Optimizing the Economic and Technical Viability of Combined Heat and Power and Advanced Control Systems

Subcontract Number: 4000009498

Principal Investigator: Dr. Robert Kramer

ORNL Technical Monitor: Robert DeVault

2003 Distributed Energy Resources Peer Review
2nd Program and Peer Review Meeting,
December 2-4, 2003, Washington DC

Project Description and Goals

- The objective of this subcontract over its planned 3-year duration is to advance distributed power technology.
  - The specific objective of work under this subcontract is to develop a packaged CHP system for use in the hotel industry.
    - Accelerate and broaden the adoption of CHP technology as a supplemental energy resource through improvements in technology and standardization.

Project Objectives

- Conduct a three-phase research and development effort to advance distributed power development, deployment, and integration by developing a CHP package for the hotel industry.
- Develop and conduct laboratory and field tests of methodologies and controls for the application (including command, communications, monitoring, efficiency, and energy systems).
- Completely document results. At conclusion, provided DOE with computer data base of relevant information.

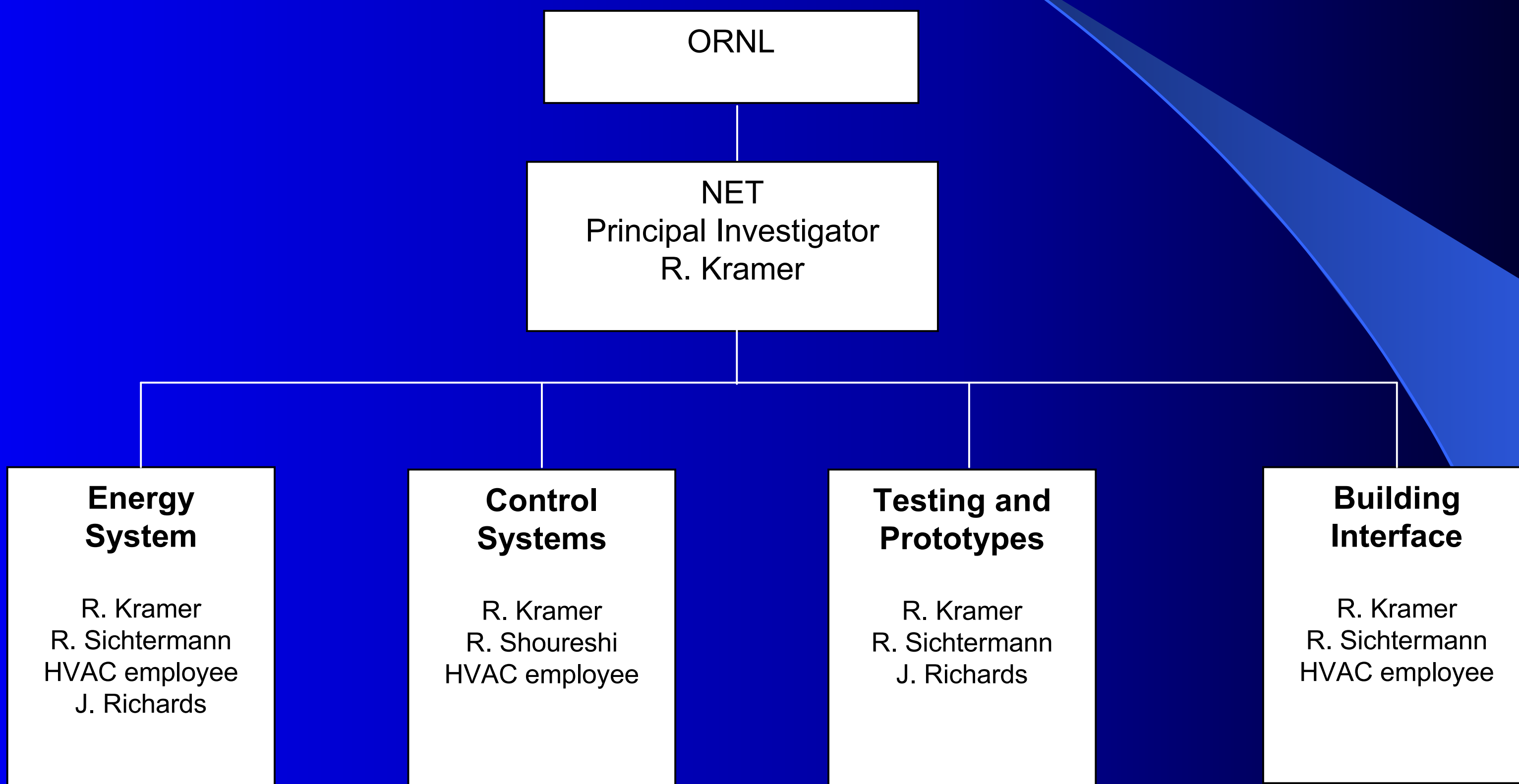
Project Timeline

- Milestones/Deliverables
  - Monthly Reports
  - First Year Report
  - Second Year Report
  - Final Report

