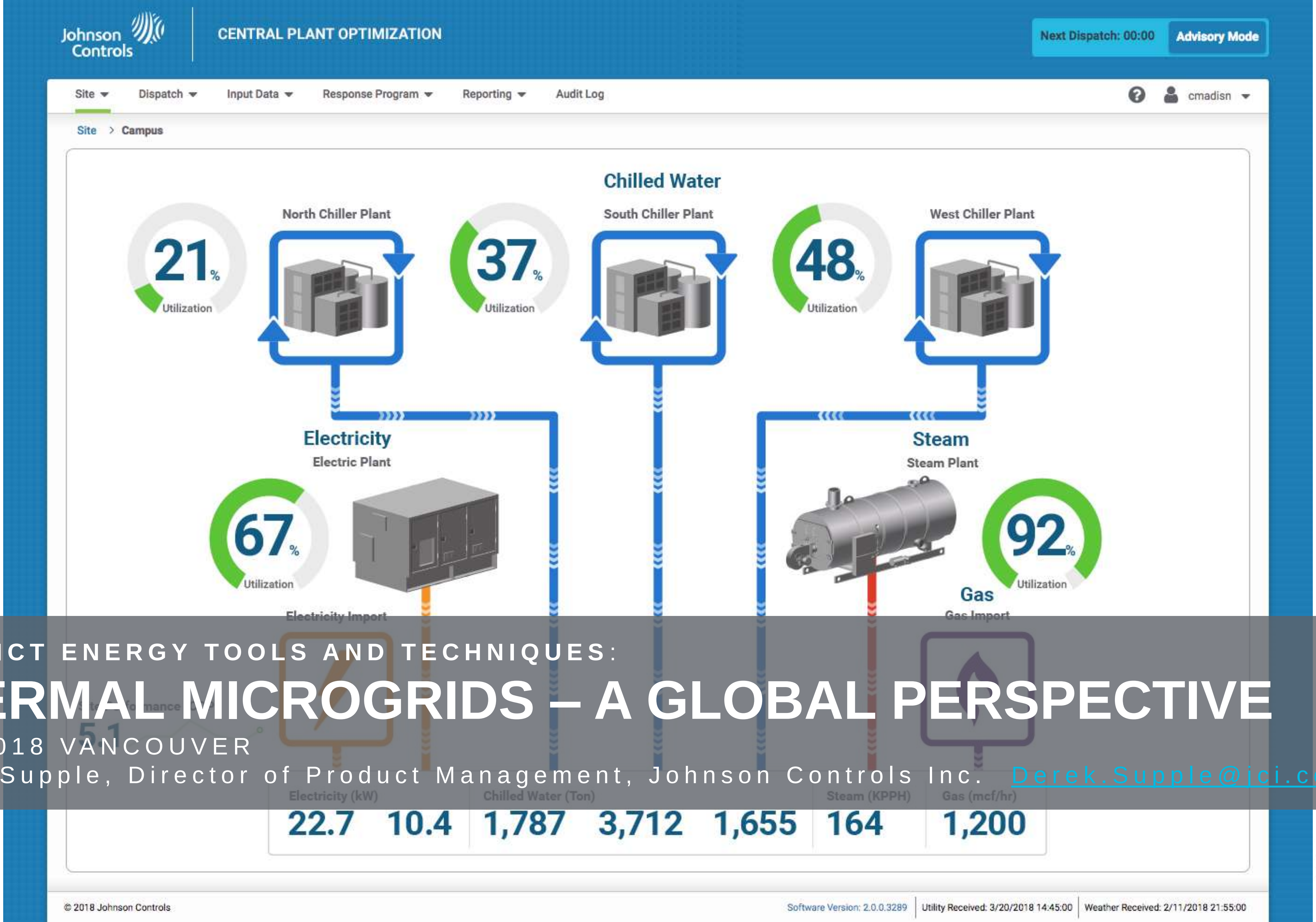


DISTRICT ENERGY TOOLS AND TECHNIQUES:

THERMAL MICROGRIDS – A GLOBAL PERSPECTIVE

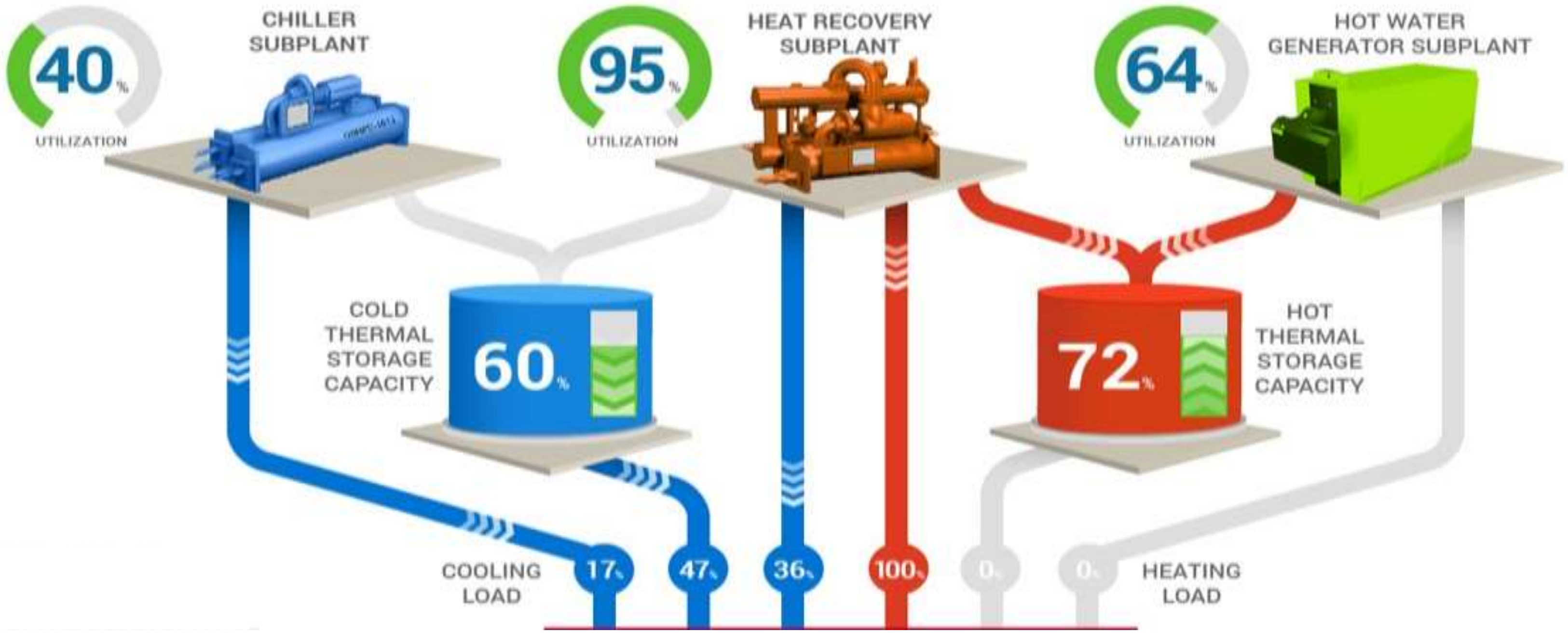
IDEA2018 VANCOUVER

Derek Supple, Director of Product Management, Johnson Controls Inc. Derek.Supple@jci.com

Thermal microgrids can be highly cost effective part of a “total energy microgrid”

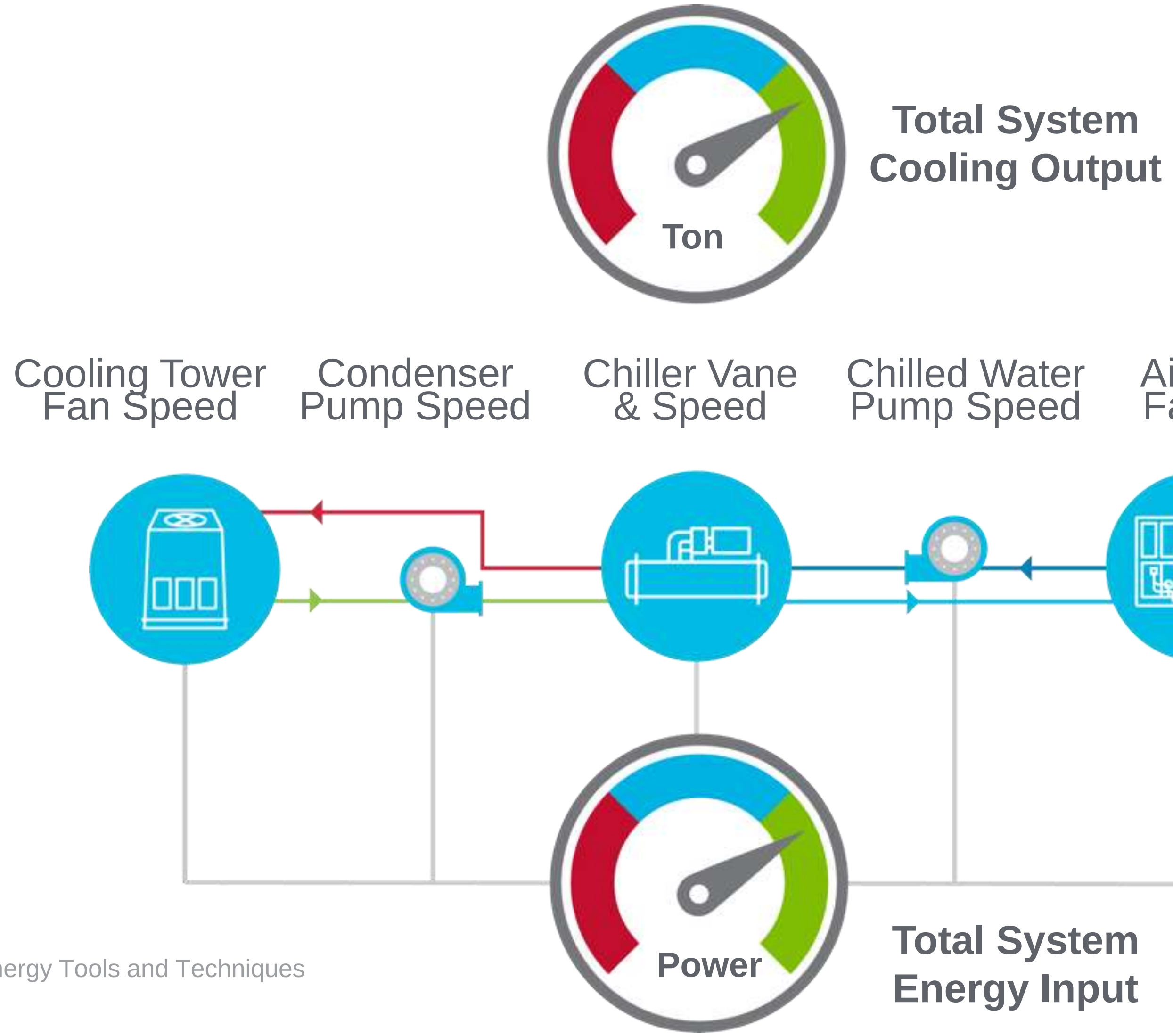
What is a “thermal microgrid”?

