CHP for Buildings Integration: Test Centers at ORNL and University of Maryland

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Washington, DC

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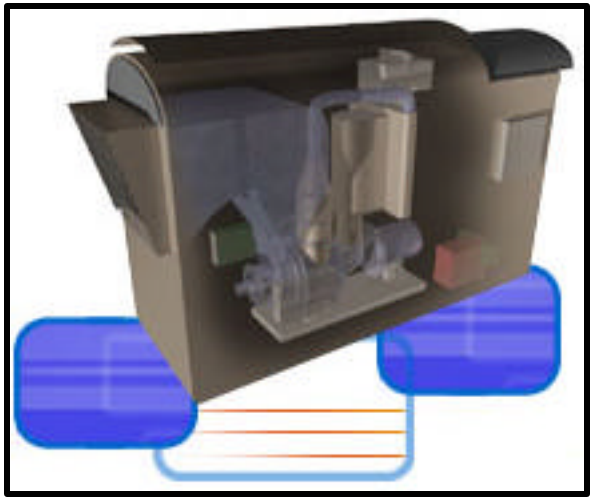
Presentation Outline

- **Integrated Equipment Systems (IES) Laboratory at ORNL**
  - **Tom Rizy, Abdi Zaltash**
- **CHP Commercial Building Integration Test Center at University of Maryland**
  - **Dr. Reinhard Radermacher, Matthew Cowie, Lucia Liao**

DOE's IES Vision
Packaged System Integration

2002: Individually optimized products combined on-site



2010: IES - single optimized package from manufacturer

IES System Components

Distributed Generation Technologies

Thermally-Activated HVAC Technologies

800ºF

600ºF

360ºF

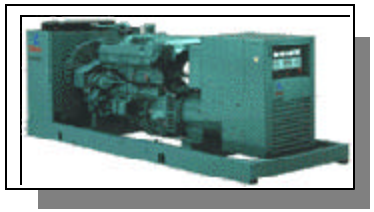
180ºF

Gas-turbine

Solid Oxide Fuel Cell

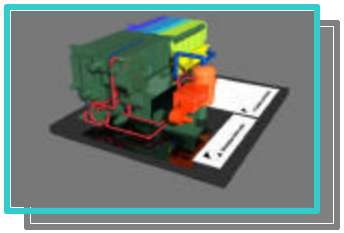
Micro-turbine

Commercial Phosphoric Acid Fuel Cell



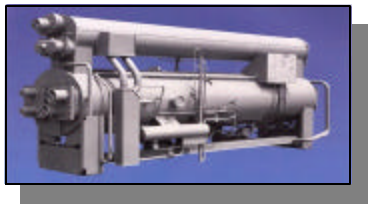
I.C. Engine

Residential PEM Fuel Cell



Triple-Effect Absorption Chiller

Double-Effect Absorption Water-Cooled Chiller



Single-Effect Absorption Chiller

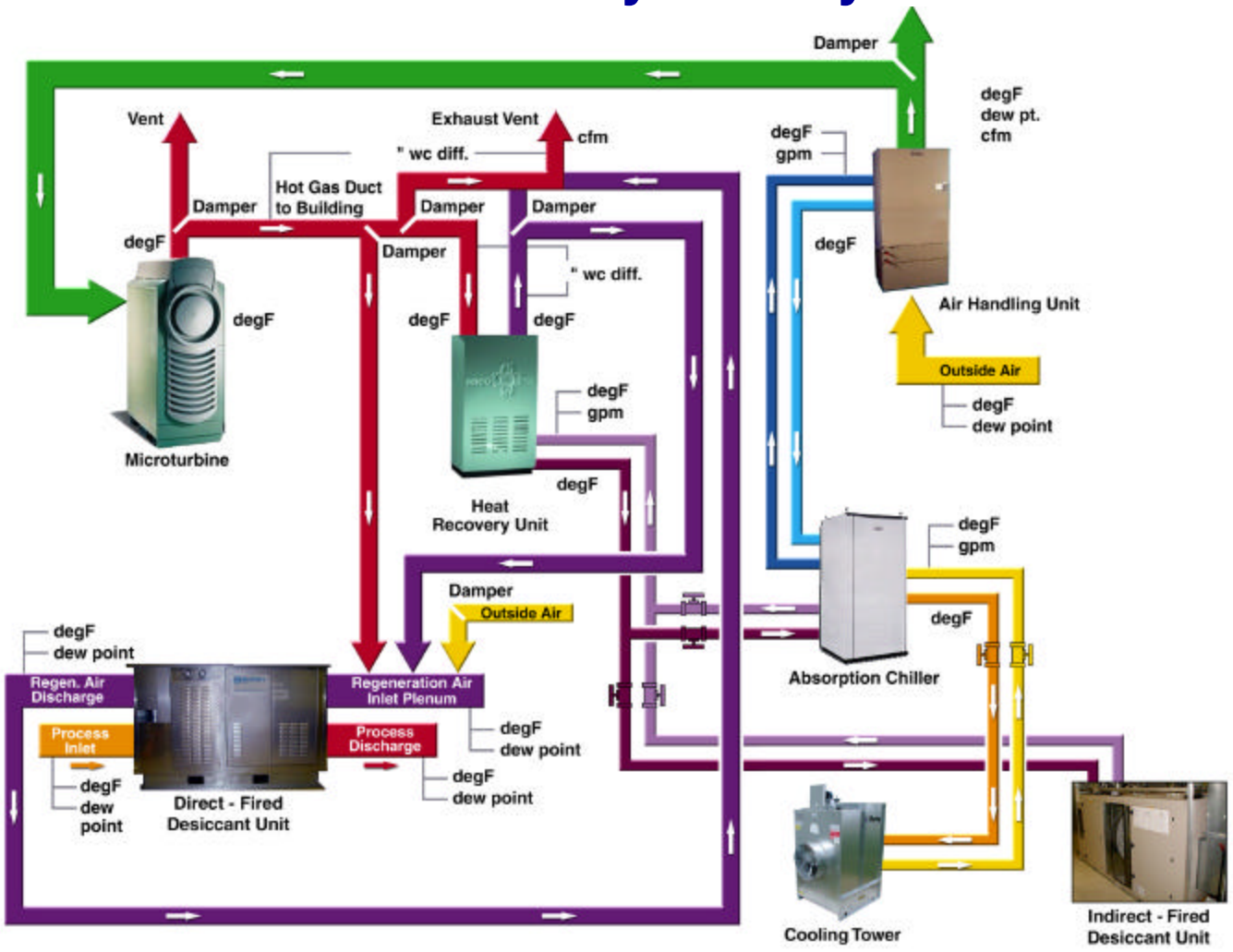
Desiccant Technology

Recoverable Energy Quality (Temp) and HVAC Technology Match

Objectives of the IES Laboratory

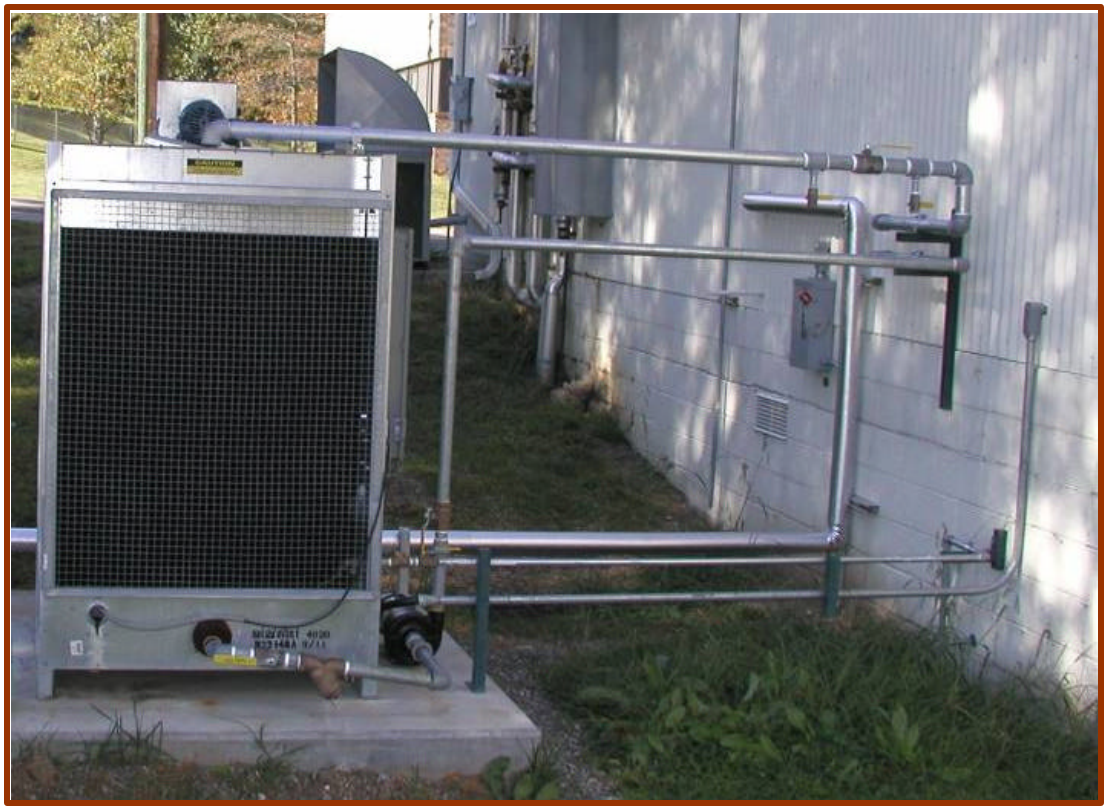
- **Benchmark DER Equipment Performance and Emissions**
- **Benchmark Integrated Equipment System Performance**
  - **Currently focused on MTG-based IES**
- **Provide Data for Computer Models and Verification**
- **Identify Component and System Improvements for current packaged IES manufacturers and "Next Generation" Products and Applications**
- **Provide Diagnostic Support for Field Test Data Analysis**
- **Support Rating/Certification Standards for IES Products**