- Budgets

	Total ($K)	DOE/NREL	Subcontractor
Base Year	600	300	300
Option Year 1	600	300	300
Option Year 2	400	200	200
Total	1600	800	800

Project Team/Partnerships



ORNL = Oak Ridge National Laboratory, NET = NiSource Energy Technologies,
R. Shoureshi controls consultant

Activities

Phase	Description	Project Year	Relevance*
1	**Initiate design and construction of initial test system** 1. Design and develop a program targeted to develop a BCHP packaged product for wide use in the hotel industry. 2. Install various BCHP systems in the hotel during construction 3. Build and operate a BCHP energy center adjacent to the hotel that will house CHP equipment as well as a research office/experimental area. 4. Test various equipment configurations and control approaches	1	3,7,11,15, 26
2	**Realize "whole building" system optimization and interface and integration with the electric grid by considering:** 1. Architecture and design 2. Building heat and power system concepts with artificial intelligence 3. Advanced controls, and interconnection with the larger grid	2	4,5,12,20
3	**Finalize the development of the various systems and interfaces into a prototype BCHP package for use in the hotel industry.** 1. Synthesize the experience and information gained during the prior two phases. 2. Develop a viable BCHP product prototype for the hotel industry.	3	4,5,15,19, 23

*** Page number of DOE's National Electric Vision Document (Final version, July 31, 2003)**

Technical Challenges of Current Practices

- At the start of the project there were many unanswered questions regarding the design, operation and interconnection of a CHP system for use in the hotel industry.
  - This project has helped to provide answers to many of these issues and thereby facilitate the implementation of CHP
- There is currently limited knowledge regarding the economic viability, efficiency, reliability, and need for CHP designs and advanced controls for the integration of CHP into hotel building systems.
  - This project is providing information, technology, procedures, and designs that can be used in the future to further meet these needs and thereby help to increase the value and viability of CHP technology

Technical Approach

- Further the penetration of CHP technology into the national energy mix by providing a cost effective, environmentally friendly design for use in the hotel industry.
- Utilize advances in CHP dynamic control systems and energy utilization to further the goals of increasing efficiency, energy utilization, and cost savings.
- Develop a field tested design that will accelerate the introduction of CHP technology. This design will include the benefit of actual operating experience in a commercial hotel.
- Utilize statistical techniques including factorial designs to enhance the efficiency of developmental activities.

Key Technical Barriers and Approaches to Overcome Them

- Acceptance of CHP concept by hotel industry
  – Demonstrate feasibility and benefit at operating hotel
- Need to match heat and electric utilization to increase overall efficiency and economic benefit
  – Develop thermal systems, advanced controls, and storage to better utilize heat
  – Investigate value, feasibility, and performance of various heat utilizing and storage devices
- Need to Increase reliability of electric supply
  – Develop transfer switching schemes for the hotel
  – Consider ways to minimize the impact of generating equipment outages
- Need to provide design and operating scheme that provides economic benefit
  – Integrate CHP system into building operation and design
  – Develop standard package that can be made part of standardized designs in the future thereby decreasing equipment and installation costs and increasing efficiency