A district energy system that combines system-level optimized heating and cooling services, distributed generation, heat recovery, and electric power management through smart control technologies.



Key Principles:

Maximizing efficiency at component level doesn't optimize at the system level



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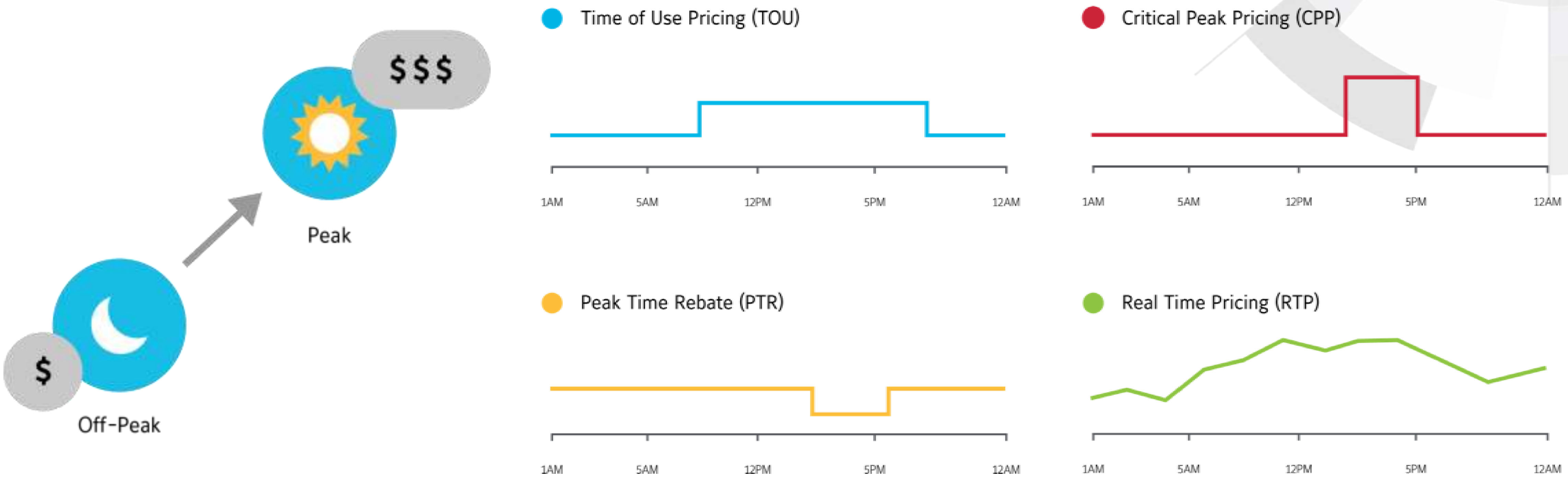
Key Principles:

Minimizing energy at each instant doesn’t always optimize economics over time

A push for smarter utility grids is resulting in more rate structures that vary by time of day and more demand response incentive programs.



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Truly minimizing utility costs or carbon footprint while meeting priority #1: ***reliable service delivery*** is a complicated challenge

Every hour of every day plant engineers could consider ***hundreds*** of possible equipment combinations and set points

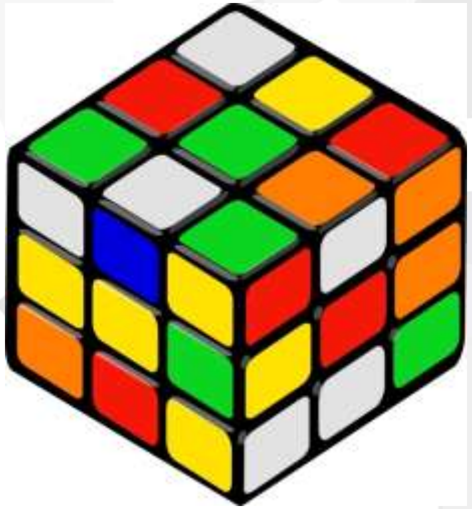
Imagine a simple plant with 5 chillers and 3 boilers. . .

- Number of boiler and chiller combinations = $2^5 + 2^3 = 40$
- Select part-load level for each variable-speed “prime mover” based on multidimensional and nonlinear efficiency curves
- Auxiliary equipment like pumps and towers add layers of complexity.
- Ever-changing loads, weather and sometimes even time of use utility prices add to the challenge.

The number of decisions an operator *could* consider is staggering.

Imagine being able to optimize dispatch decisions every 15 minutes.

“That's something we just couldn't do manually.”