Integrated Energy Systems (IES) Laboratory Facility



IES Laboratory – Outdoor Configuration

30 kW Microturbine



Cooling Tower for 10 Ton (35 kW) Single-Effect Absorption Chiller

IES Laboratory – Indoor Configuration

Exhaust Heat Recovery Test Loops

IES Laboratory
Key Milestones

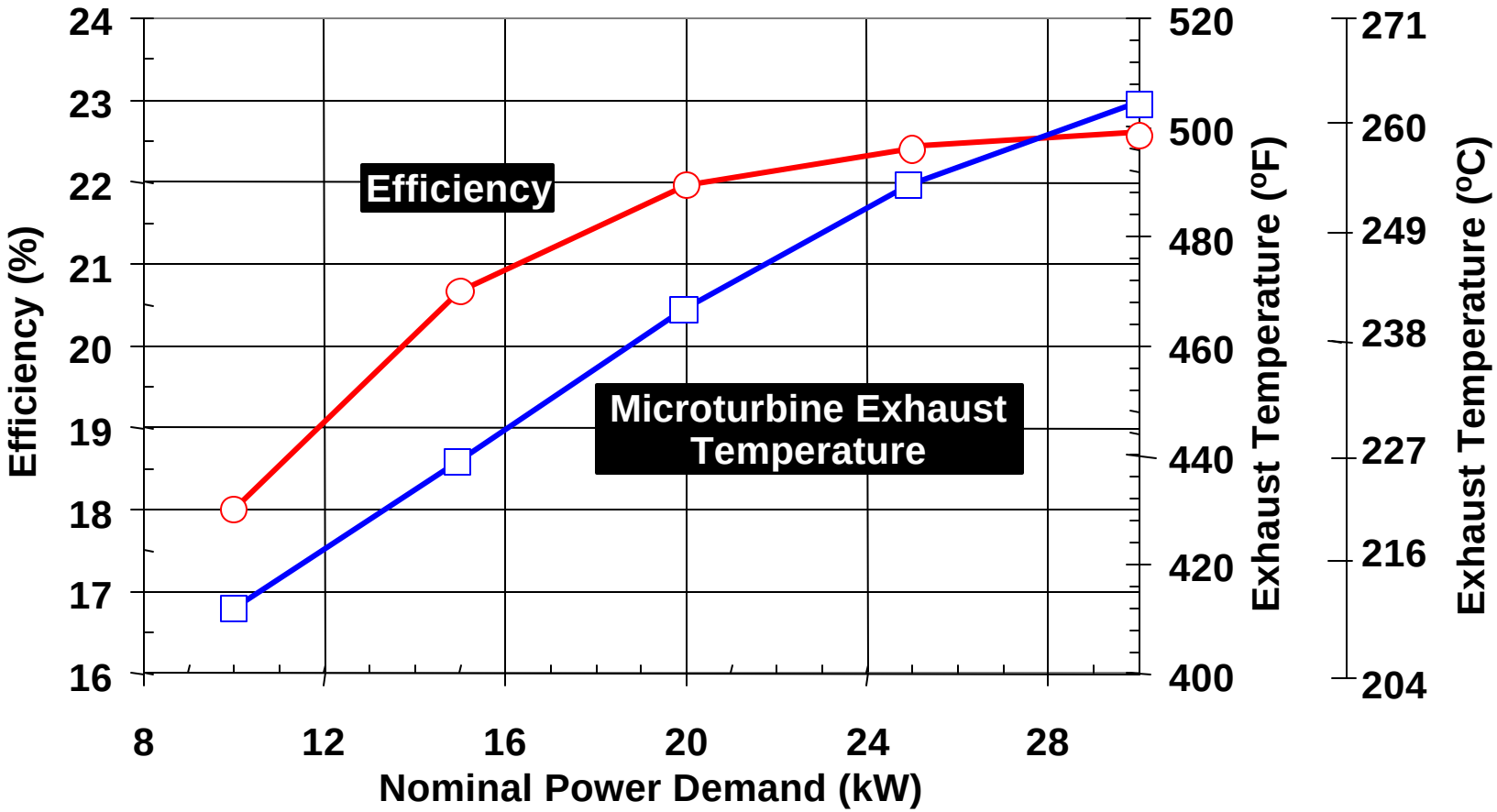
- **Designed and Setup in CY2000 and CY2001**
- **Commissioned at the end of CY2001**
- **IES Testing of 30 kW MTG-based system**
- **Designated as "National User Facility" in Summer 2002**
  - **Provides industry with greater access and control to various IES testing that can be conducted at the laboratory.**
- **Early success story regarding HRU re-design by manufacturer**
- **User agreement signed with first industry user last month**

Areas of IES Performance Testing

- Microturbine Baseline Performance (MTG)
- Heat Exchanger (Air-to-Water) Thermal Loop
  - Recover exhaust heat with air-to-water HRU
  - Indirect-fired desiccant dehumidifier
- Desiccant Dehumidification Thermal Loop
  - Direct-fired desiccant dehumidifier
- Absorption-Chiller Thermal Loop
  - Use 10 ton single-effect indirect-fired absorption chiller
  - Supply 44ºF (7ºC) chilled output water to provide cooling

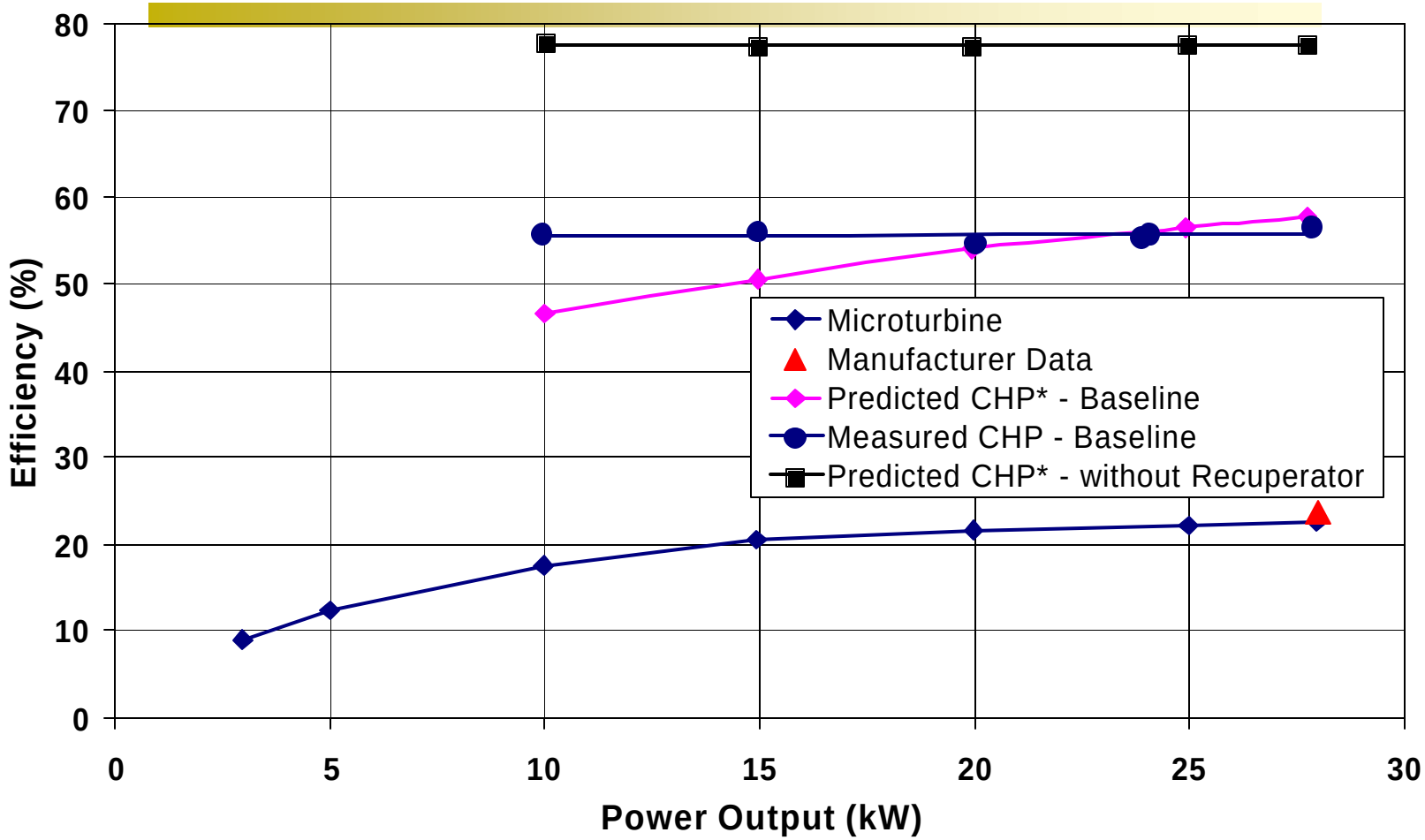
Microturbine Benchmark

Efficiency vs. Power Output*



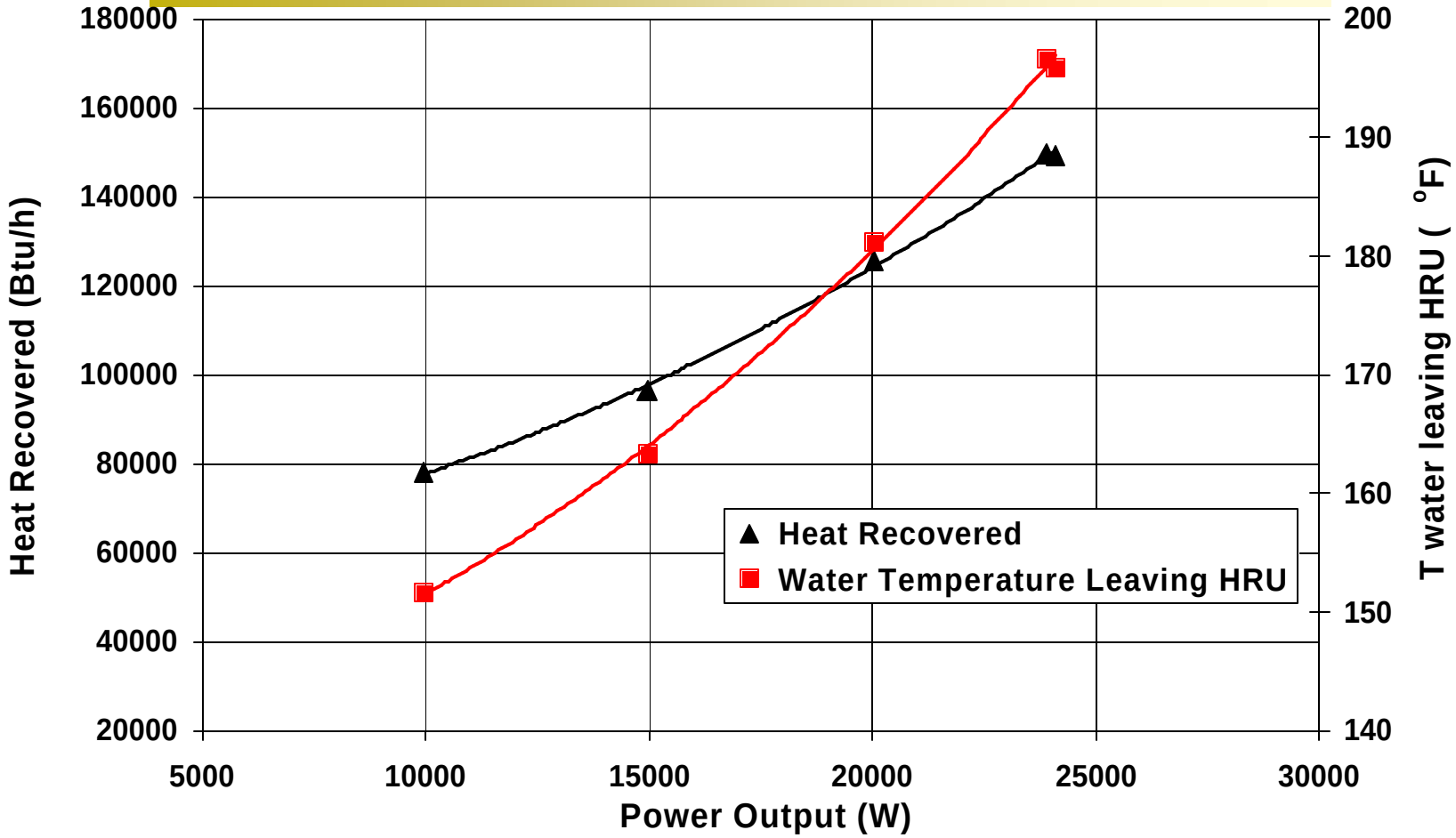
** Based on Natural Gas Higher Heating Value (HHV), outside ambient temperature between 30 to 40ºF (-1 to 4ºC)*