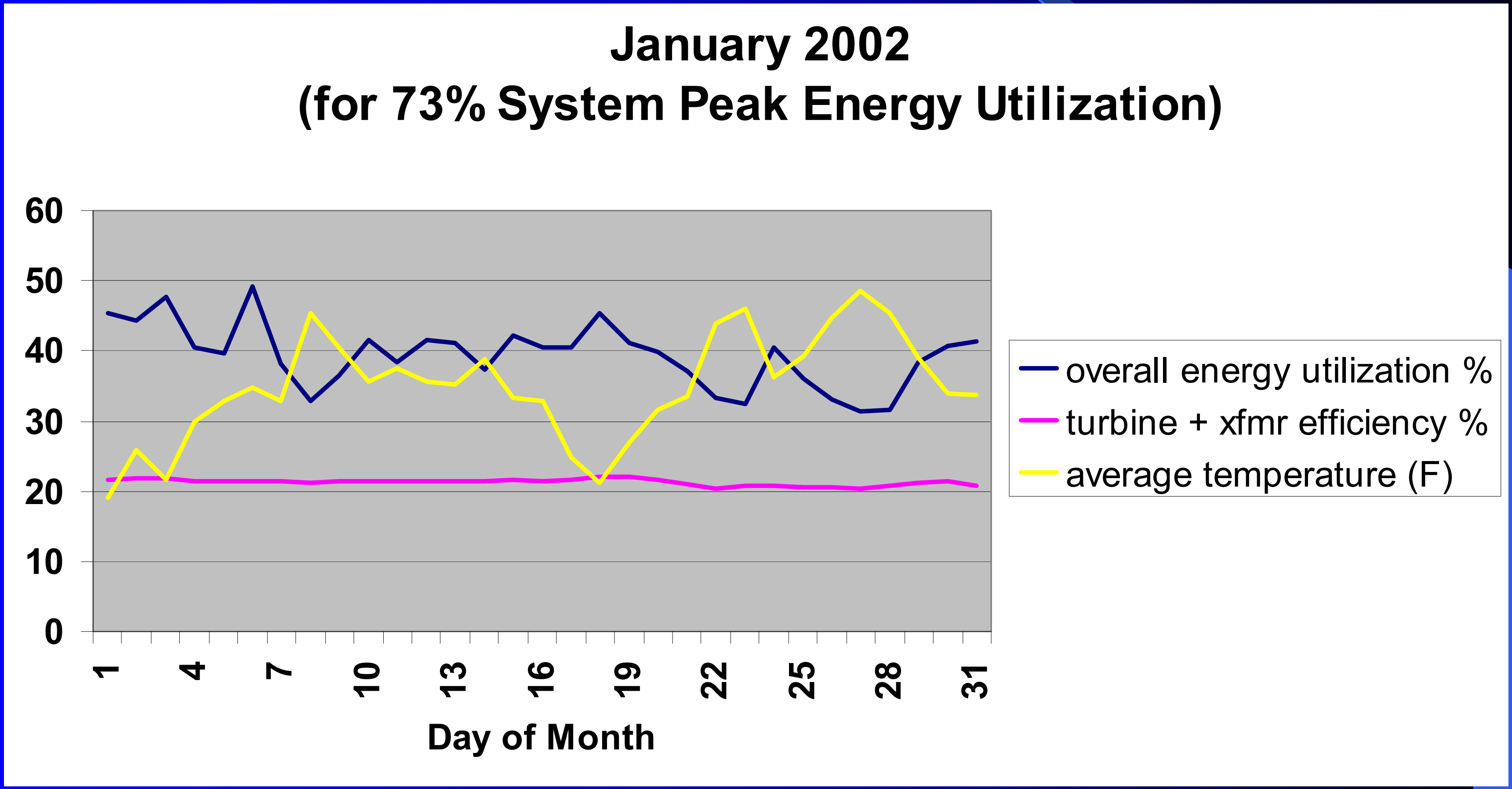
CHP Considerations

- Basic Design Issues
  - Start by considering what the end user wants.
    - Economics
    - Reliability
    - Power Quality
    - Choice

Experience at other commercial CHP test sites developed by NET provided a basis for the inclusion of actual commercial operating information in the design of the current effort.

Version I **Version II**

Energy Utilization (Not Optimized)