Model Predictive Control (MPC) provides a math-based and physics-based “classic optimization” approach for control of thermal microgrids

Controls the variables based on sophisticated rules:

- Reset Sequences of Operation
- Iterative Step & Wait
- Relational Control, and/or
- Natural Curve Fit / Equal Marginal Principle

Supervisory Control (Rules-based)

Supervisory Control <u>AND</u> Optimization

Applies “classic” optimization procedures with objective functions (e.g. minimize cost) subject to constraints (e.g. laws of physics)

Objective Function:

$$\min(J) = \sum C_{ch} P_{ch} \Delta t + \sum C_{gas} F_{gas} \Delta t + \sum C_{tw} P_{tw} + \sum C_{pmp} P_{pmp} + \sum C_{dc} \max(P) + \sum C_{hr} P_{hr} \Delta t$$

Equality Constraints:

$$Q_{ch} + Q_{hr} = Q_{loadcw\_t_0} \pm Q_{TEScw} \qquad Q_{hw} + Q_{hr} = Q_{loadhw\_t_0} \pm Q_{TES_{hw}}$$

$$\cdots\cdots$$

$$Q_{ch} + Q_{hr} = Q_{loadcw\_t_1} \pm Q_{TEScw} \qquad Q_{hw} + Q_{hr} = Q_{loadhw\_t_1} \pm Q_{TES_{hw}}$$

Inequality Constraints:

$$Q_{ch} \le \max(Q_{ch}) \quad Q_{TES} \le \max(Q_{TES}) \quad Q_{TES} \le \min(Q_{TES})$$

$$\cdots\cdots$$

Predictive cost optimization algorithms respond to myriad ever-changing inputs

Predictive Cost Optimization

Inputs & Predictors

- Utility Market Rates
- Load Predictions
- Weather Forecasts
- Equipment Performance
- Calendar/ Maintenance

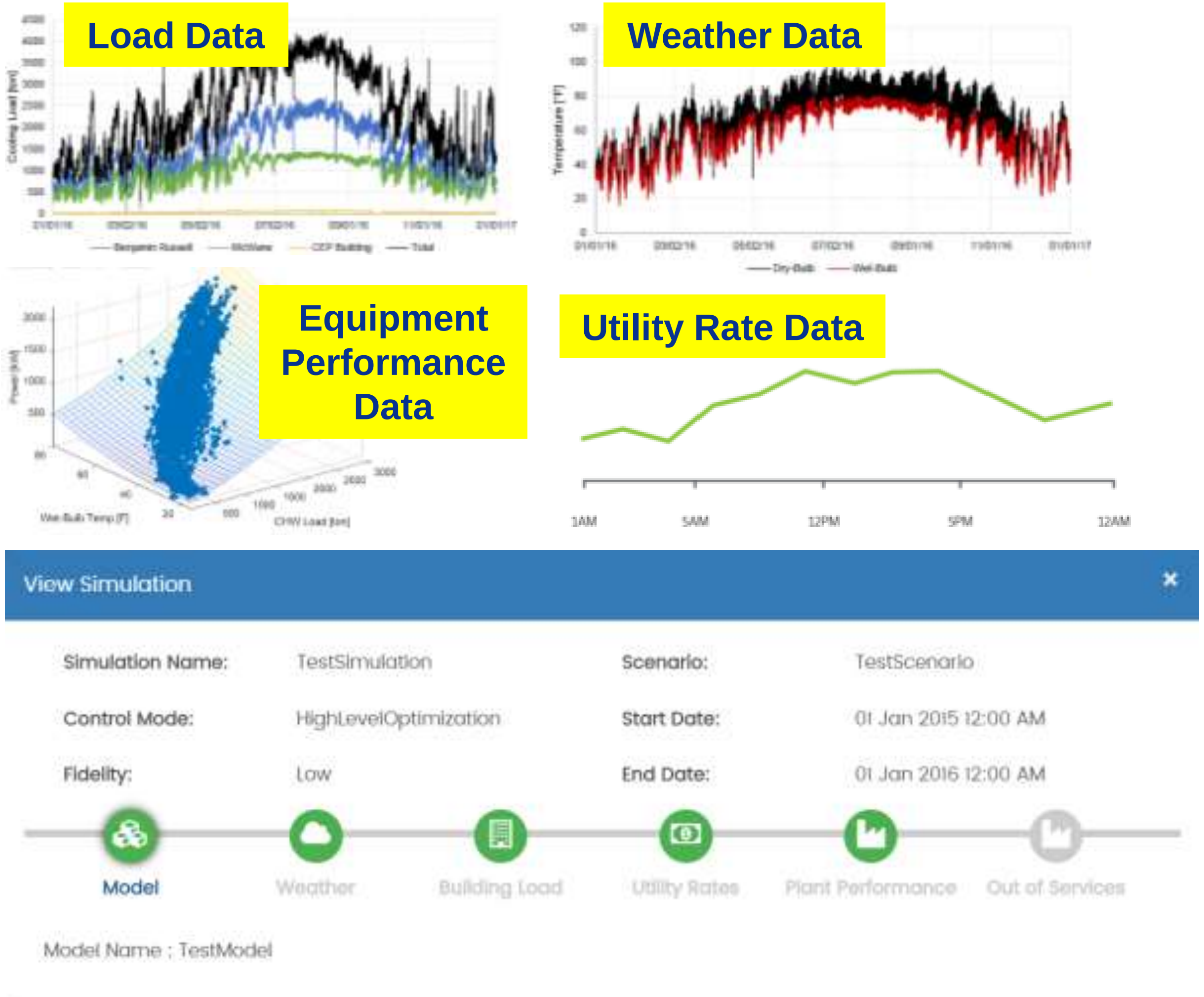
District Energy Plant

Equipment Dispatch & System Set Points

- Chillers
- Cogeneration
- Boilers
- Pumps
- Battery Storage
- Cooling Towers
- Heat Exchangers
- Heat Pumps