Microturbine and CHP Efficiencies Based on HHV of Natural Gas

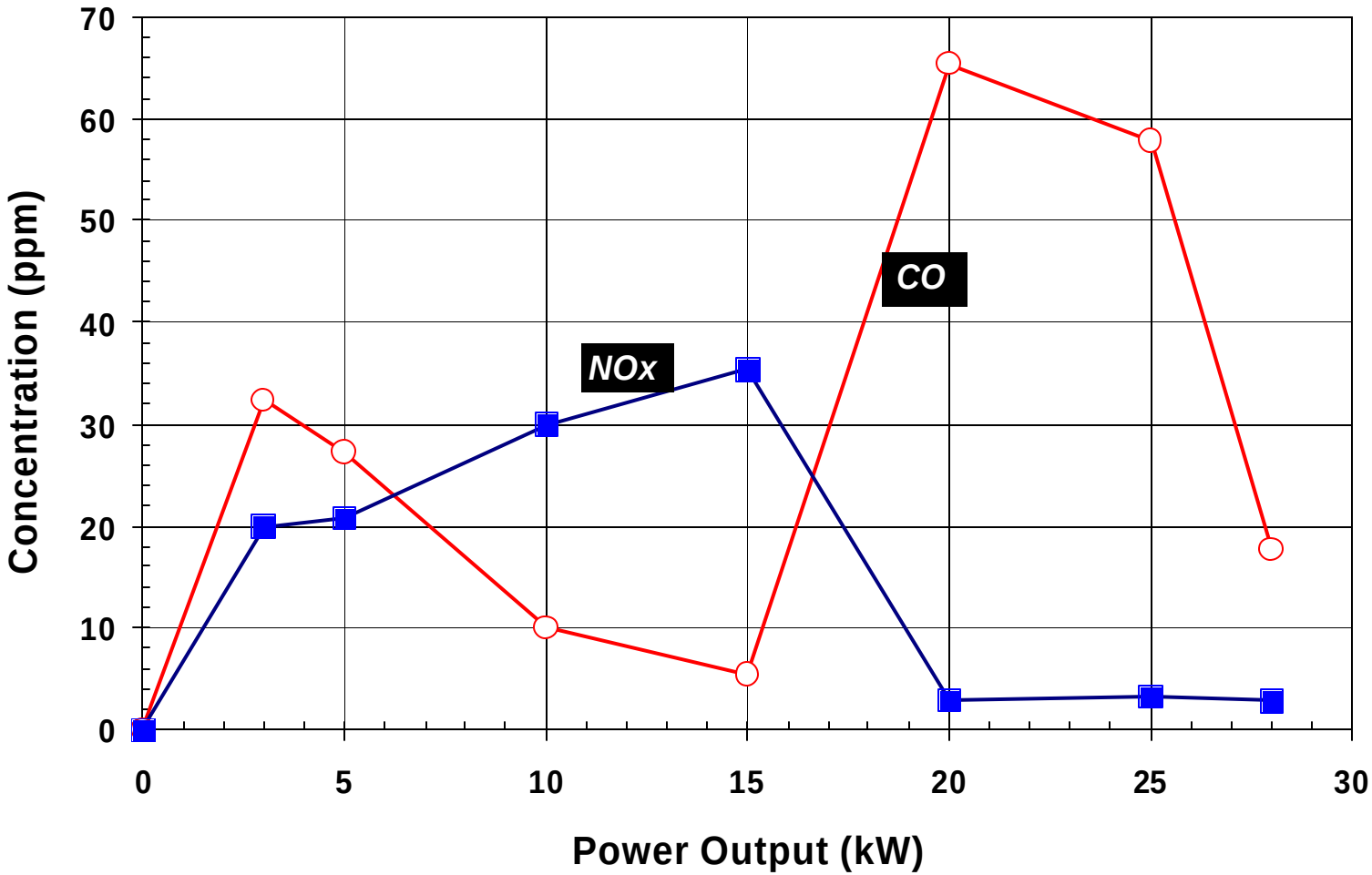


**Based on 127°C (400K) or 260°F flue gas rejected to the atmosphere*

Heat Recovery in the HRU with Water Flow Rate of 19 gpm or 4.3 m^3/h



Flue Gas Emissions at Various Power Outputs (Steady-State)



Summary of Microturbine Performance

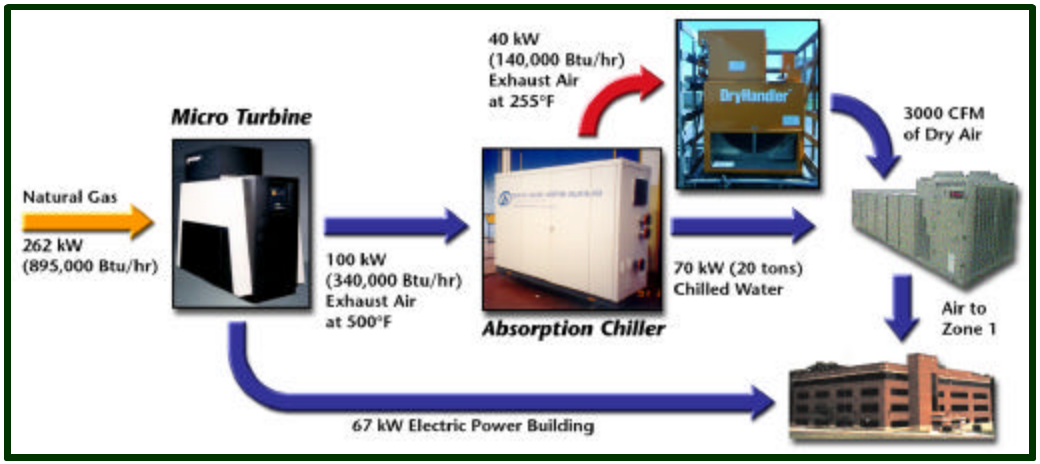
- **Efficiency of Unit Drops Off Significantly with Power Output**
- **Above 65°F (18°C), Turbine RPM Limit Causes Drop Off in Power Output**
- **Only Major Problem Encountered is the Natural Gas Compressor**
- **Low Emissions At Full Power: Emissions Increase At Lower kW**
- **Developed/verified a semi-empirical CHP mathematical model**
- **Obtained analytical relationship between the changes in the CHP system using linear analysis**
- **Model predicted significant improvement in CHP system efficiencies with elimination of microturbine recuperator**

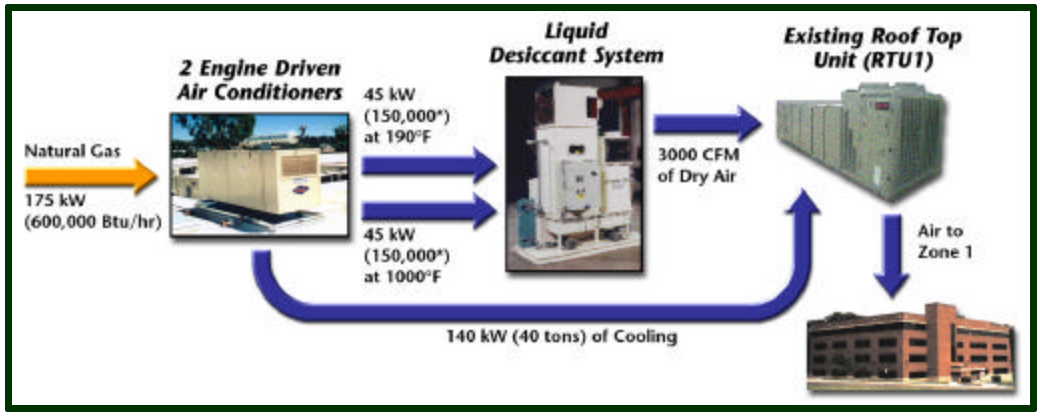
Future Work

- **Near Future Testing**
  - **Test larger MTGs - industry moving towards larger units to make them more attractive to the marketplace**
  - **Extend testing to encompass other DR systems such as reciprocating engines and fuel cells**
- **Laboratory's National User Designation**
  - **Increases flexibility to work directly with business and industry in developing/testing IES**
  - **Model and test modular IES package systems to improve technology and accelerate its introduction to the market**
- **Future - assessment of IES controls and advanced diagnosis & thermal energy storage**

University Test Center for IES/Building Integration

University of Maryland, College Park





Center for Environmental Energy Engineering

OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

U of M Staff Partnering With ORNL's CHP Integration Laboratory Personnel

- **Integrate equipment into CHP systems**
- **Integrate CHP systems into commercial buildings**
- **Demonstrate performance potential in an occupied building**
- **Provide essential technical knowledge to manufacturing partners**

The CHP Integration Test Center is a Platform for Professional Collaboration

- ORNL - Sensors (CO_2 and Humidity)
- PNNL – Whole Building Diagnostician
- NREL – Liquid Desiccant Components
- Energy Storage (DOE, Energetics, NRECA, Sandia – Distributed Energy Technology Simulator)
- Southern Research Institute, EPA, Honeywell – Independent Verification of Micro-Turbine Performance and Emissions
- ORNL – Integrated System Performance Evaluation

Integration Test Center Building

- TYPICAL, MEDIUM SIZE OFFICE BUILDING, 51,000 FT^2,
- 4 FLOORS, 2 ZONES
- 90-TON ROOF TOP UNIT FOR EACH ZONE
- COOLING ALL YEAR
- ECONOMIZER CYCLE
- VAV WITH ELECTRIC REHEAT
- LOW LEVEL CONTROLS
- GAS RARELY USED
- ELECTRIC ~300 kW PEAK
- 10 YEARS OLD, 200 OCCUPANTS

IES Test Center
Key Milestones

- **Baseline data collected in CY00**
  - **Installed data acquisition system: >160 sensors**
  - **Performed baseline building and micro-turbine performance**
  - **Performed baseline of indoor environment**
- **Commissioned Integrated Systems in CY01**
  - **System #1 (Honeywell MT, Broad Chiller, ATS desiccant)**
  - **System #2 (Goettl Engines, Kathabar desiccant)**
  - **Tested Trion air filter**
  - **Performed indoor environmental assessment**
- **Tested modified integrated systems in CY02**
  - **System #1 (replaced Honeywell with Capstone MT)**
  - **System #2 (replaced 1 Goettl engine)**
  - **Tested both systems on propane**

HP VEE - DAQ40.vee

File Edit View Debug Flow Device I/O Data Display Window Help

Main

Start

Time of Last Reading: Wed 28/Feb/2001 1:00:37 PM

Microturbine Efficiency (%): 24.21

* Estimate (as of 2/27/01)

Damp1: 0: 4.446m

Damp2: 0: 3.894m

Delay: 0

Interval: 60

..\..\DATA\HP VEE\022811.dat

Total Accumulated Actual Savings (kW-hr) *: -237.84

Total Accumulated Potential Savings (kW-hr) *: 1285.05

Total Accumulated Actual Savings ($) *: $ -3.44

Total Accumulated Potential Savings ($) *: $ 25.88

CO2 (ppm)

R1 S.A.	R1 R.A.	R2 S.A.	R2 R.A.
0: 410.9	0: 480.4	0: 489.5	0: 529

Temperature (F)

R1 SA	R1 R.A.	R1 M.A.	Space...
50.99	71.11	-13	00: 74.92
			01: 73.99
			02: 76.51

R2 SA	R2 R.A.	R2 M.A.
59.11	72.19	54.93

Relative Humidity (RH)

R1 S.A.	R1 R.A.	R1 M.A.	Space...
19.46	12.93	264.1	00: 12.69
			01: 14.26
			02: 13.97

R2 S.A.	R2 R.A.	R2 M.A.
16.75	12.29	27.18

Gas line

Flow Rate (CFM)	Temp(deg. F)
0: 566.6E36	0: 2.944E39

SRI Testing

Comp. ...	Temp (C)	RH (%)	P (psia)
2.379	0: -1.228E39	0: 122.6	0: 495E36

Pressure (psig): 0: 113.5E36

.\SRI-DATA\SRI-022811.dat

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Power (kW)

T1	HP1&2	RTU1
15	27.8	9.26
25.28	46.7	15.56

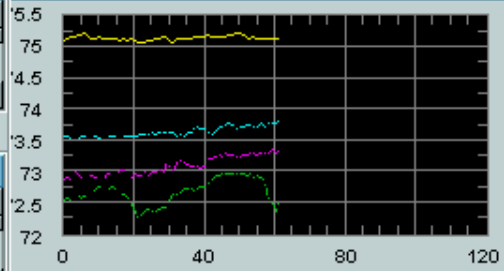
T2	HP3&4	RTU2
14	23.2	10.7
23.5	39.03	18.04

Total	kW	V
168.1	0: 103.8	0: 1.04

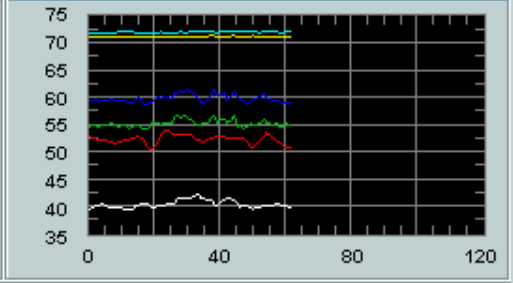
Airflow

CFM
0: 2866
1: 2324
2: 8634
3: 9525
4: 12.98k
5: 10.25k

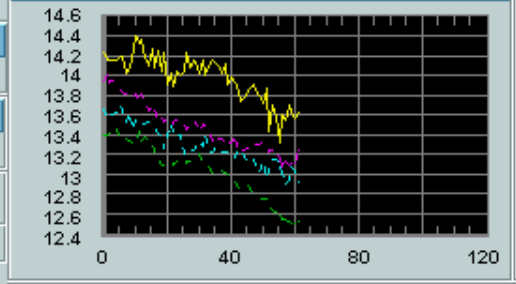
4-Hour Space Temperature History (F)