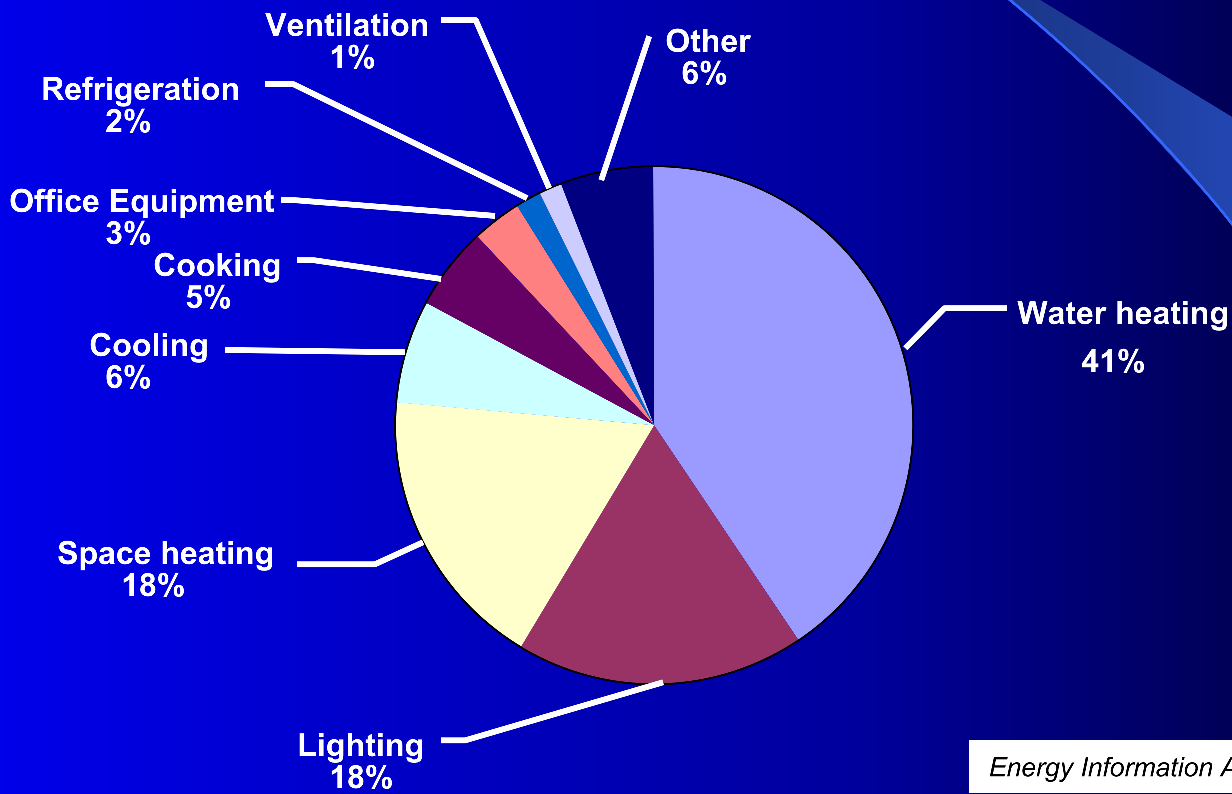
System Design and Performance Issues

- This energy utilization is not high enough to meet long term goals.
- How can we improve this?
  - Intelligent controls
    - Neural Networks
    - Fuzzy Logic
  - Integration of the system into the building and the building into the system.
  - Dynamic energy management and control
- Reliability, PQ, and Grid Interaction

Why the Lodging Sector ?

- Energy use profile
- Number of new units
- Competitive pressure
- Possibility to standardize CHP into building designs

Major Fuel Consumption for Lodging Sector



Energy Information Administration, 1995

Developmental Package

- 3 Microturbines with advanced heat recovery (solar cells in second year and possibly fuel cell in the future)
- Electricity for use in hotel (selected grid isolation & computer bumpless transition)
- Heat for use in hotel
  - Space heating (multiple hydronic zones in floor)
  - Hot water heating
  - Swimming Pool & Spa Heating (future: desiccant dehumidification)
- Advanced energy controls to maximize efficiency and cost savings.
- Building integration concepts

First Year Accomplishments

- 1. Developed individual component designs and/or specifications for the components of the initial CHP system.
- 2. Determined how these systems will be integrated into the test facility.
- 3. Designed and built initial test systems.
- 4. Tested individual systems.
- 5. Assembled individual systems into an initial package.
- 6. Installed package at Site and integrate with building.
- 7. Performed initial testing of initial CHP system.
- 8. Performed further system tests and developments based on test results.