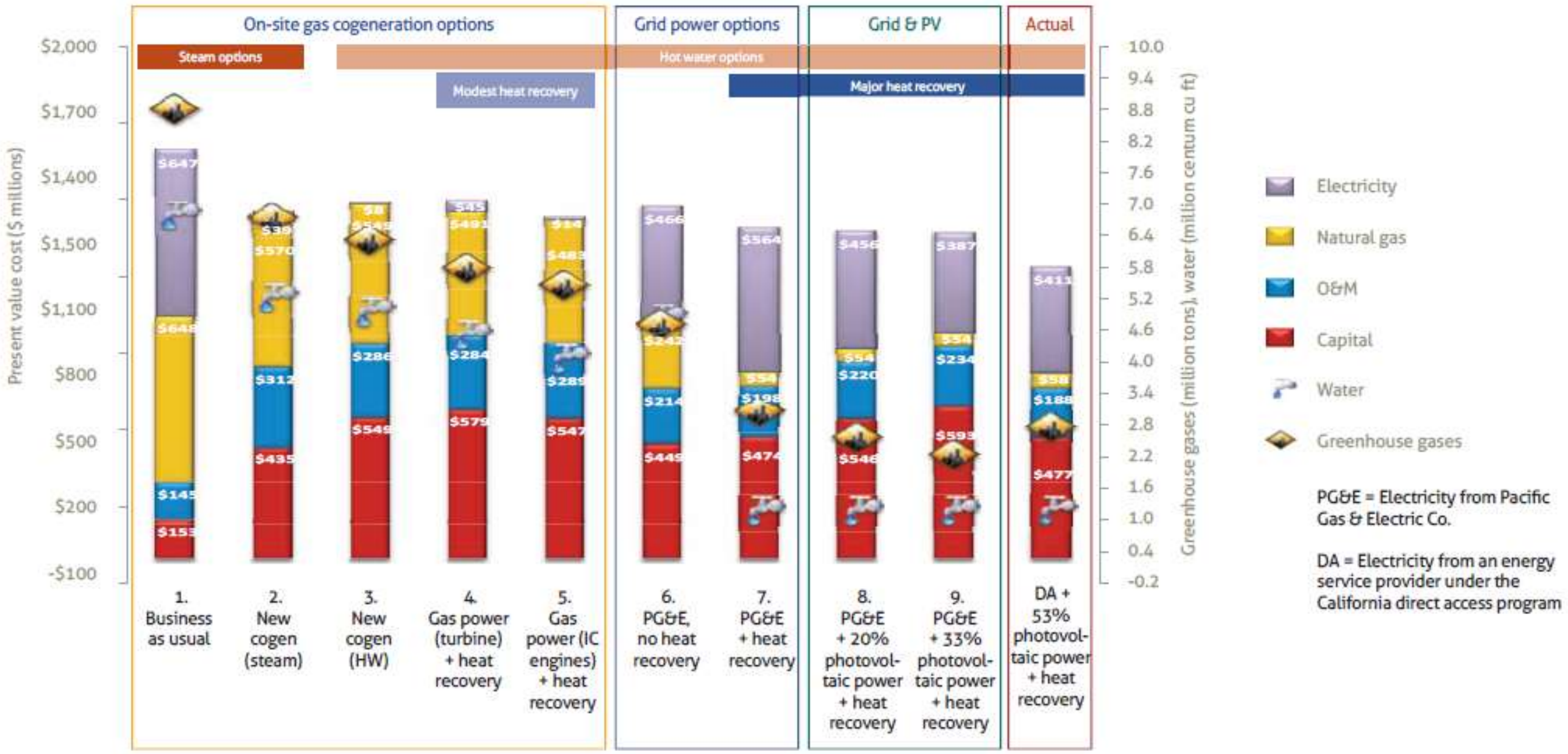
Monitor & Adapt

Emerging District Energy “**Planning Tools**” for detailed energy cost simulation



- **Develop 8760 models of utility usage, peak demand, and costs**
- **Perform what-if scenarios based on actual operating conditions**
- **Inform design decisions to reduce lifecycle operating costs**
- **Helps to right-size plant equipment to reduce first cost**
- **Supports annual budgeting and ongoing O&M decisions**
- **Enables measurement & verification (M&V) of savings for project investments**

Using Model Predictive Control (MPC) as a simulated control strategy enables robust lifecycle cost and GHG analysis to select best combination of properly-sized equipment



Stagner (2016) "Stanford University's Fourth Generation District Energy", IDEA District Energy Quarterly

"I knew when we had a model that would show how the system would work every hour of the year, no engineer could look at it and cast doubt…

…In the end, the design withstood peer reviews from external consultants, professors, and very knowledgeable board members. It breeds a lot of confidence to actually have the data to back up a recommendation."