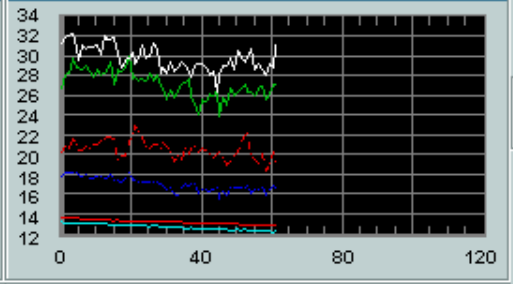
4-Hour RTU Temp History (F)



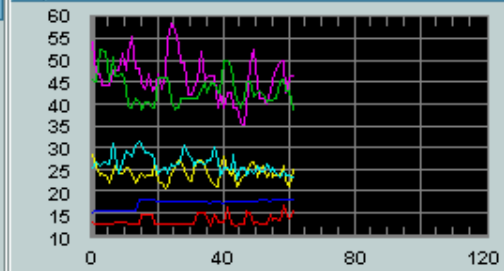
4-Hour Space RH History (%)



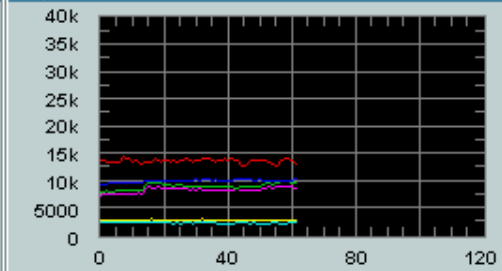
4-Hour RTU RH History (%)



4-Hour Power History (kW)



4-Hour Flow Rate History (CFM)



VAV	H	F	RTU1	RTU2
1			EF	
2			C1	
3			C2	
4			HG1 46.5	84.8
5			HG2 48.9	41.9
6			L1	
7			L2	
8			SF1 5.4	8.8
9			SF2 4.6	7.2
10				
11				

Natural Gas

ft.^3 /int.
0: 15
1: 0
2: 0

Bldg Press

Z1...	Z2...
-0.067	0.019

Weather Station

OA F: 39.99

OA RH %: 31

CO2...: -500

Solar W/m^2: Sunny 709

Wind Speed mph: 9.9

Press...: 29.82

Wind Direction deg: 314

Ready

STD PROF MOD WEB

Start BASLin... HP... PE... DA... LO... VIS... IT... Ex... 1:01 PM

Tree Site Page - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Back Search Favorites History

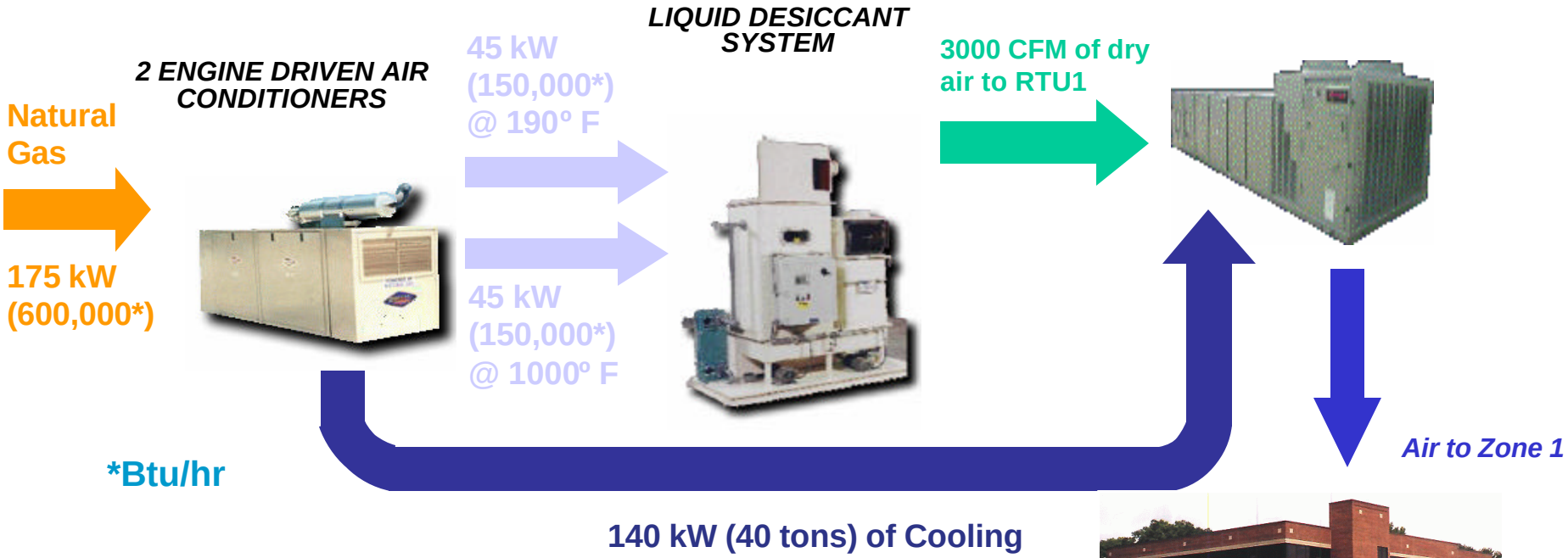
Address http://129.2.32.252/stations/UofMdBCHP01/TREE/SiteTreeIE[1.htm Go

Links Yahoo! University of Maryland BCHP Homepage Data Acquisition System

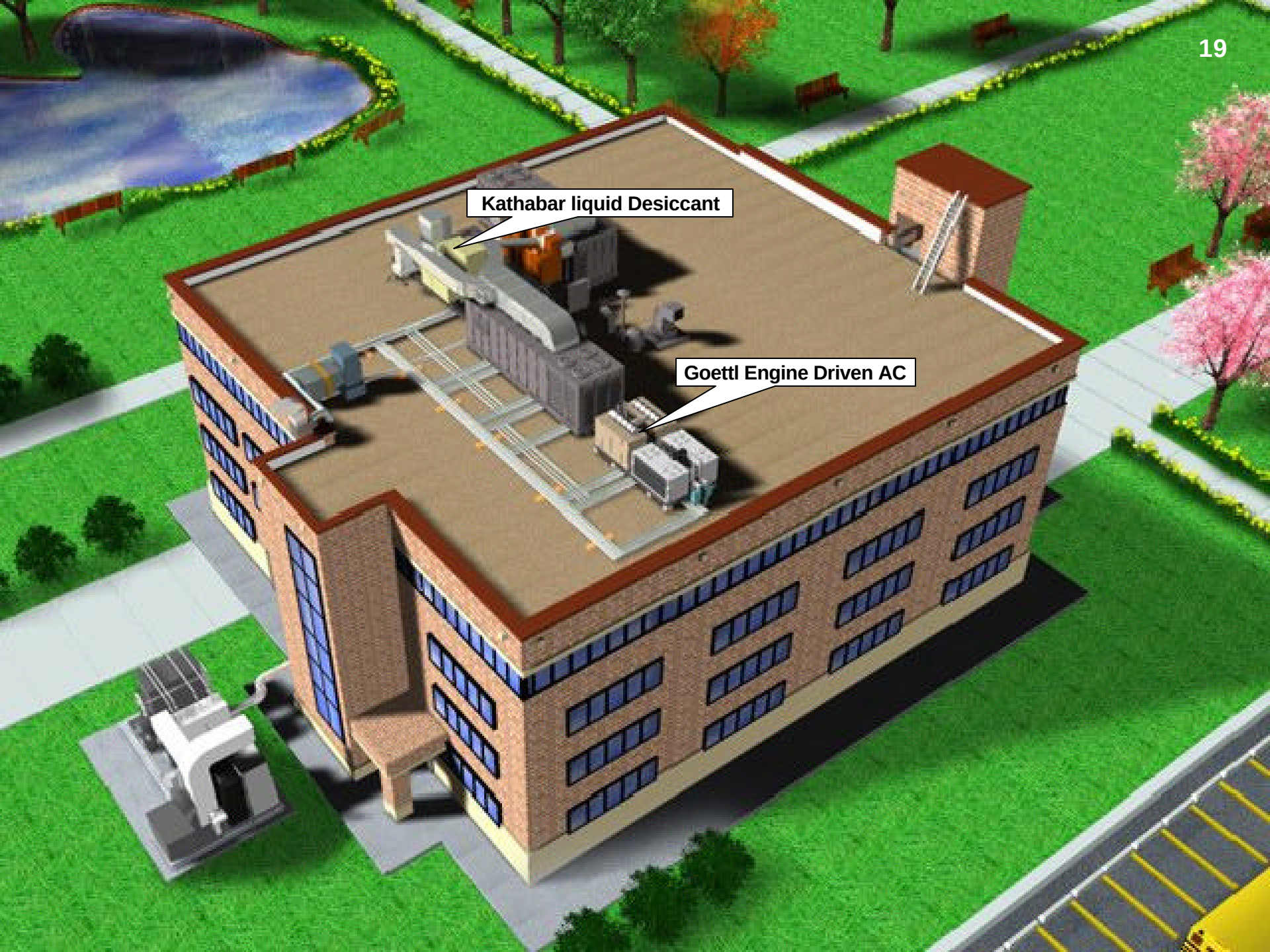
- U of MD Chesapeake Hall
- Broad Chiller
- ATS Dessicant Unit
- Roof Top Unit 2
- Logs
- Log Archive
- Alarms
- Alerts