Hotel Site

Hotel IES Overview

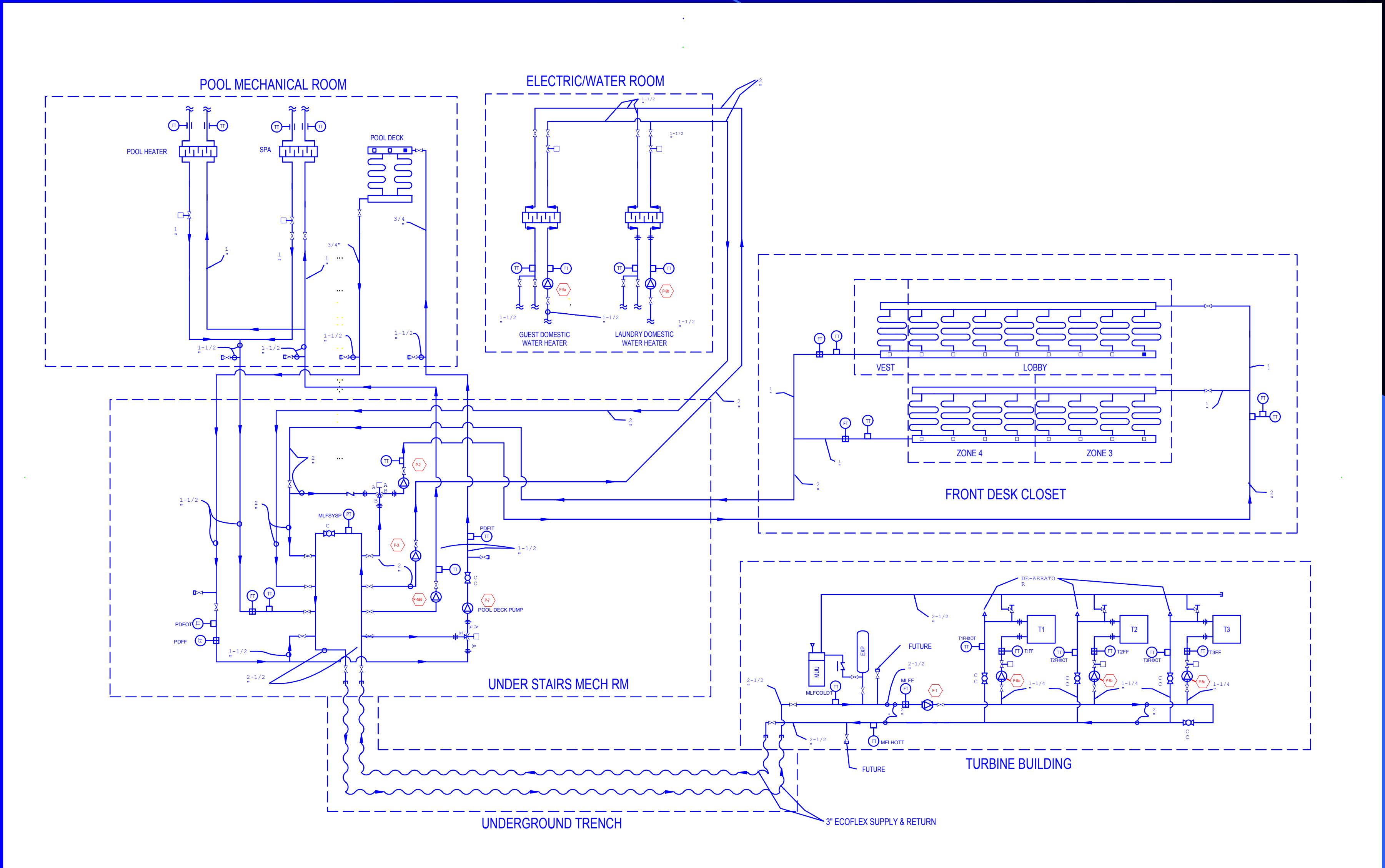
Site During Construction

CHP Building

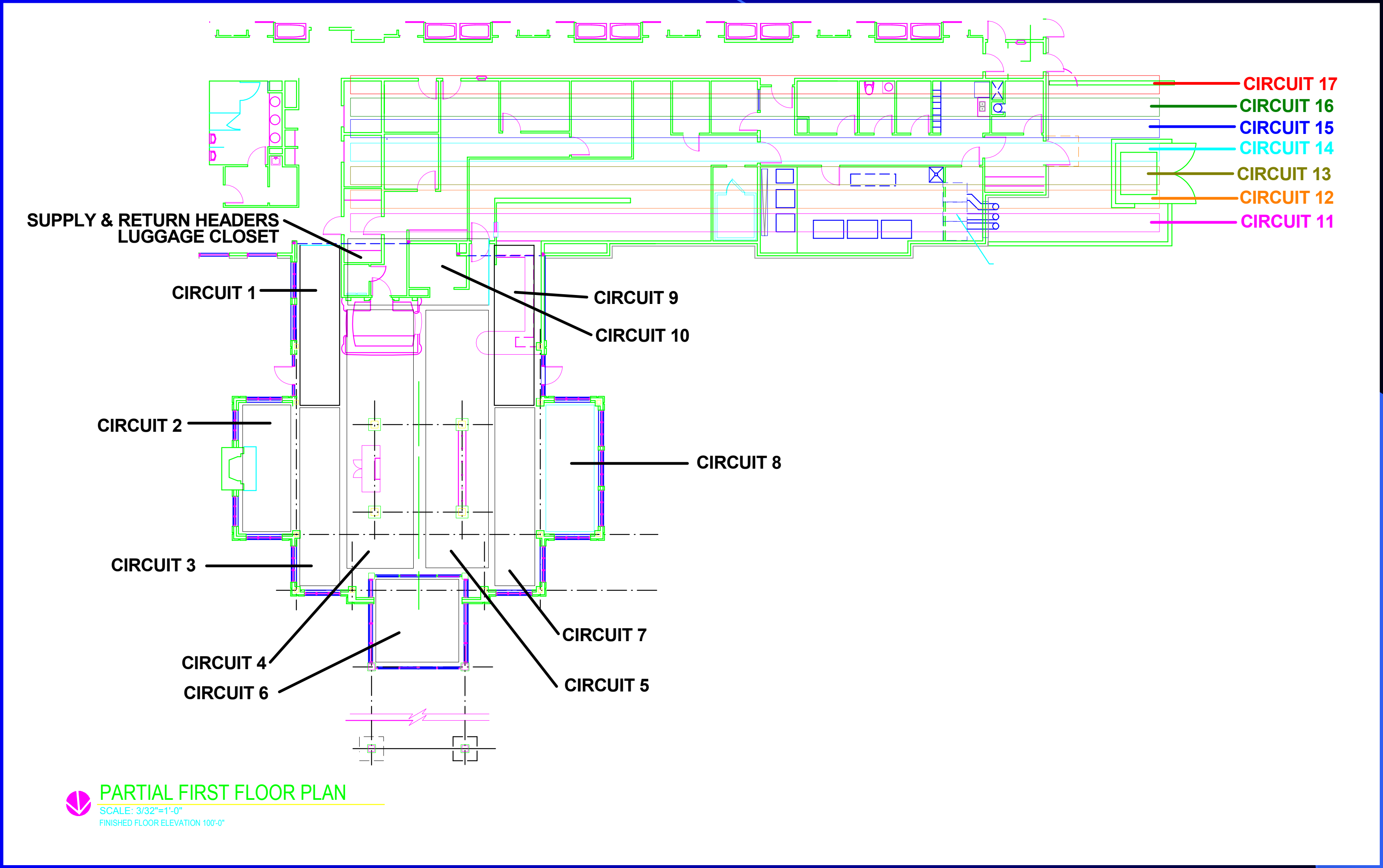
Inside CHP Building

Hydronic Control (Main Floor)

Current System Piping Configuration



Hydronic Zones



Option Year 1 Objectives

- Realize "whole building" system optimization and interface and integration with the electric grid through the use of the heat and power system, artificial