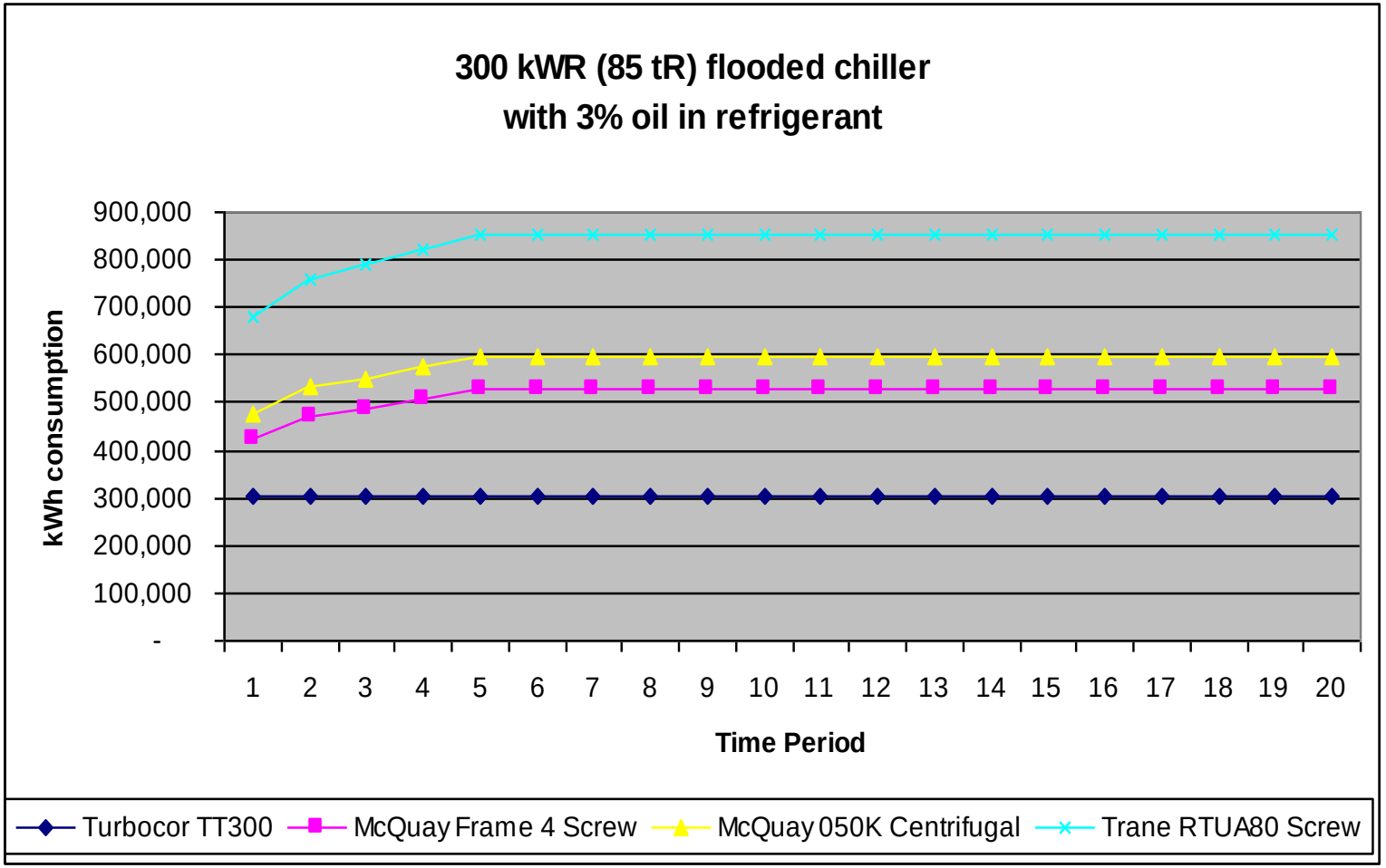
Compressor Comparison



Typical IPLV's

- Reciprocating comps:
  - 0.9-1.2kw/TonR (2-3 COP)
- Screw compressors:
  - 0.6-0.7kw/TonR (5 COP)
- Turbocor compressor:
  - 0.4kw/TonR (9 COP)

Sustainable energy efficiency with oil degradation (ASHRAE study 2002)



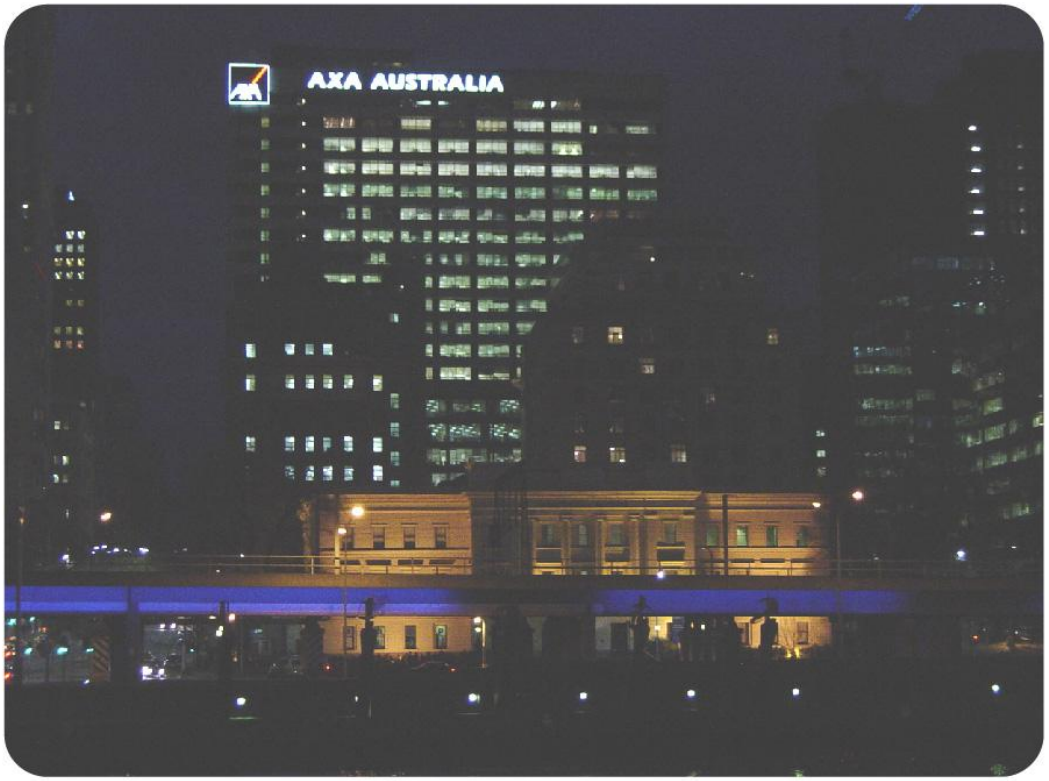
Removing compressor oil removes major chiller maintenance costs