www.enme.umd.edu/ceee/bchp

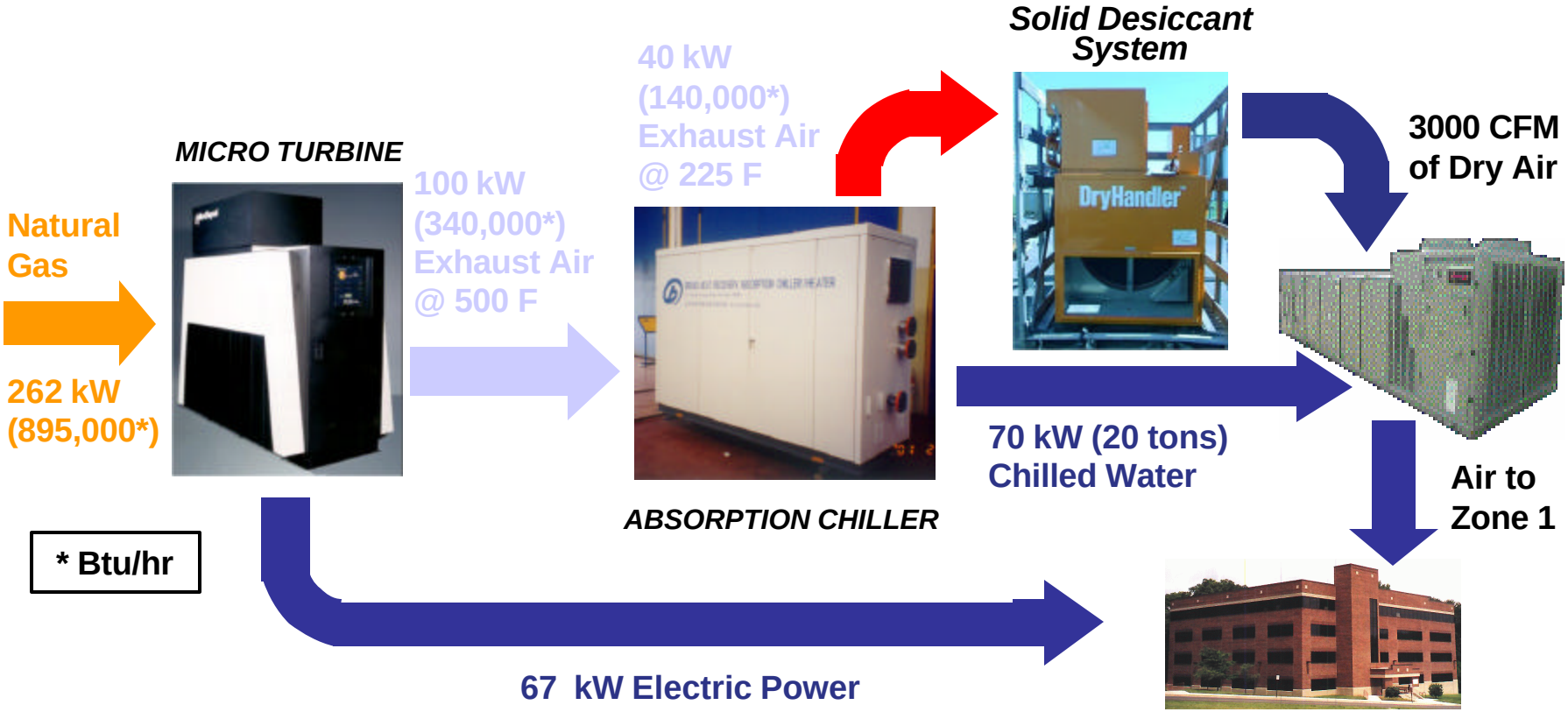
CHP System 1



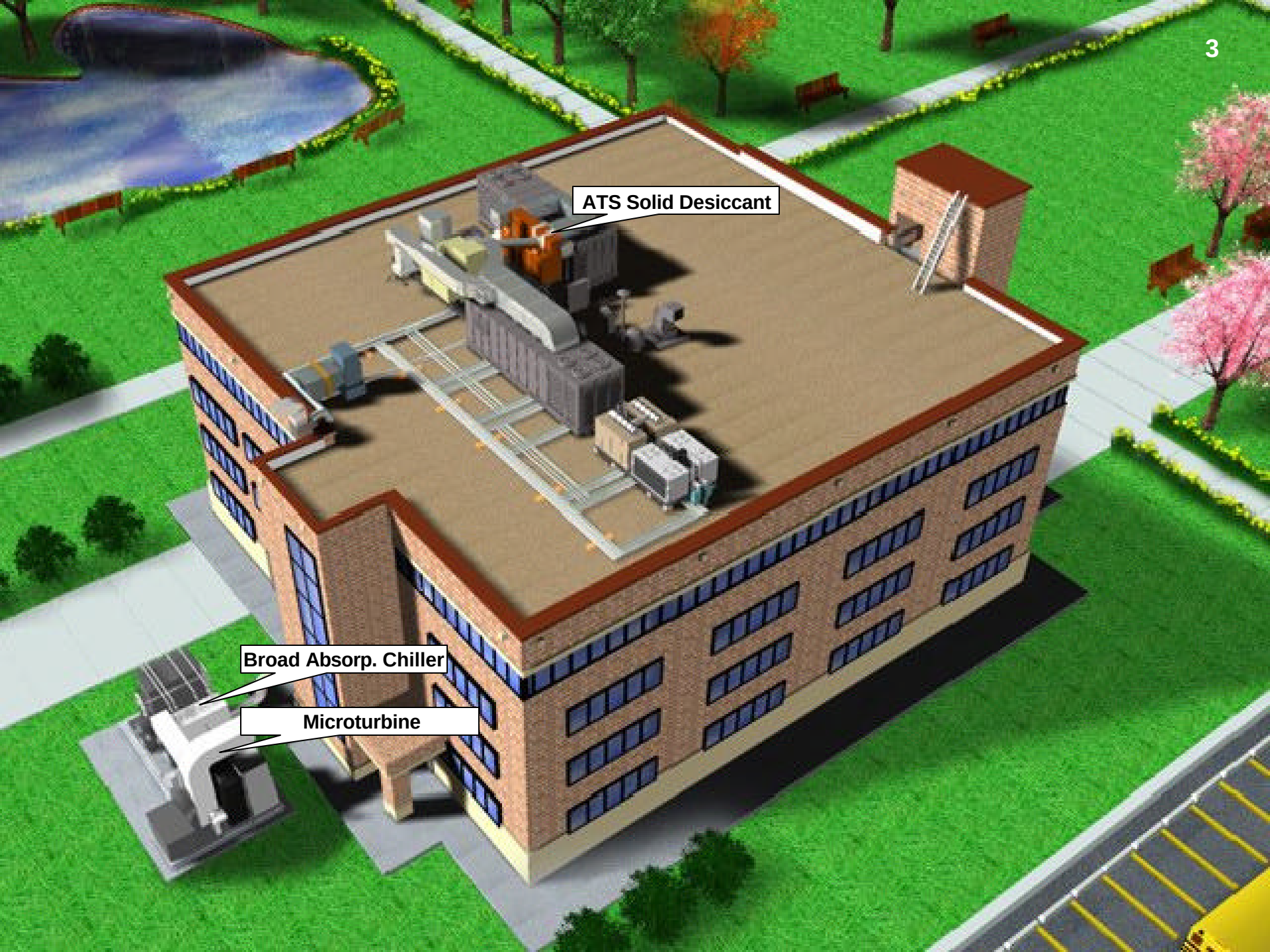
- **Engine Jacket Water & Exhaust Used to Regenerate Desiccant**
- **Liquid desiccant only waste heat driven**


Kathabar liquid Desiccant
Goettl Engine Driven AC

CHP System 2 – Year 1



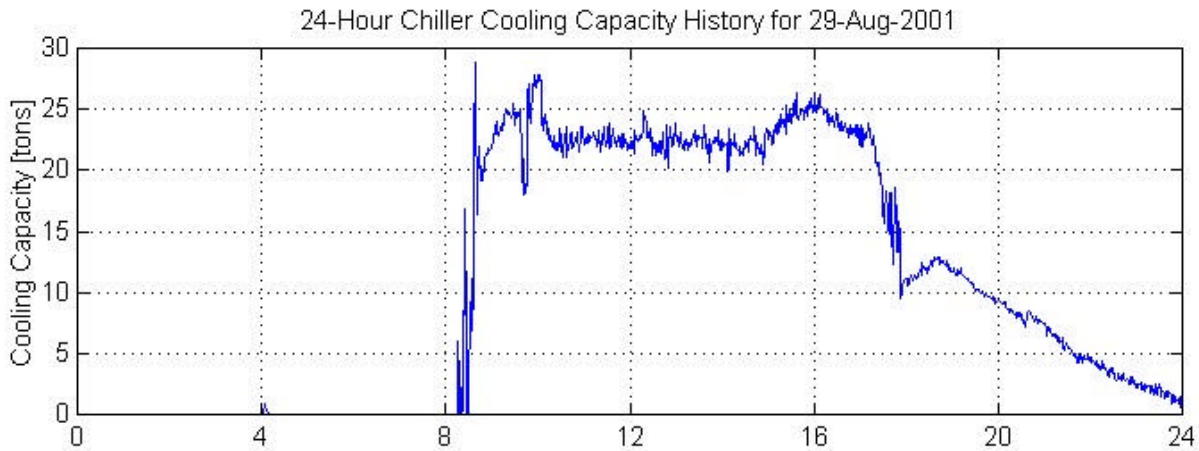
- Turbine efficiency 25.6 %, with chiller 63.5 %, and with desiccant 79.2%
- Single effect absorption chiller with COP of 0.7
- Supplemental cooling provided by existing RTU

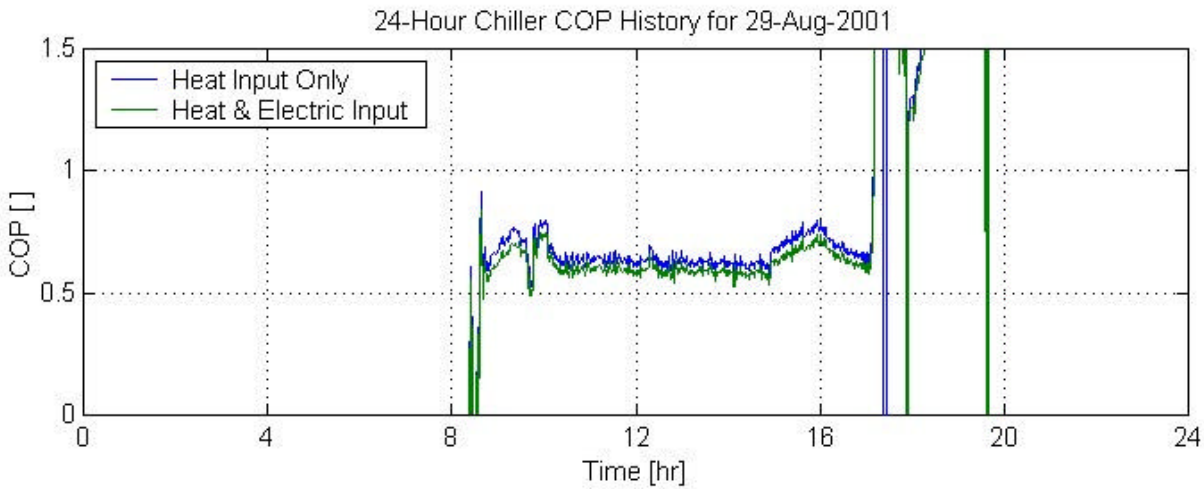

ATS Solid Desiccant
Broad Absorp. Chiller
Microturbine

Broad Absorption Chiller

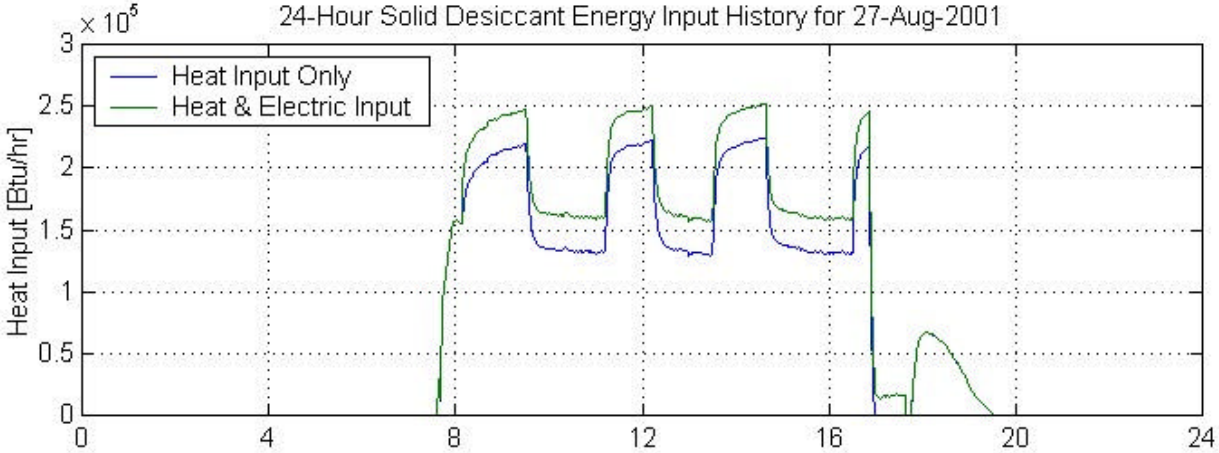
- Microturbine exhaust driven only
- 20-ton nominal capacity
- Single effect, COP = 0.7
- VFD fan drives exhaust through generator
- Microturbine power drives chiller & auxiliaries about 10 kW
  - Chilled water pump
  - Condenser water pump
  - Cooling tower
  - Exhaust fan
  - Solution and refrigerant pumps