- Joe Stagner
Executive Director
Department of Sustainability and Energy Management
Stanford University

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PROJECT PROFILE

Kent State University, OH

- 2nd largest in OH public university system: 43,000 enrollment
- Kent campus district energy plants serve 110 buildings, 6 million sq ft
- 12MW cogeneration system (2 gas turbines)
- 13,000 tons of chilled water capacity across 7 separate plants serving 3 loops
- Combination of electric centrifugal, steam turbine, and absorption chillers
- 4 boilers, 2 duct burners, and 1 heat recovery steam generator

Thermal Microgrid Optimization at Kent State University’s Kent Campus

Completion of CPO system commissioning and transition to Auto mode began in Dec 2017

System continuously monitors ~1,000 input variables:

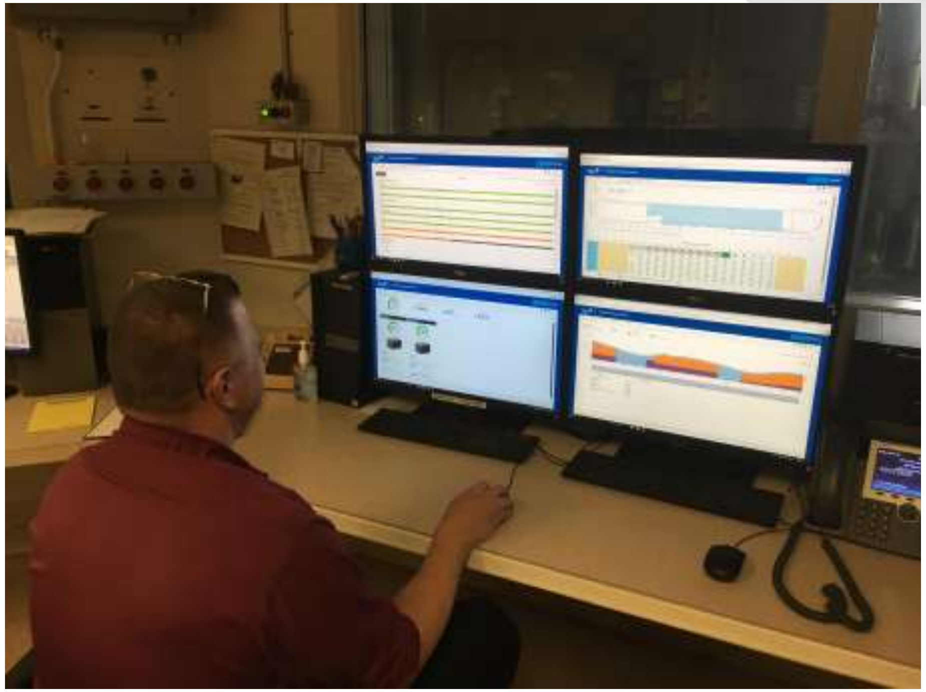
- Current loads and operating conditions
- Seven-day weather forecasts
- Real-time market prices for economic load demand response (ELDR)
- Electricity, water, and natural gas rates
- Campus events that may impact loads
- Equipment maintenance schedules

Dispatches ~150 control decisions every 15 minutes to ***minimize cost***, not just energy use, over 7-day horizon

Expected to help KSU generate over **$1 million** annually in utility savings and added ELDR revenues

"This system brings together all seven separate chiller plants into one platform that we can view easily, simultaneously, and from any remote location. Then it finds the optimal solution across the system, and accounts for changes every 15 minutes. That's something we just couldn't do manually...

\- **Dr. Frank Renovich, Associate Director of Energy Operations**



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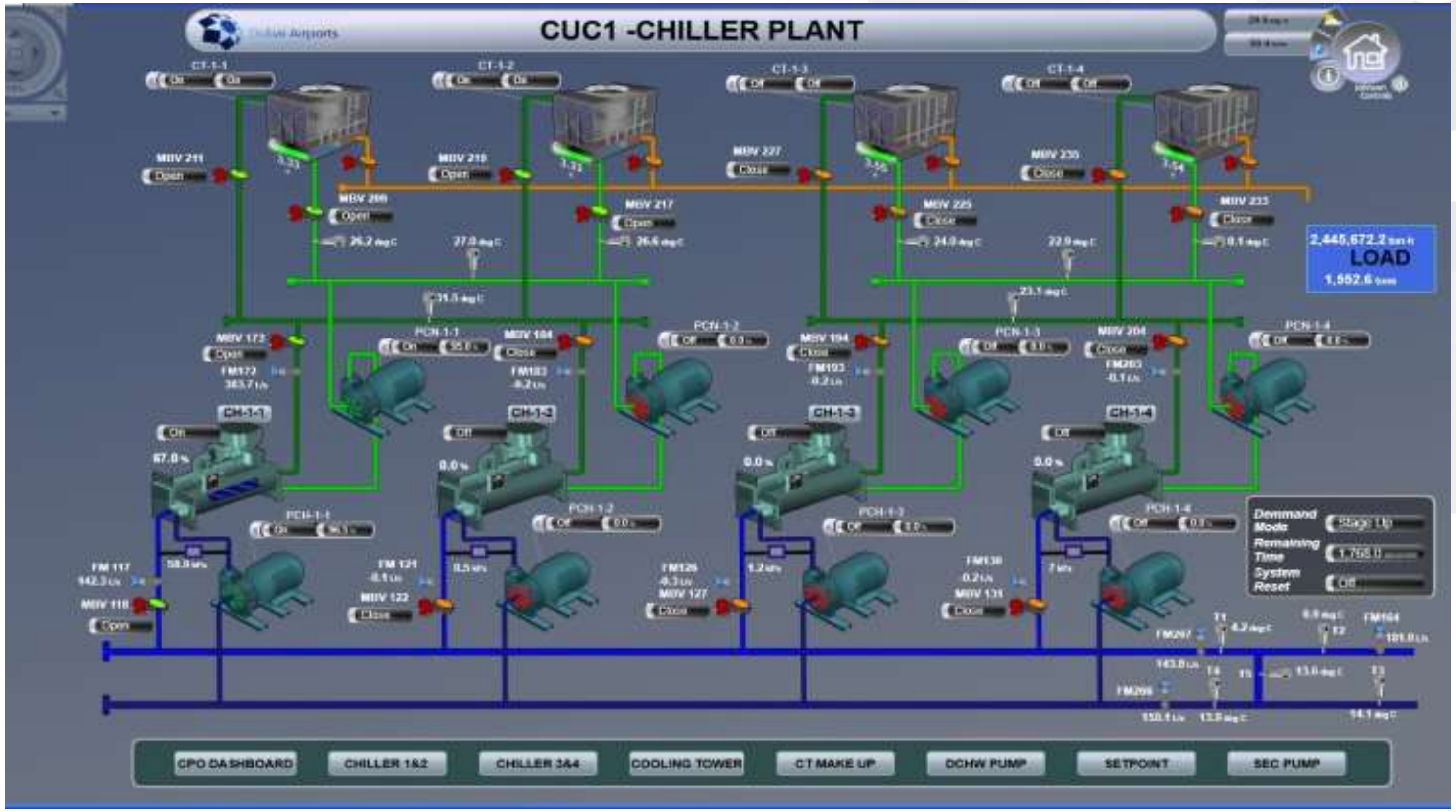
District Energy for Warmer Climates