intelligence and advanced controls, and interconnection with the larger grid.

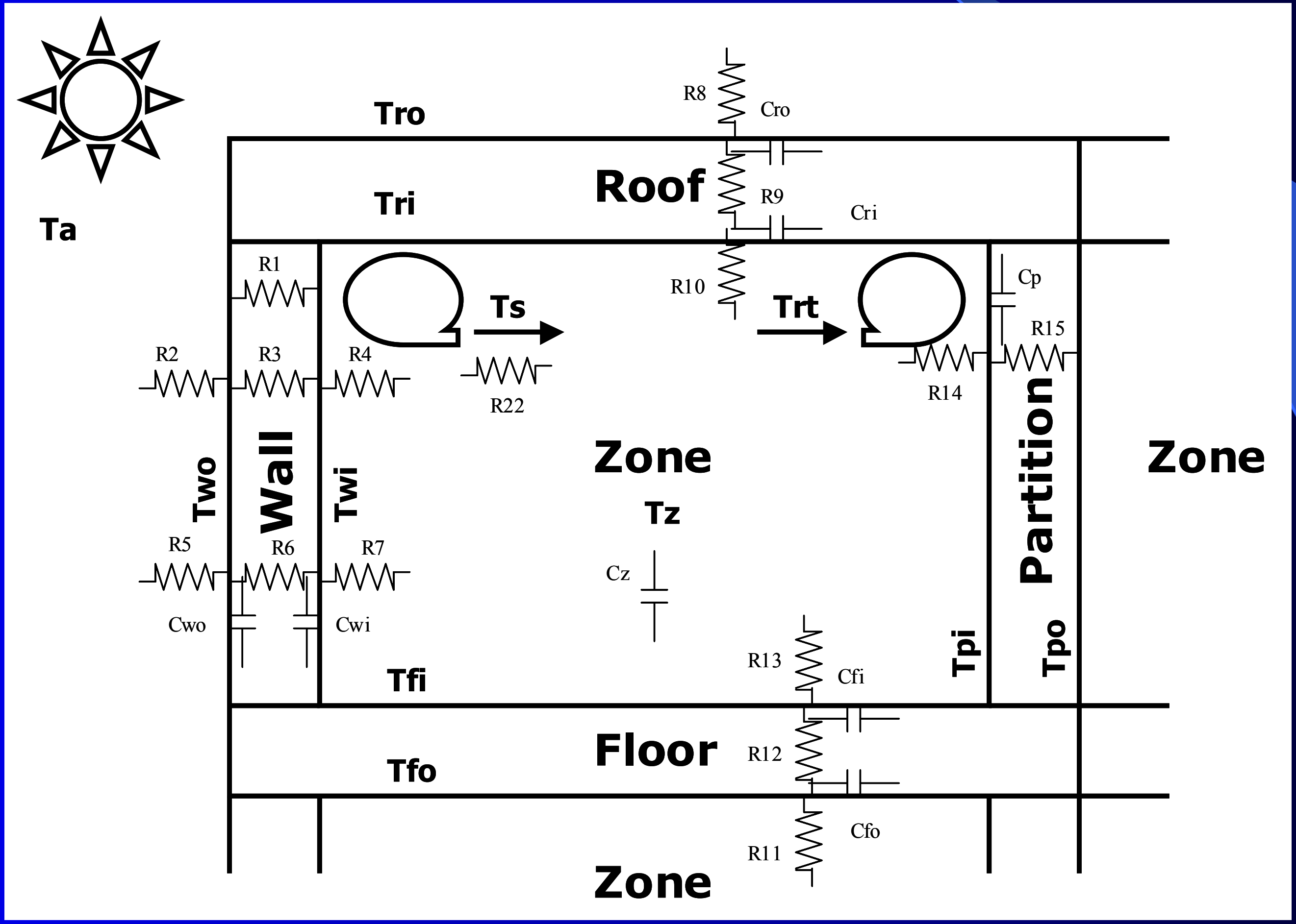
Optimization Objectives

- Develop advanced control techniques for distributed power systems that facilitate development, deployment and integration.
- Long-term goal: Design ways to extend CHP into the physical design and controls of a building itself.
  - Maximize efficiency and commercial viability of the technology