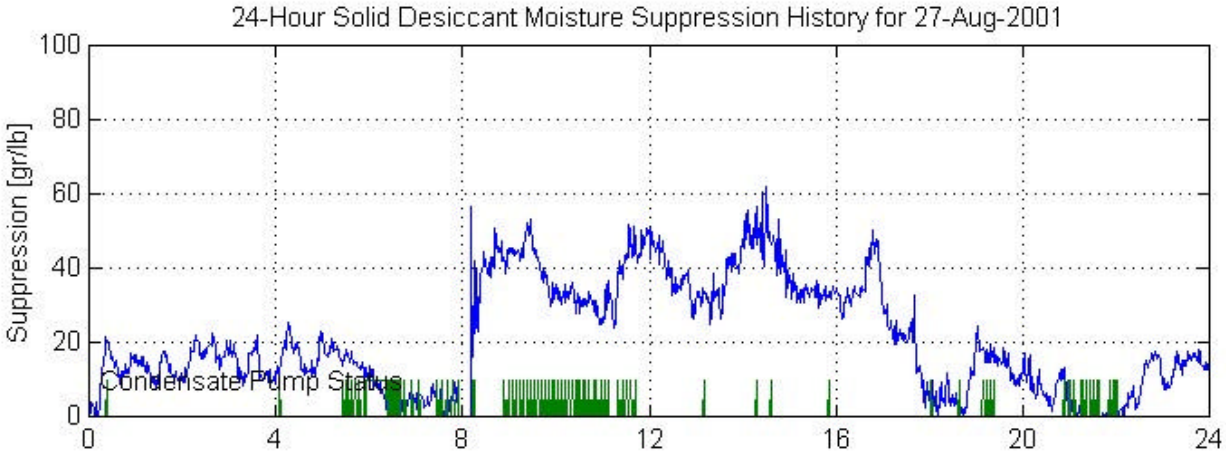
Absorption Chiller Data



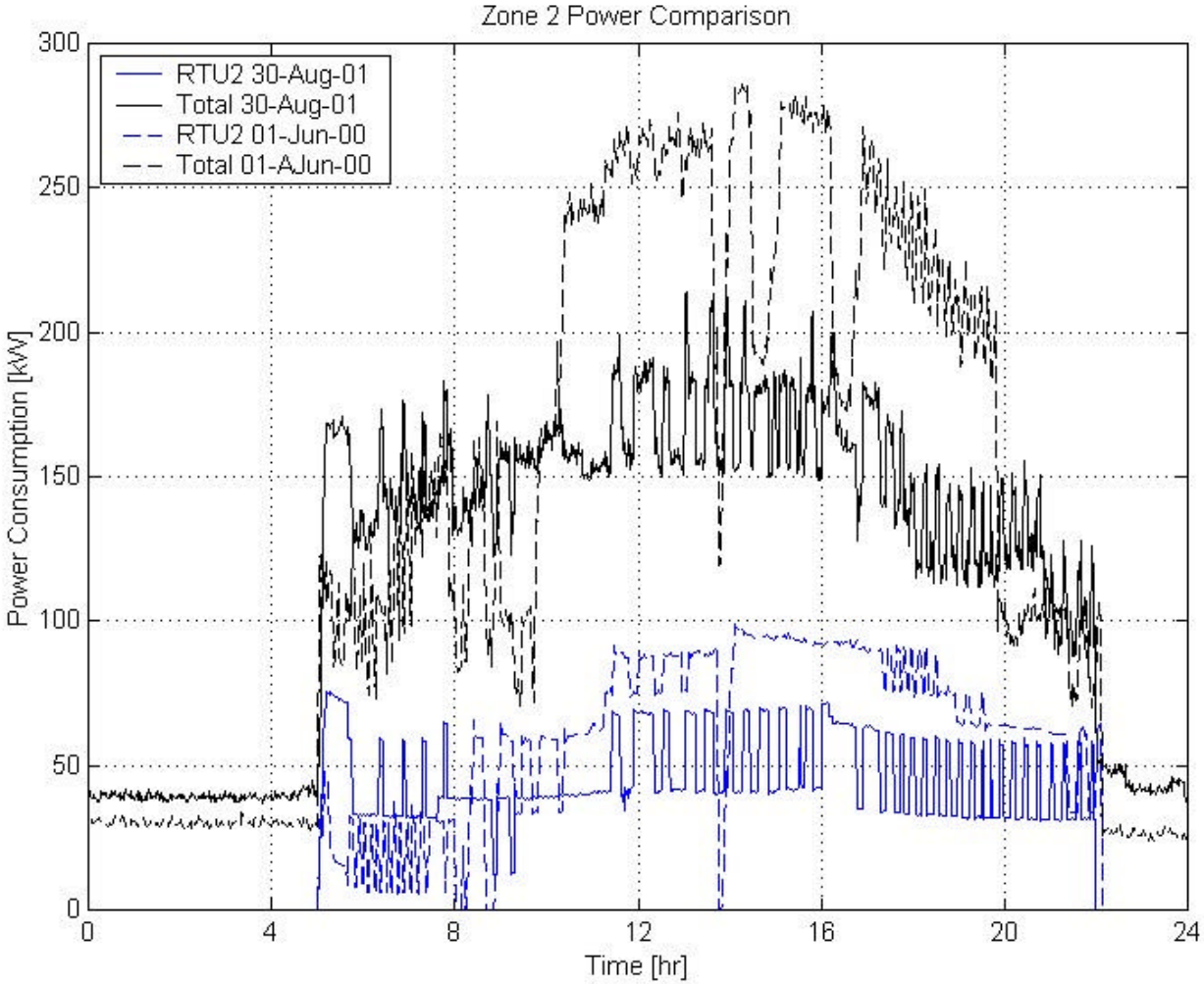


Solid Desiccant Performance

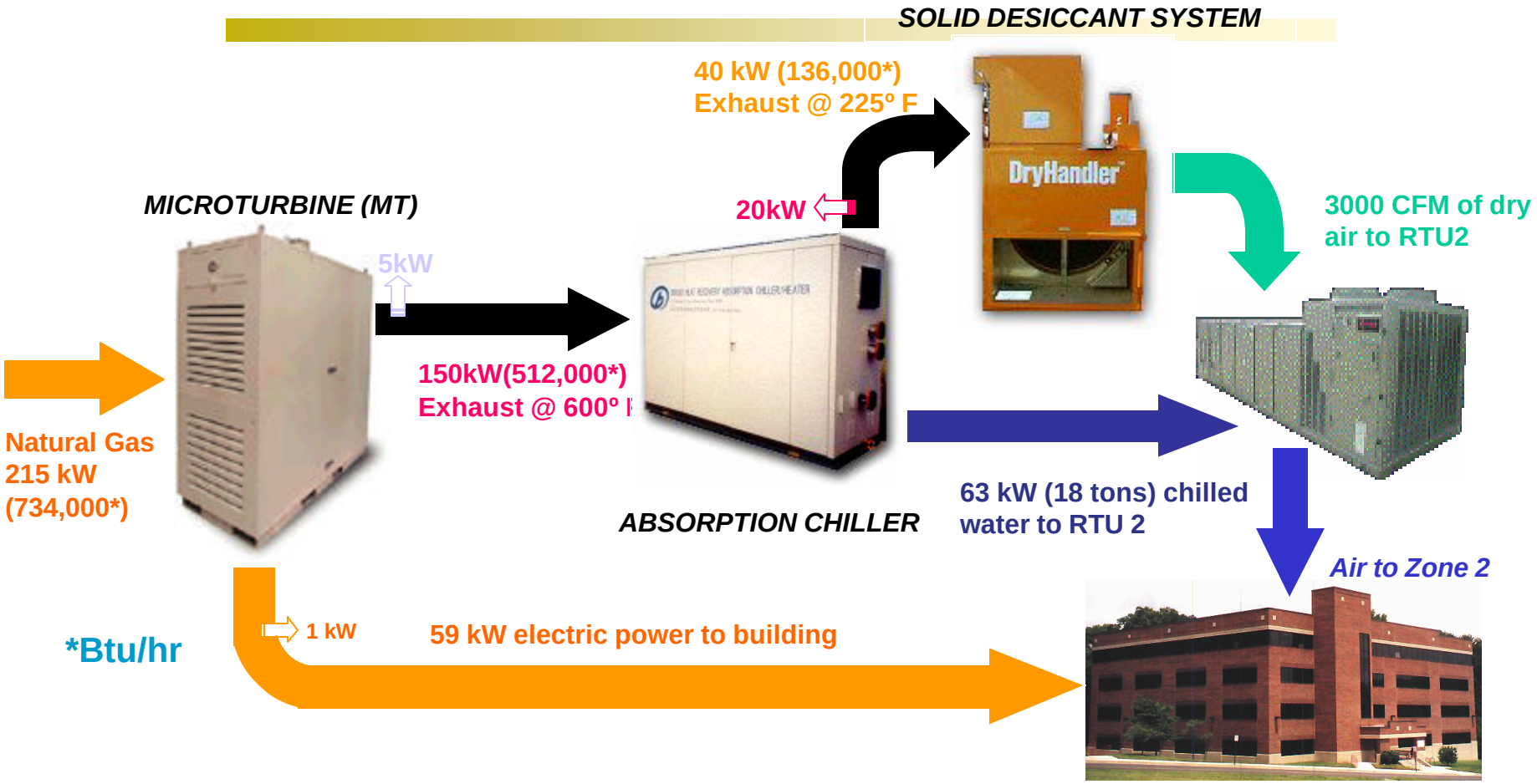


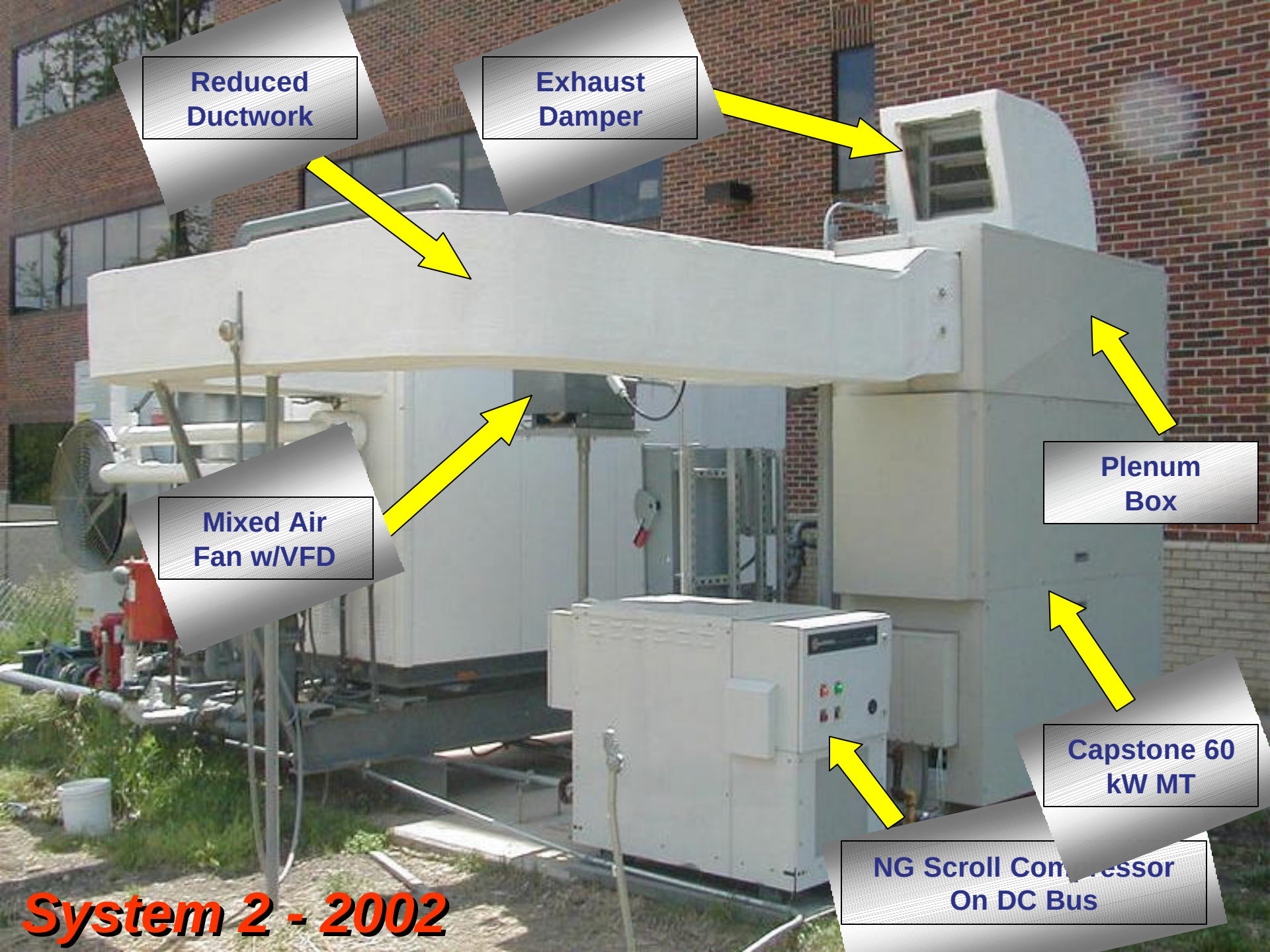


Comparison


Zone 2 Power Comparison
RTU2 30-Aug-01
Total 30-Aug-01
RTU2 01-Jun-00
Total 01-AJun-00
Power Consumption [kW]
Time [hr]
0
50
100
150
200
250
300
0
4
8
12
16
20
24