- Copeland and AHRI report that over 70% of chiller failures in the field are due to problems with compressor oil return
- Oil-free design removes 70% of conventional field service risks and costs
- Current US field reports confirm maintenance cost reduction by at least 50%
- Traditional chiller business model turned on its ear

Oil-free centrifugal chillers now well-proven in market worldwide

- Water cooled: often use flooded shell and tube evaporator and condenser (e.g. McQuay, York Millennium, Smardt Group)
- Air cooled: Smardt Group, Climaveneta
- Modular product increasing in difficult retrofit sites (e.g. Multistack, Smardt Group)
- Some markets now showing oil-free centrifugals at over 40% chiller market share by value (e.g. Smardt Group in Australia)

First Turbocor beta units, March 2001. Still running reliably.



AXA Insurance, Melbourne, Australia

First Australian installation.

Sears Mall, Halifax, NS

35% year-on-year energy savings: first Canadian installation

Case Study
Juvenile Hall, San Diego

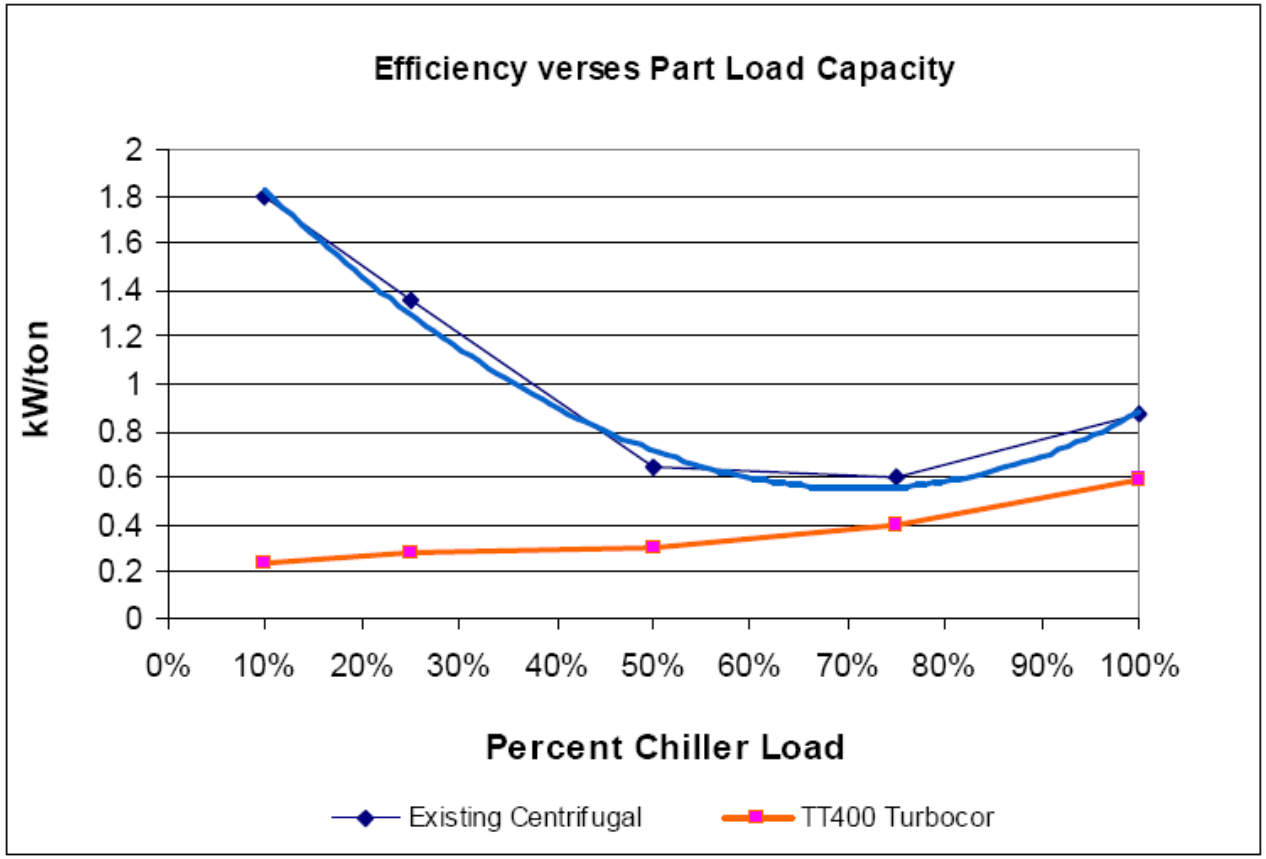
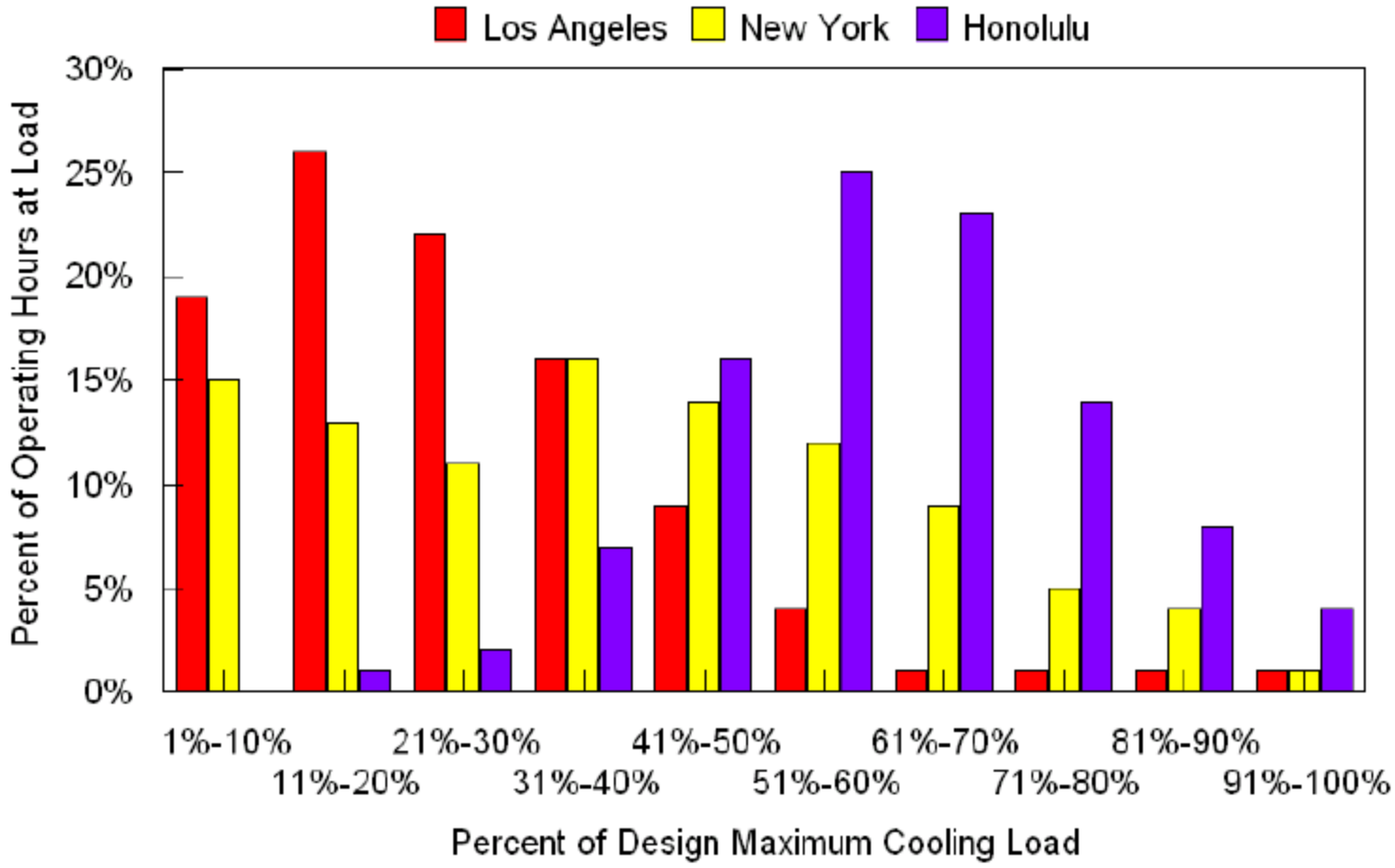


Figure 7 – Extrapolated efficiency versus part load curves for the existing 450-ton centrifugal chiller verses the retrofitted 450-ton TT400 Turbocor chiller.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51%-60%
61%-70%
71%-80%
81%-90%
91%-100%
Percent of Design Maximum Cooling Load

Smardt oil-free centrifugal chiller range growing fast worldwide

- Over 1700 reference sites as at Jan 2010
- Widest product range in
  - water-cooled,
  - air-cooled,
  - condenserless,
  - evap-boosted air cooled
  - heat recovery and
  - compact modular and split models