Al Maktoum International Airport CUC-1 Plant, United Arab Emirates

- Chilled water district energy
- 8000 ton refrigeration capacity including 4 water-cooled chillers
- Constant Primary Flow / Variable Secondary Flow
- Baseline Annual Average System Efficiency = **1.018 kW/ton**



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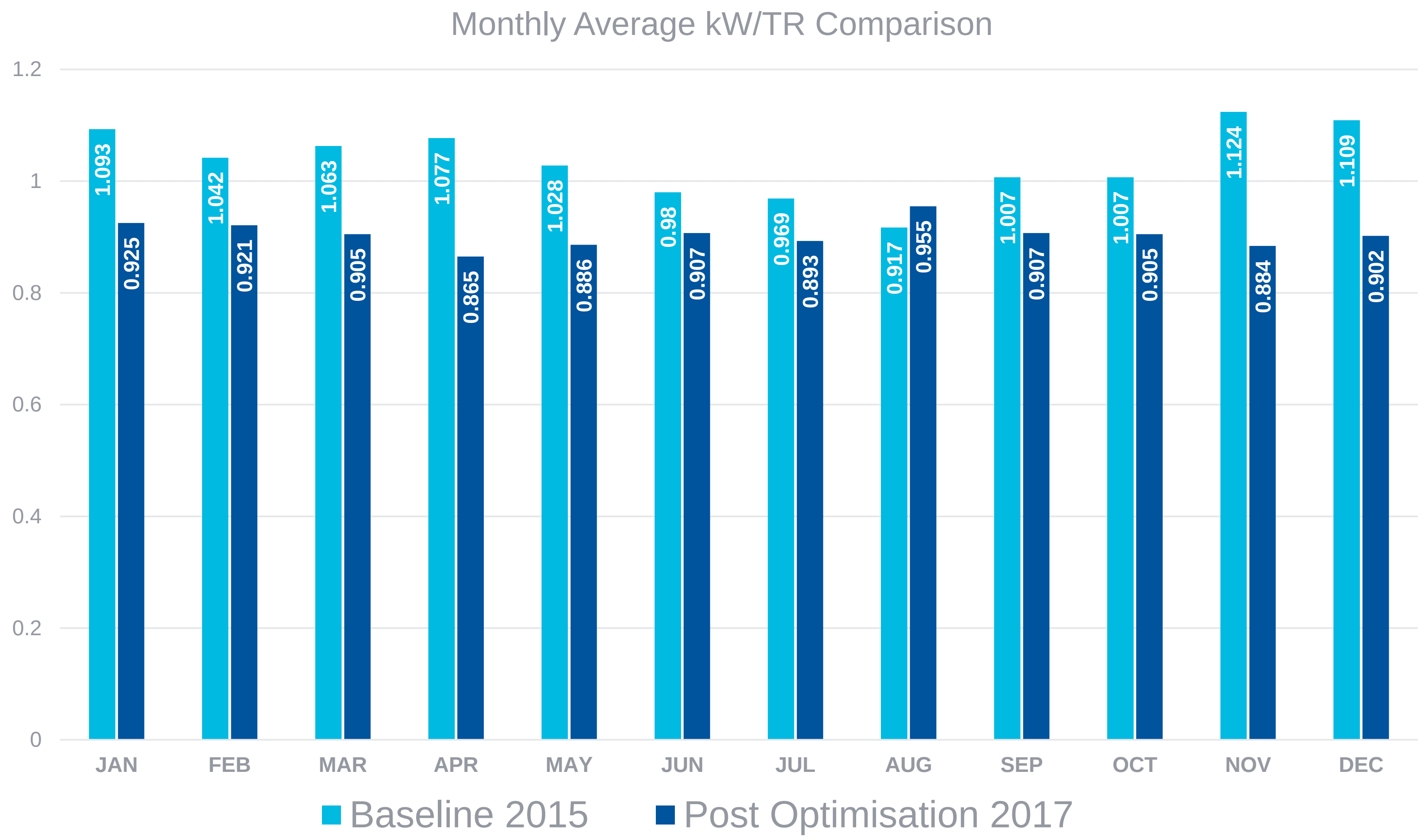