CHP System 2
Modified with Capstone 60 MT

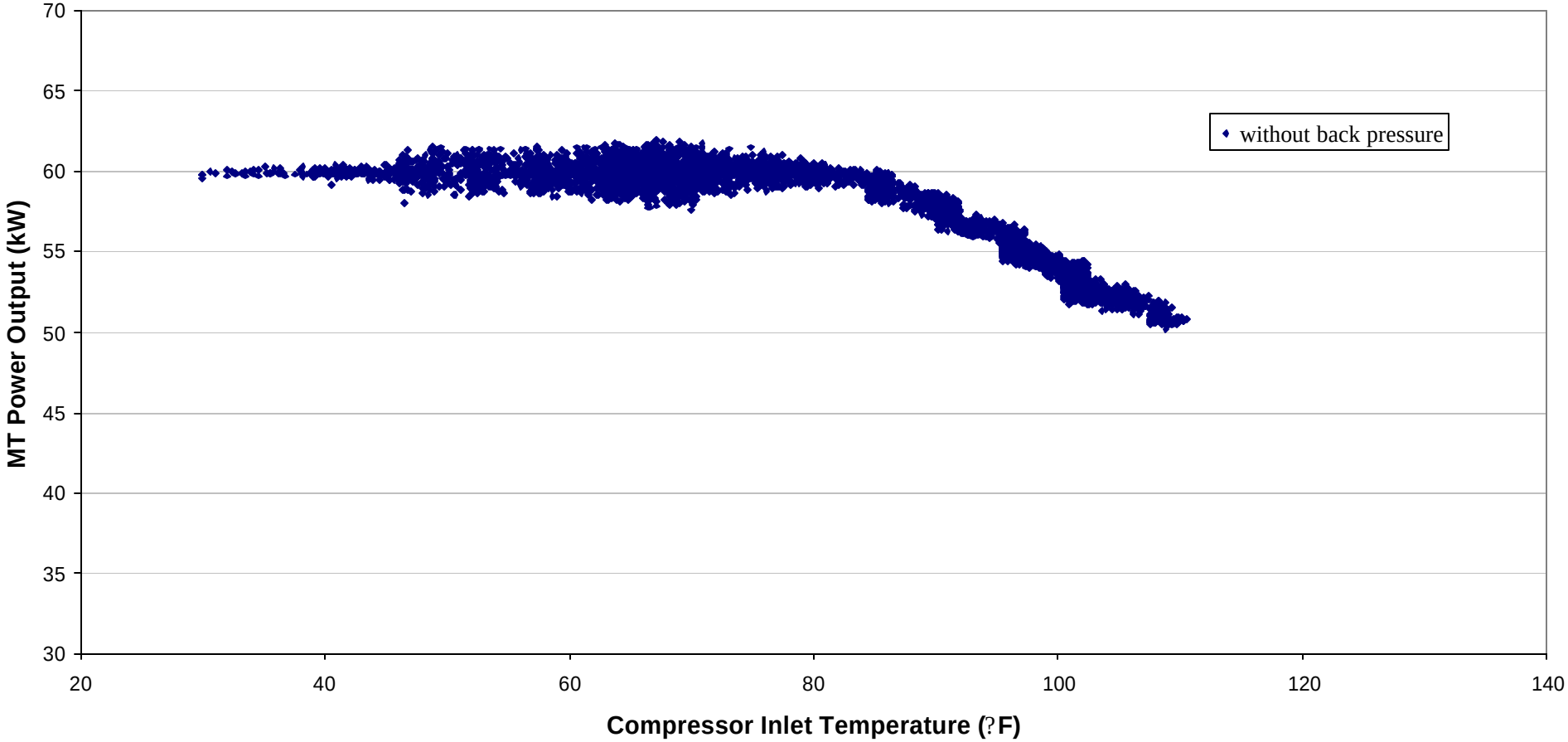


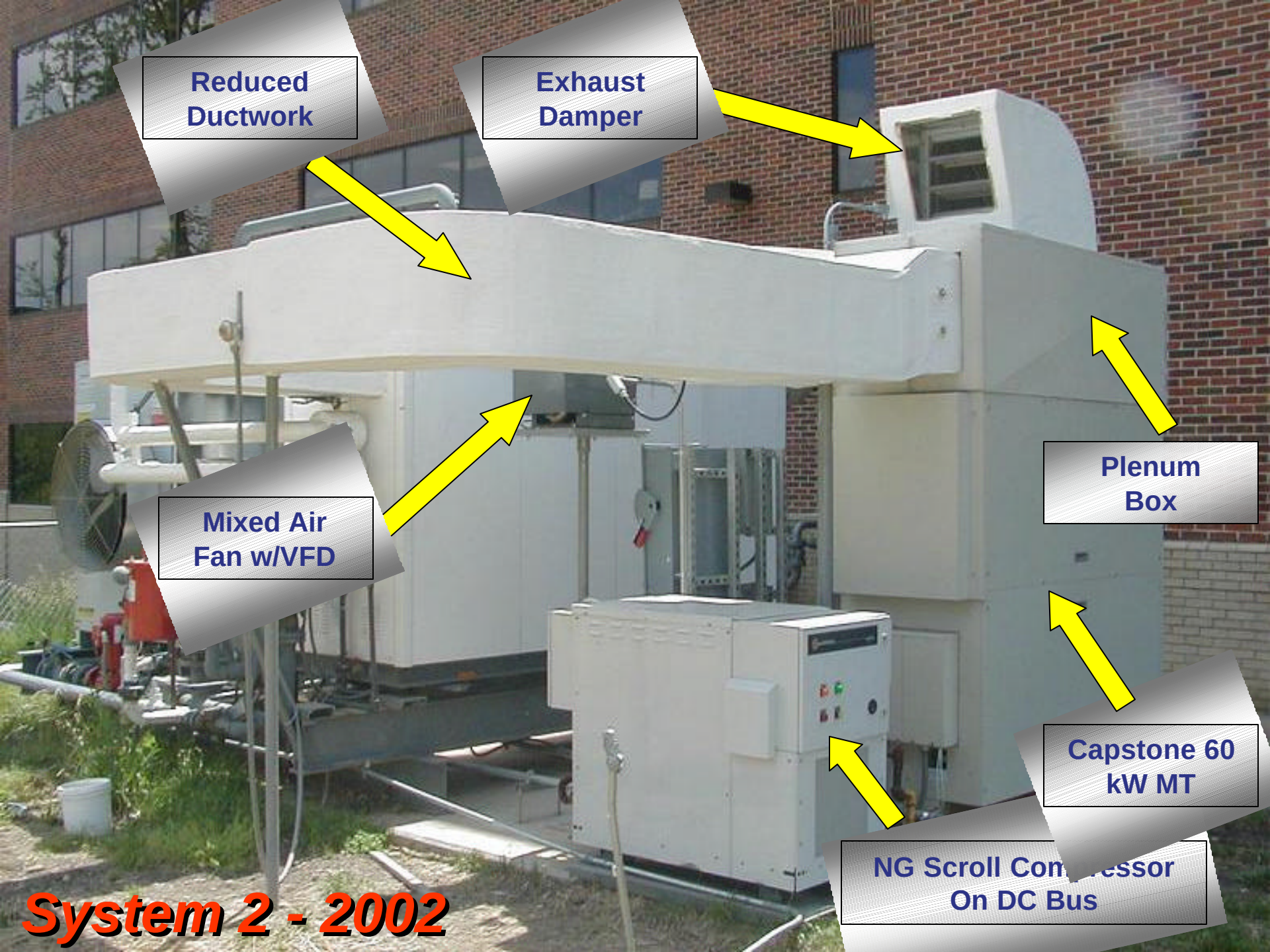

Reduced Ductwork
Exhaust Damper
Mixed Air Fan w/VFD
Plenum Box
Capstone 60 kW MT
NG Scroll Compressor On DC Bus
System 2 - 2002

Microturbine

- Clear relationship between compressor air inlet temp and power output.

Compressor Inlet Temperature vs. MT Power Output




Reduced Ductwork
Exhaust Damper
Mixed Air Fan w/VFD
Plenum Box
Capstone 60 kW MT
NG Scroll Compressor On DC Bus
System 2 - 2002

Plenum Box
Modification
BROAD HEAT RECOVERY ABSORPTION CHILLER-HEATER

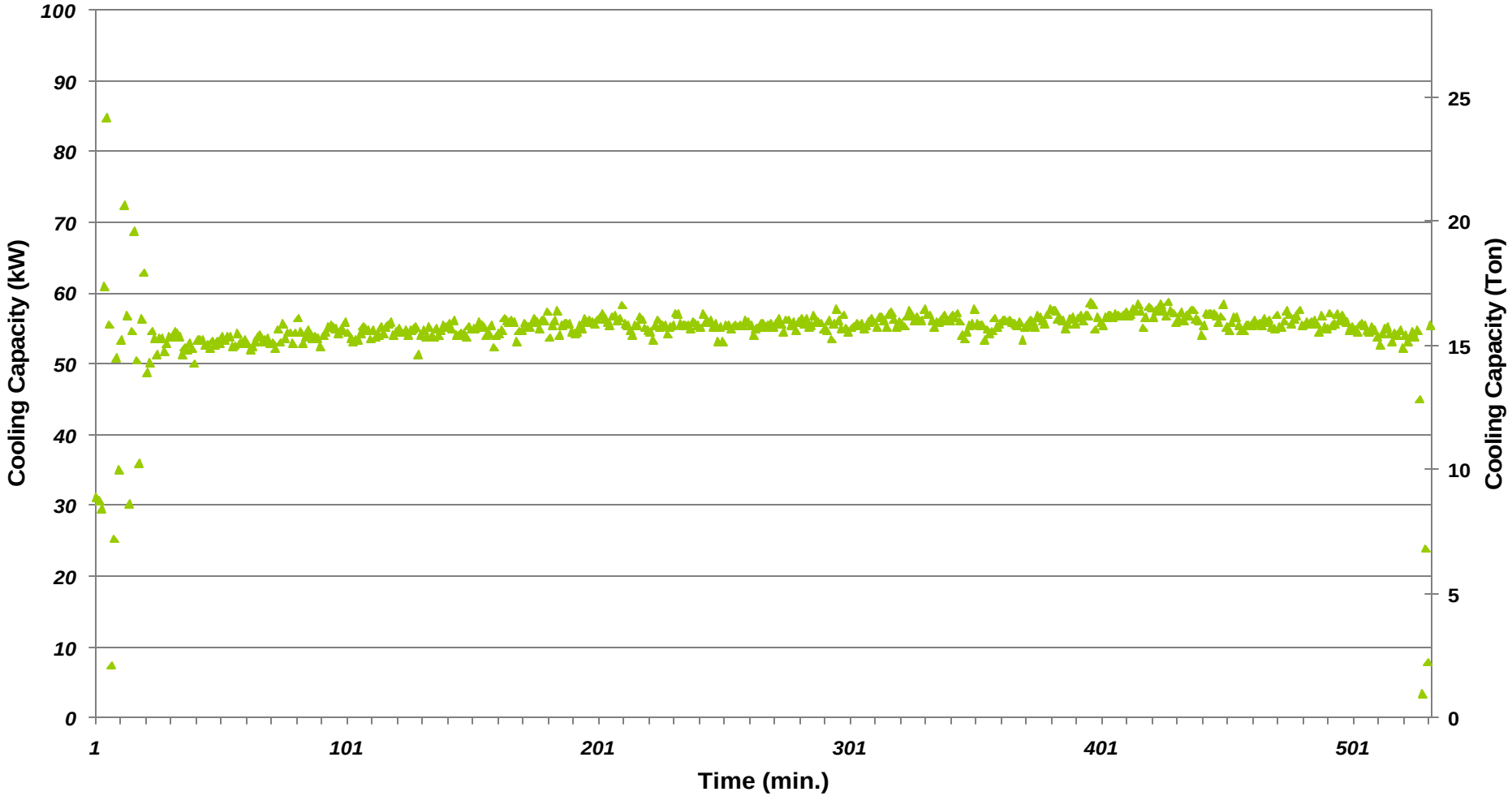
Start-Up Issues

- **Burned out fuses in Capstone MT caused by compressor faults → specialty fuses replaced.**
- **Copeland compressor faults:**
  - **Compressor ran at max speed & led to VFD burnout & fuse burnout → replaced VFD & fuses.**
  - **Burned out VFD caused by faulty gas pressure transducer → replaced transducer.**
  - **Low inlet pressure faults caused by faulty inlet pressure switch → replaced switch.**