Smardt Group product range

Air cooled
60-240tonR

Water cooled
60-1000tonR

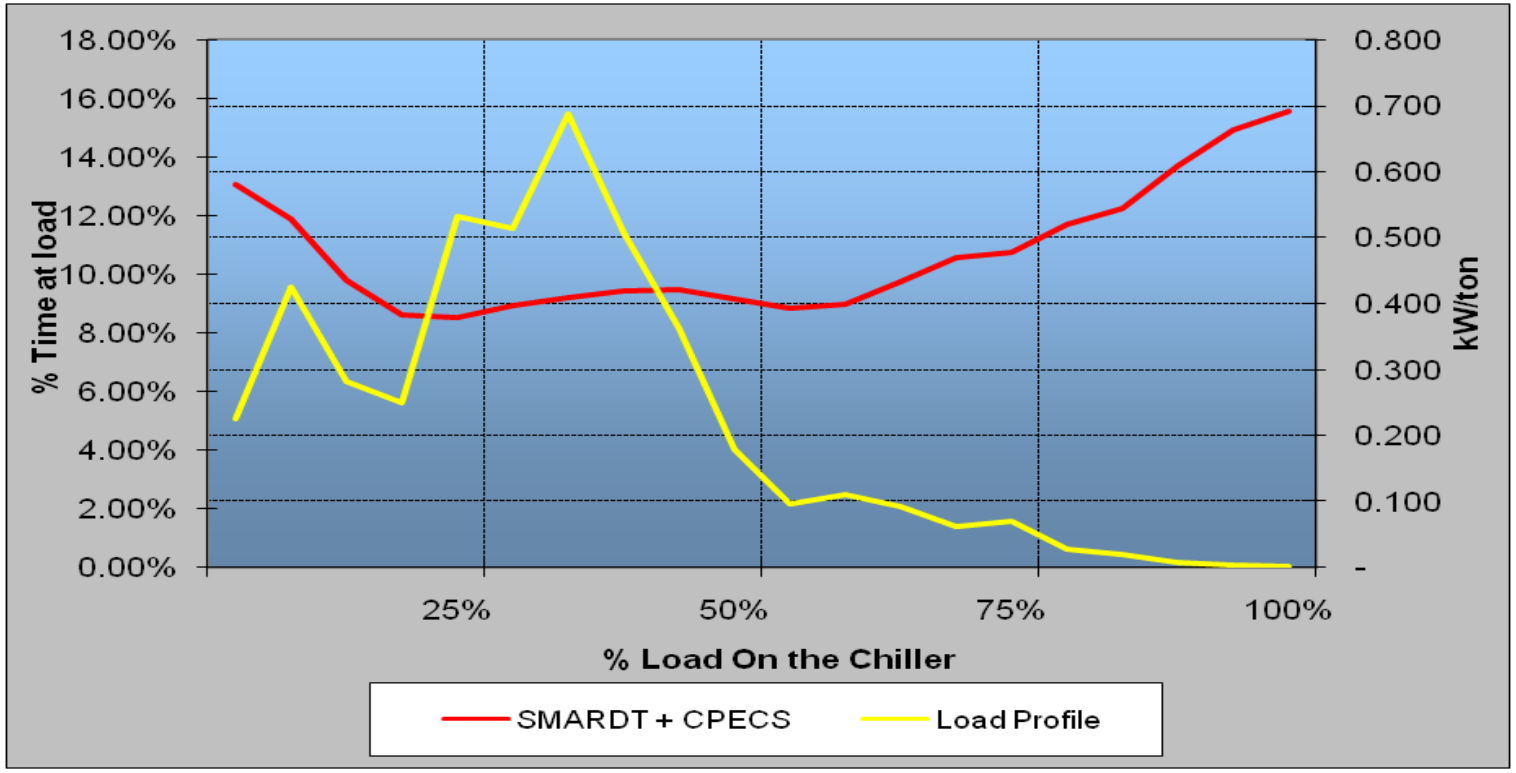
Evaporatively cooled
60-255tonR

Next steps in chiller paradigm shift

- 1. Start with oil-free centrifugal chiller
- 2. Expand variable-frequency concept to embrace whole chiller plant
  - Add VFD's to pumps and tower fans
  - Optimize efficiency of whole chiller plant as an integrated system
  - Measure and verify with calibrated instruments
  - Example is the Smardt/Kiltech integration of Smardt chillers with the Kiltech CPECS (Central Plant Energy Control System) (several others in development)
  - CPECS algorithms optimize the combination of VFD operating speeds which always delivers the lowest energy consumption for the system

VFD's & Part Load

- ASHRAE studies report that comfort cooling systems operate at part load more than 96% of the time;load profiles vary with type of building, function and location. Below is a Phoenix school:



VFD’s & Part Load

- As the cooling load fluctuates on a building so do the demands for air, water and refrigerant flow rates.

- In a typical building all equipment used to move air conditioning fluids utilize rotating electrical motors. By applying variable speed drives to each of these motors we can achieve flow reduction or capacity modulation to exactly match only what the building requires by altering the motor electrical frequency (Hz).

VFD's & Part Load

- Centrifugal devices such as pumps, centrifugal chillers & fans offer large energy reductions when operating at less than design speeds. Pump/fan affinity laws may be used to estimate the performance increases.
- Power input is proportional to the cube of the shaft speed $\frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3$

- A pump or fan operating at 80% of design speed only uses 50% of the full speed power

- VFD chilled water plants can therefore utilize energy saving measures via the use of VFD's some 96% of the year

Typical Performance – 10yr Old Chiller Plant

- Plants of this age typically utilize fixed speed chilled water pumps, chillers and tower fans and have very little ability to reduce energy at part load.

- Annual performance levels:

  - **Chiller** **.8 kW/TR**
  - **Pumps** **.35**
  - **Tower fans** **.05**

  - **Total:** **1.24 kW/TR**

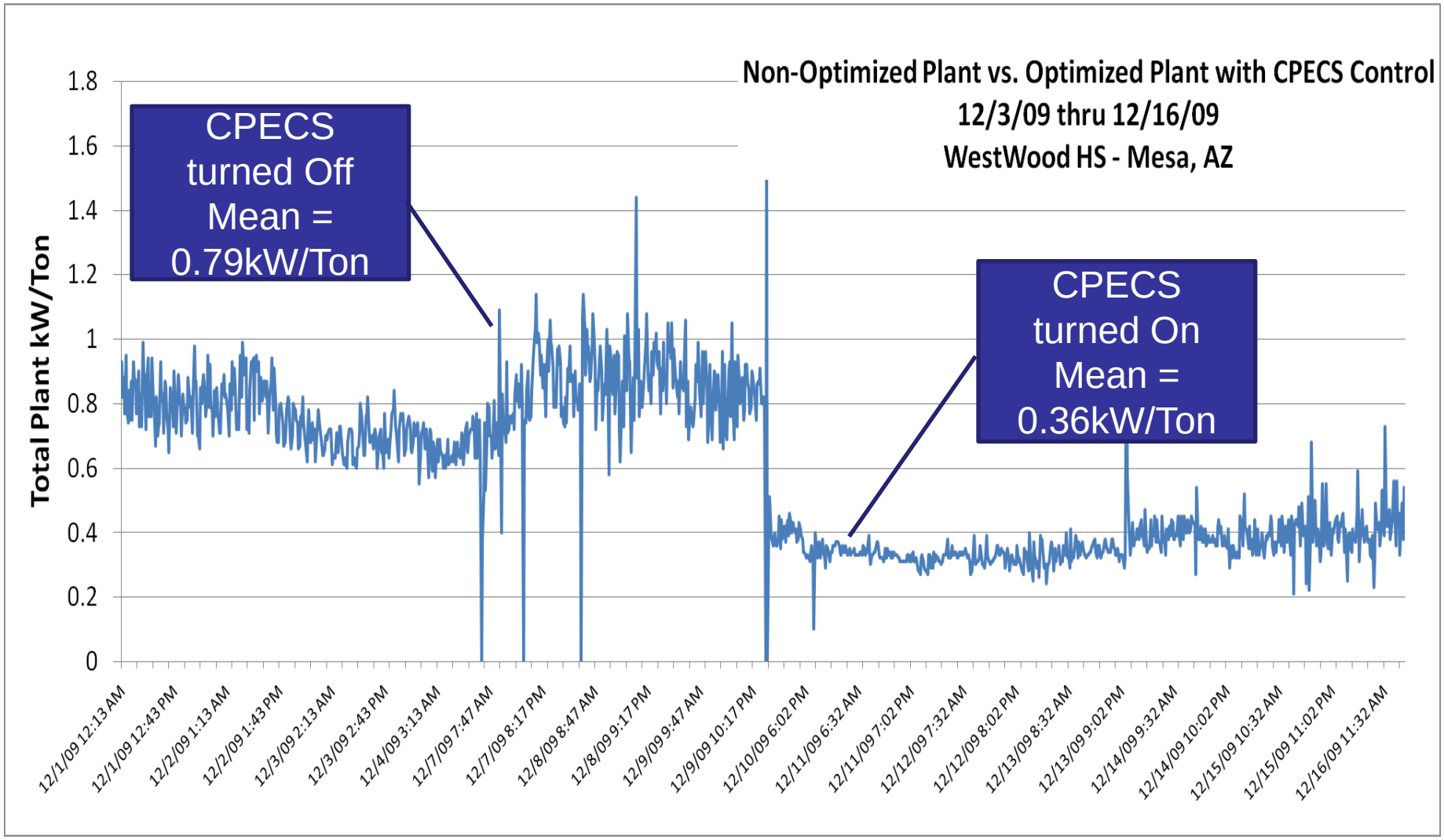
Typical Performance – New High Efficiency Chiller Plant

- Newer plants with premium priced equipment generally operate with VFD driven chillers and cooling tower fans, constant speed chiller pumps and VFD driven building pumps

- Annual performance levels, high-efficiency equipment, not optimized as a variable speed plant system:

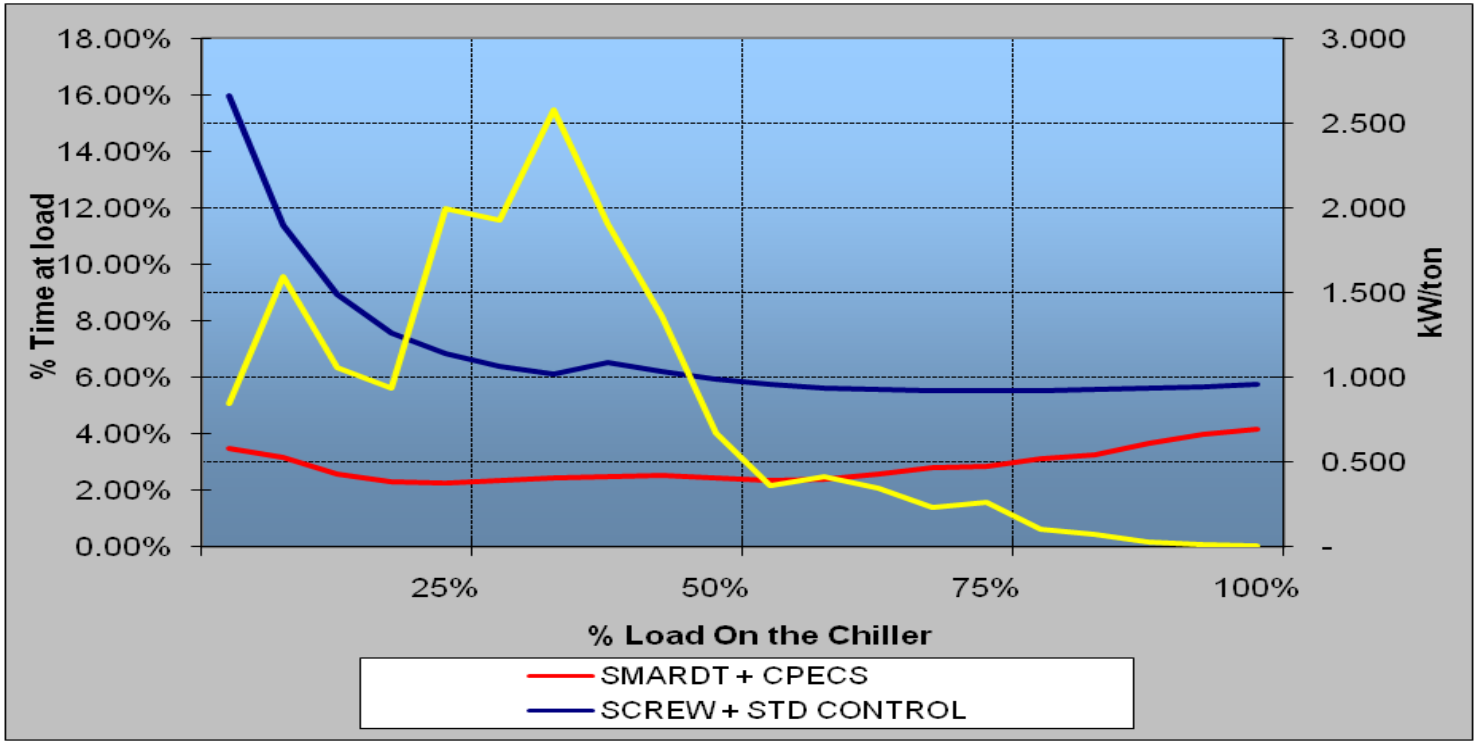
  - **Chiller .40 kW/TR**
  - **Pumps .23 kW/TR**
  - **Tower fans .03 kW/TR**
  - **Total plant .71 kW/TR**