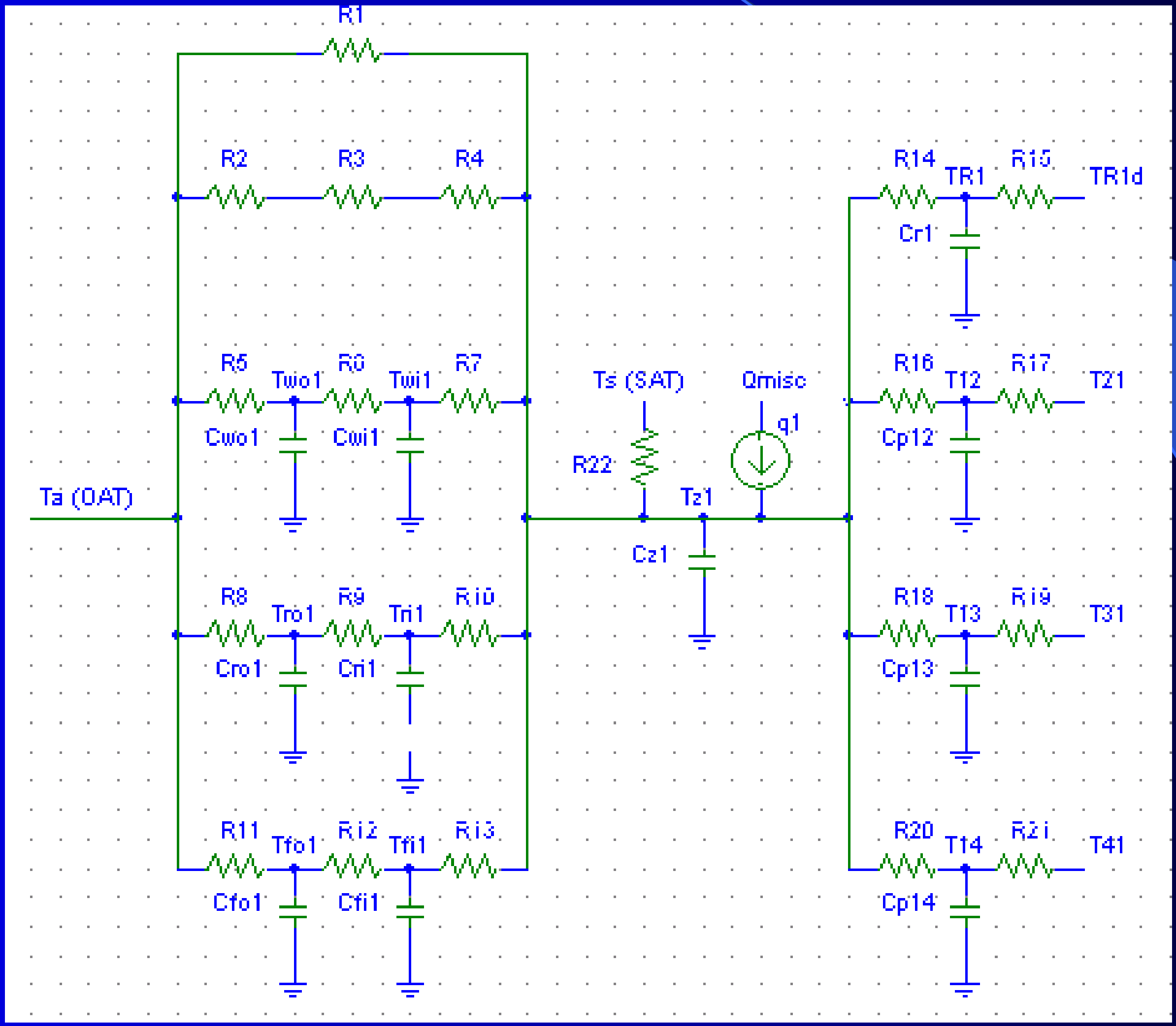
CHP Optimization

- Control algorithm for IES would reduce life time operating cost.
- Compare cost of grid electricity, locally produced electricity, and cost of fuel consumption, e.g. gas, and locally produced heat.
- Energy supply optimized to give maximum benefit from available source options.
- Optimization model determines unit commitment & set points.
- Model predicts hourly building load data, including: kWh use, Btu use, kWh for water heating, Btu for water heating, kWh for space heating & cooling.