Impact Summary

Investment	AED 855,000
Avg Improvement in kW/TR	12.5%
Energy Savings	2,053,047 kWh/yr
Cost Savings	AED 923,871/yr
Simple Payback Period	0.93 Years

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SCOPE International AG, Chennai, India

- Chilled water plant serving office environment
- 1,725 Ton-R plant including both water-cooled and air-cooled chillers of differing vintages
- Variable primary flow configuration
- Baseline Annual Average Plant-wide Efficiency = **1.25kW/ton**
- SCOPE International sought to upgrade two chillers, add variable speed drives, and implement controls to holistically optimize:
  - chiller selection,
  - VSD chiller speed,
  - chilled water and condenser water pump speed, and
  - cooling tower fan speed

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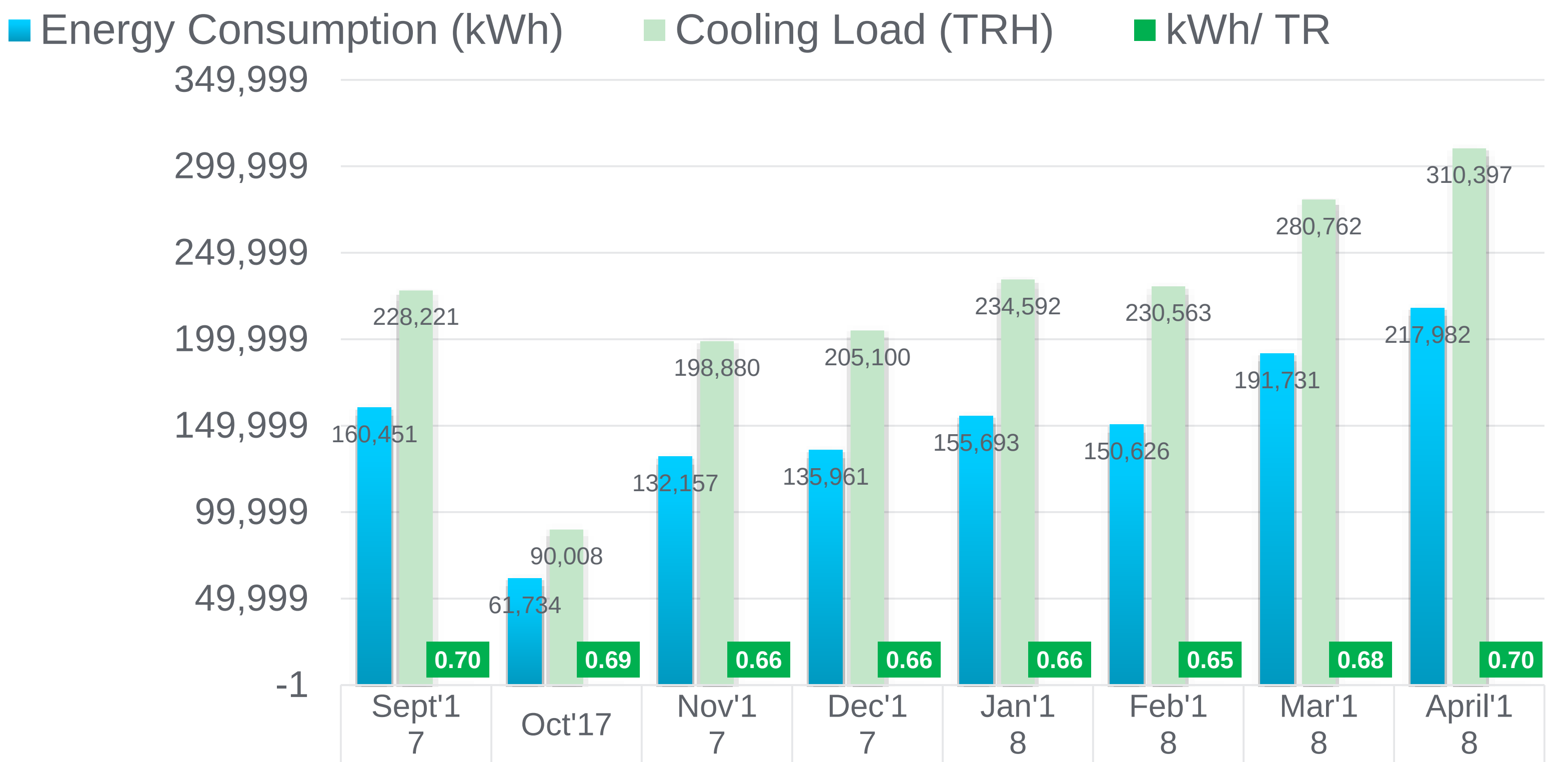
District Energy for Warmer Climates

SCOPE International AG, Chennai, India



	Sept'17	Oct'17	Nov'17	Dec'17	Jan'18	Feb'18	Mar'18	April'18
Energy Consumption (kWh)	160,451	61,734	132,157	135,961	155,693	150,626	191,731	217,982
Cooling Load (TRH)	228,221	90,008	198,880	205,100	234,592	230,563	280,762	310,397
kWh/ TR	0.70	0.69	0.66	0.66	0.66	0.65	0.68	0.70

Impact Summary

Improvement in Average kW/TR	43%
Energy Savings	2,357,200 kWh/yr
Peak Demand Reduction	405 kVa
Cost Savings	INR 2,17,37,200

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