CPECS System – empirical data



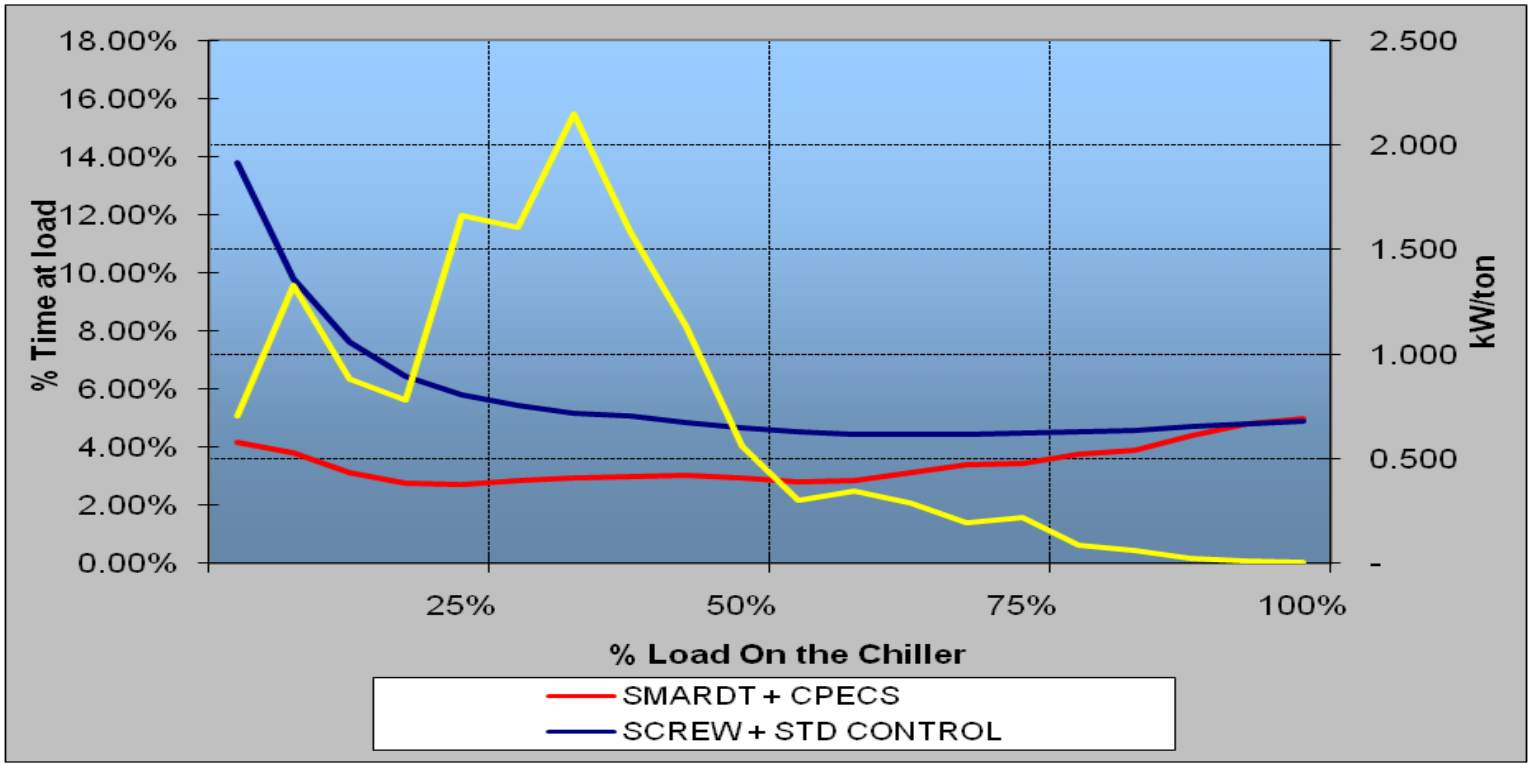
Energy Comparisons

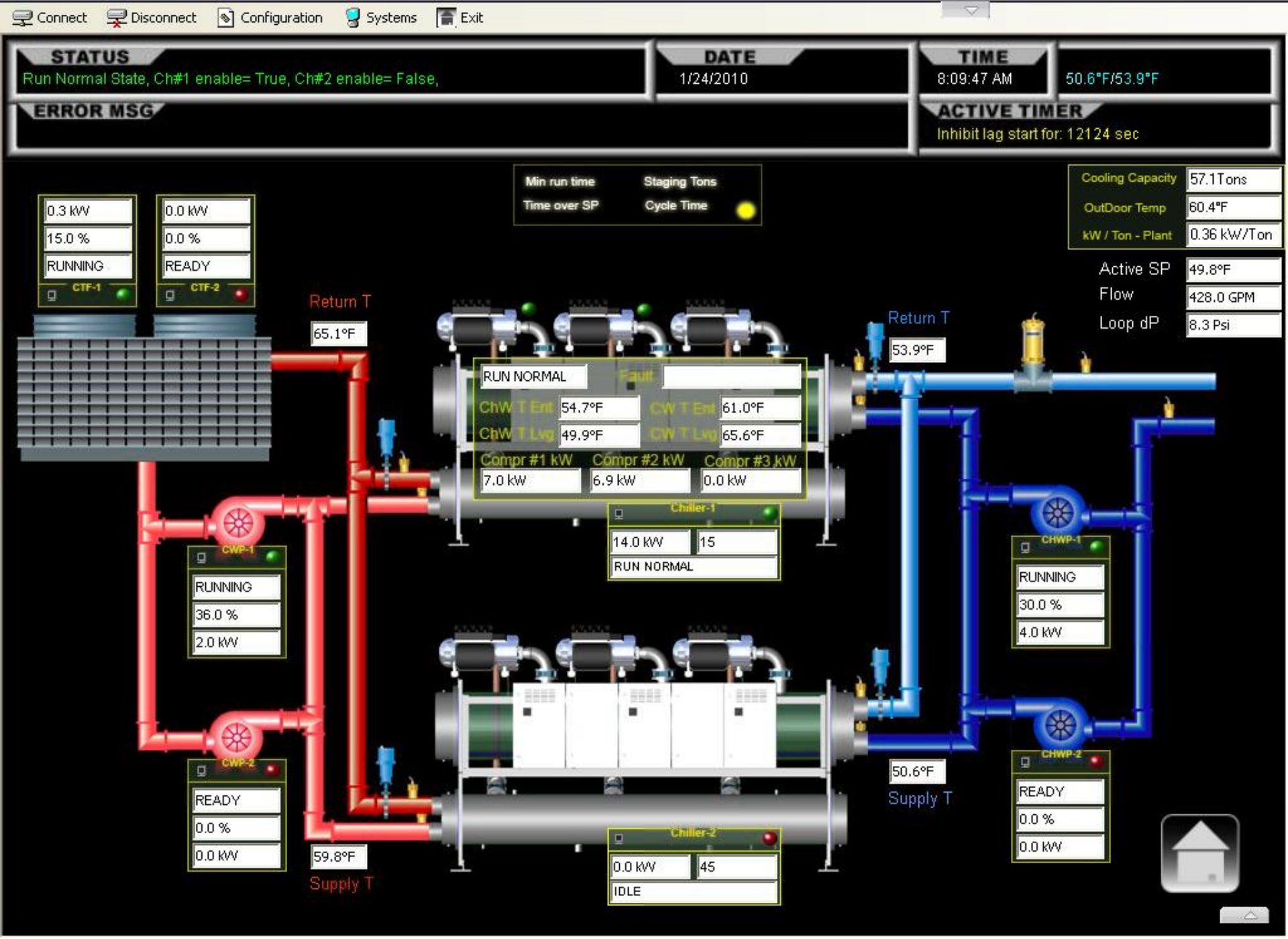
- Water cooled constant speed screw plant Vs CPECS & SMARDT oil free.
  - 45% to 60% Energy reduction based on location and type of occupancy.



Energy Comparisons

- Water cooled VFD screw or centrifugal plant Vs CPECS & SMARDT oil free.
  - 35% to 47% Energy reduction based on location and type of occupancy.




Connect
Disconnect
Configuration
Systems
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STATUS
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DATE
1/24/2010
TIME
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50.6°F/53.9°F
ERROR MSG
ACTIVE TIMER
Inhibit lag start for: 12124 sec
Min run time
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Time over SP
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Cooling Capacity
57.1Tons
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60.4°F