Broad Absorption Chiller

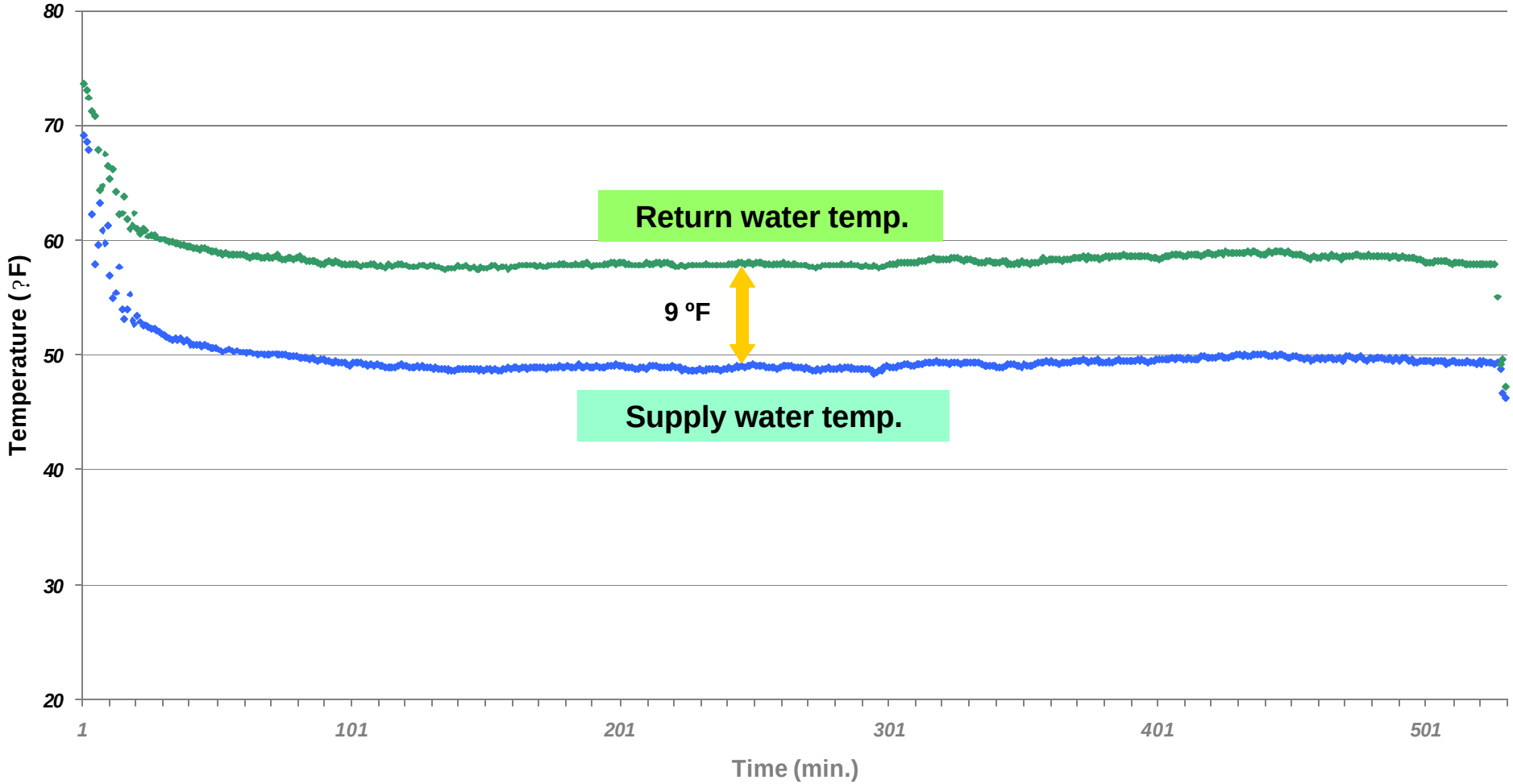
- Cooling capacity can be continuously maintained around 17 tons, it needs less than 1 hour to stabilize
- Average exhaust inlet temp. 520 ºF , outlet temp. 235 ºF
- Chilled water flow rate is 45 gpm
- Parasitic power is 6.4kW
- Chiller COP_{therm} =17ton*3.5/92kW=0.65

Chiller Cooling Capacity

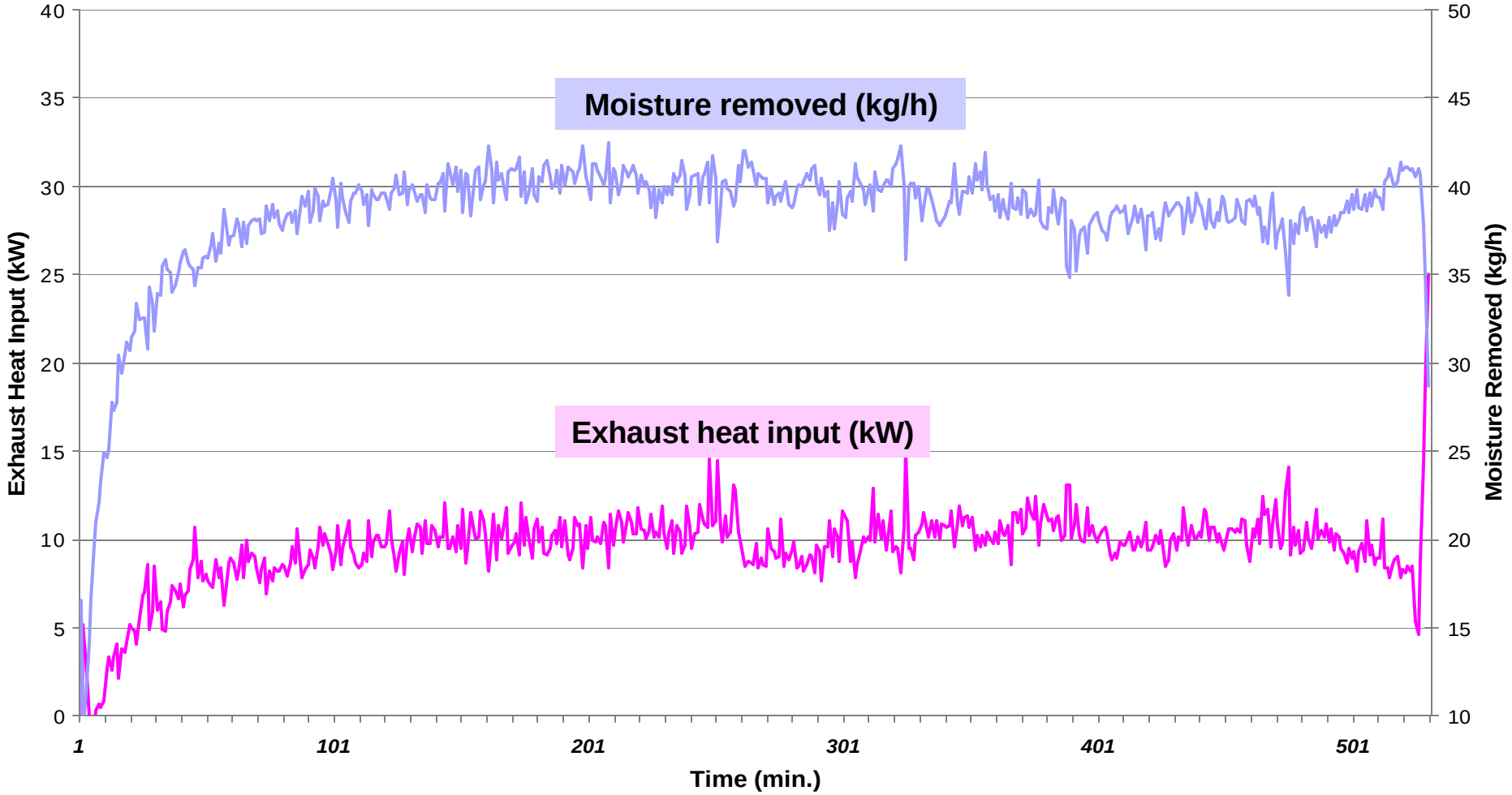


Chilled Water Temperature

- Chilled water temperature: supply 46~49 º F, return 55~58 º F



ATS Solid Desiccant System



Accomplishments

- Two Systems Installed and in Operation
- Education and Information Dissemination
  - Tours, Conferences
  - Technical Papers, Website
- Humidity, Comfort Implications, Other Aspects under Investigation
- Current/Future Work
  - Minimize parasitic loads
  - Controls Integration
  - Complete System Performance Analysis
  - Increase heat recovered from engines

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Cooling Heating and Power

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Integrated Energy Systems

Discover the world of Integrated Energy Systems.

CHP Virtual Tour

Take a virtual tour of the Integration Test Center at the University of Maryland's Chesapeake Building !

Data Acquisition System

View the current conditions at the Chesapeake Building.

Control and Monitoring

Try an interactive demonstration.
username: guest
password: user

CHP Test Center

- The **Integrated Energy Systems Test Center** is designed as a research facility that explores the intricacies of integrating advanced power generating equipment, such as microturbines and fuel cells, with waste heat activated technologies such as absorption chillers and desiccant systems.
- The **Chesapeake Building**, which currently has two CHP systems installed, is a fully instrumented platform for conducting research on advanced energy efficient and environmentally friendly building technology.

CHP System 2

What's New

- Chinese Delegation Visit the CHP Integration Test Center on March 26, 2002.
- British Parliament Members Visit the CHP Integration Test Center on January 30, 2002.
- The recent Microturbine Applications Workshop was held at the University of Maryland Inn and Conference Center on January 17-18, 2002.
- The Sem-Annual CHP Consortium meeting was held in Atlantic City on Jan. 12, 2002, from 3:00 pm to 6:00 pm.
- The CHP team welcomes the newest member !

[More Information...]

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[More Information...]

Tech Briefs

Browse the DOE Tech Briefs and Program Plans for CHP.

CHP Guidebook

View the Guidebook of the CHP Test Center.

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[More Information...]

Events

- **February 28, 2002** - International District Energy Association (IDEA) annual conference in Denver, Colorado.
- **March 12, 2002** - DG & On-site Power Conference in Atlanta, GA.
- **May 2002** - iTHERM at the Georgia Institute of Technology.
- **June 22-26, 2000** - ASHRAE Summer Meeting, Symposium on CHP for Buildings in Honolulu, HI.
- **August 2002** - IHTC in Grenoble, France.
- **September 17 - 20, 2002** - 5th IIR-Gustav Lorentzen Conference on Natural Working Fluids will be held in Guangzhou, China.
- **September 24-27, 2002** - International Sorption Heat Pump Conference will be held in Shanghai, China.
- **October 9-11, 2002** - Association of Energy Engineers (AEE) 2002 Combined Heat & Power Expo / Cogeneration Congress in Atlanta, Georgia.
- **November 17-22, 2002** - American Society of Mechanical Engineers (ASME) - International Mechanical Engineering Congress and Exposition, New Orleans, LA.

[More Information...]

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University of Maryland, Department of Mechanical Engineering
College Park, MD 20742

Thanks !

University of Maryland 1856

CEEE Center for Environmental Energy Engineering

ornl Oak Ridge National Laboratory

DAIKIN

Honeywell

Baltimore Aircoil

pepco

RMF Engineering, Inc. Professional Engineers

TRION

EPRI

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

Washington Gas

ATS Stulz Air Technology Systems, Inc.

TRIDIUM

EPA United States Environmental Protection Agency

BROAD AIR CONDITIONING
远大空调有限公司

CAPRON

GOETTL AIR CONDITIONING

TRIGEN

KATHABAR