kW / Ton - Plant
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49.8°F
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CTF-1
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READY
CTF-2
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CHWP-2
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Chiller-2
0.0 kW
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IDLE
50.6°F
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Protocol has been opened successfully. IP 10.0.207.93 Level 3. High level - Administrator 28799910

Connect | Disconnect | Configuration | Systems | Exit

STATUS
Run Normal State, Ch#1 enable= True, Ch#2 enable= False,

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49.7°F/54.8°F

ERROR MSG

ACTIVE TIMER
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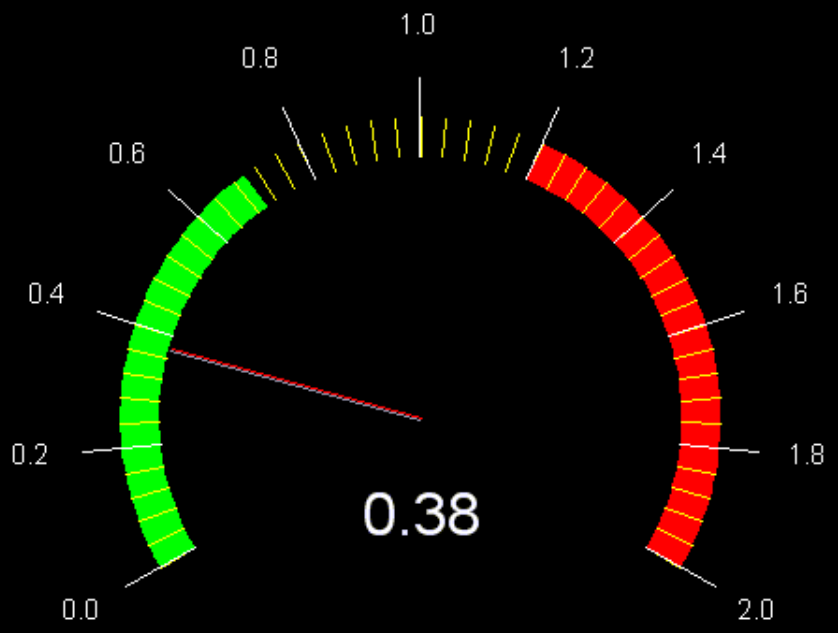
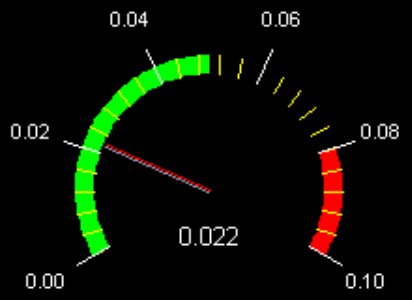
Plant Performance (kW/Ton)



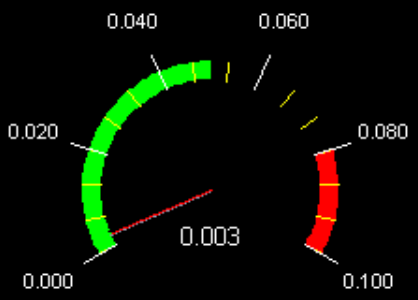
Chiller Performance

CHWP Performance

CWP Performance



Tower Performance



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ROI, payback calculations

- ROI for fully optimized Smardt/CPECS plants varies with:
  - Hours of plant operation per year.
  - Cost of electricity
  - Location and function of building

- Typically additional costs incurred to supply CPECS optimization and additional VFD's runs from:
  - 0.8yrs (high usage plant such as process cooling or labs)
  - 2.9yrs (low usage building such as 9month per year school)

Summary

- Major market shifts toward high energy efficiency and low lifetime operating costs appear to be underway and to be irreversible, destroying the traditional lowest-first-cost chiller business model
- The oil-free centrifugal chiller world has arrived but is still new. The technology is still disruptive.
- The leap towards variable-speed chilled-water plants offers a double-whammy win for owners.
- The rest of the very conservative HVAC industry will simply have to adapt.

Smardt/CPECS comes in #1,#2,#3,#4,#5,#6 for Energy Grants in AZ Schools, Jan 20 2010

STATE OF ARIZONA
SCHOOL FACILITIES BOARD

Meeting Date: January 20, 2010 **Agenda Item X.b.**

Subject: **X. ARRA Energy Grant Awards**

b. Consideration and possible vote to accept, reject or modify the Energy Efficiency Grant Awards

Background
The Governor's Office through the Department of Commerce Energy Office directed $20,000,000 of the State Energy Program as part of the American Recovery and Reinvestment Act funding for solar and energy efficiency projects for schools.

The School Facilities Board is using $12,921,548 for energy efficiency projects. Through a competitive selection process, the Board will provide grant funding for 30% of the project cost up to $1 million per district. The district will be responsible for 70% of the project cost either through performance contracting or any available local funds. The grant application deadline was November 6, 2009. The SFB received 105 applications from 44 school districts. The application project cost total reached $103,810,266. The criteria for project selection are Life-cycle payback, Energy savings measured by unit reduction, Energy savings measured by dollar reduction, and Impact on the school utility budget

Evaluation
The SFB received 105 applications for energy efficiency grants. Attached is the summary scorecard for all of the applications. Applications were evaluated based on the following criteria (total 100 points):

Life-cycle Payback/Cost Benefit Ratio (40 points): The cost benefit ratio is based on proposed project savings times its useful life versus grant funds requested. Cost benefit ratio = annual project savings x useful economic life/grant funds requested

Energy Savings measured by unit reduction (20 points): The unit reduction is based on energy savings in terms of Btu saved per square foot. Energy Savings = Btu saved/School Square Footage

Energy Savings measured by dollar reduction (20 points): The unit reduction is based on energy savings in terms of dollars ($) saved per square foot. Energy Savings = Dollars ($) saved/School Square Footage

Impact on the School Utility Budget (20 points): The electricity and gas savings are calculated against the utility budget that includes annual cost of gas and electricity. Percent Utility Savings = 100 X Annual savings ($) / Annual Electricity & Gas bill ($)

Disqualified Projects
In addition to the evaluated projects, staff has included a list of disqualified applications. Applications were generally disqualified for three reasons. First, the district did not include the required documentation to support the concluded energy savings. Second, the application did not meet the life-cycle criteria as defined by ARS §15-213.01 (b). Thirdly, the district has started the project already and is requesting reimbursement.

Useful Economic Life
The economic useful life of different building components are based on Database of Energy Efficient Resources (DEER). DEER is a California Energy Commission and California Public Utilities Commission (CPUC) sponsored database designed to provide well-documented estimates of energy and peak demand savings values, measure costs, and effective useful life (EUL) all with one data source.

Other Important Notes
- The evaluation team from the SFB and Department of Commerce Energy Office provided an opportunity to Energy Savings Performance Companies, School Districts and Contractors to discuss the applications.
- The evaluation team reviewed proposed energy savings and costs for each application, providing equal opportunity to each application.
- Savings are based on energy savings alone, and do not include operational savings.
- The federal guideline restricts the use of energy efficiency grant funds on water saving projects.

Recommended Awards
SFB staff recommends awarding 29 projects to 25 districts. In total, these projects with an estimated cost of $43,600,825 will save $5,567,738 per year. The average payback for these projects is approximately eight years.

The projects recommended for award are as follows:

Mesa Unified School District
6 schools

Total Project Cost:	$869,412
Amount Requested:	$260,824
Recommended Award:	$260,824

Project Scope: HVAC Control

District Funds:	$608,588
Estimated Savings:	$258,487 per year

Energy Savings: The project is estimated to save 8,531 MMBtu per year.

Afterword

“The only by-product of energy efficiency is wealth.”

The Economist, May 8 2008.

SMARDT