Building Model Zone



Electric Equivalent



State Space Representation for Temperature and Humidity

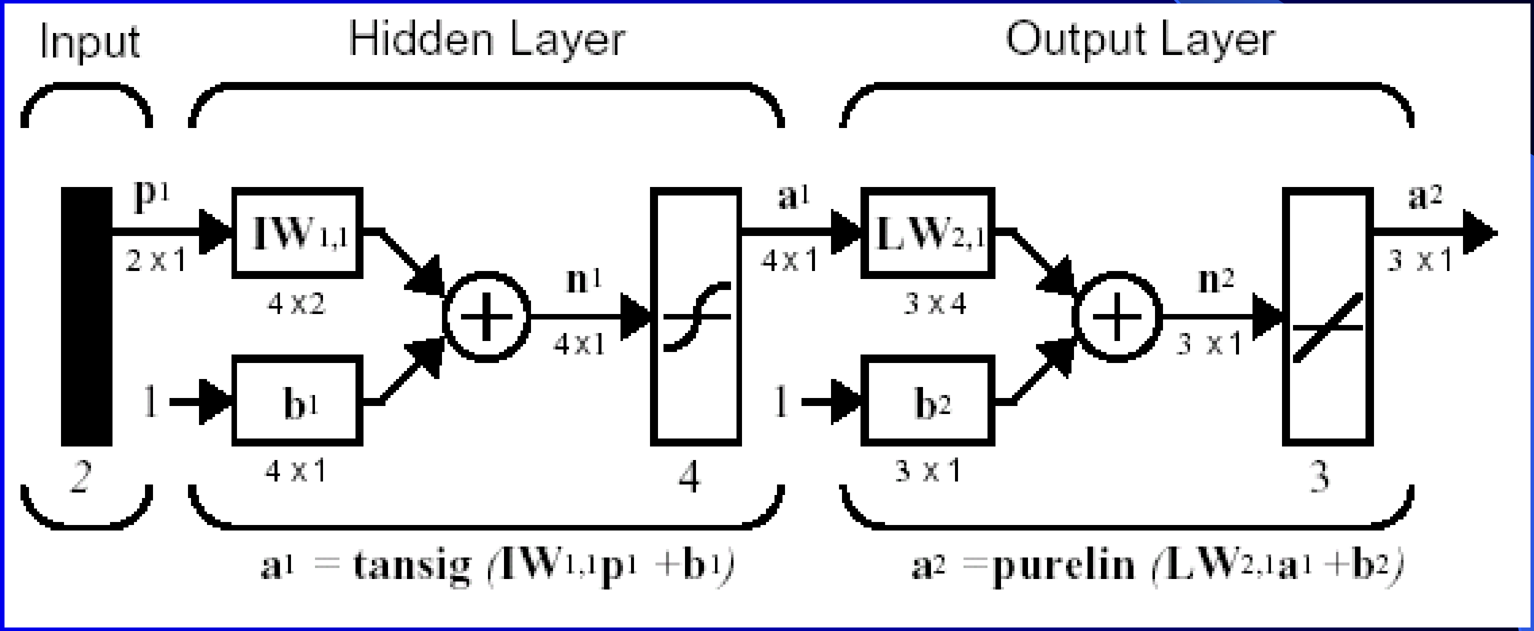
$$\begin{bmatrix} \dfrac{dTs}{dt} \\ \dfrac{dTd}{dt} \end{bmatrix} = \begin{bmatrix} -\dfrac{\alpha a + \alpha r}{Ca} & 0 \\ \dfrac{w}{Cd} & -\dfrac{w + \alpha a}{Cd} \end{bmatrix} \begin{bmatrix} Ts \\ Td \end{bmatrix} + \begin{bmatrix} \dfrac{\alpha\_chp}{Ca} & \dfrac{\alpha a}{Ca} & \dfrac{\alpha r}{Ca} \\ 0 & \dfrac{\alpha a}{Cd} & 0 \end{bmatrix} \begin{bmatrix} \Delta Tgly \\ Ta \\ Tsi \end{bmatrix}$$

$$\begin{bmatrix} \dfrac{dXs}{dt} \\ \dfrac{dXd}{dt} \end{bmatrix} = \begin{bmatrix} -\dfrac{fs}{Va} & 0 \\ \dfrac{fs}{Vd} & -\dfrac{fs}{Vd} \end{bmatrix} \begin{bmatrix} Xs \\ Xd \end{bmatrix} + \begin{bmatrix} \dfrac{fs}{Va} & 0 \\ 0 & \dfrac{1}{Vd.\rho a} \end{bmatrix} \begin{bmatrix} Xsi \\ h(t) \end{bmatrix}$$

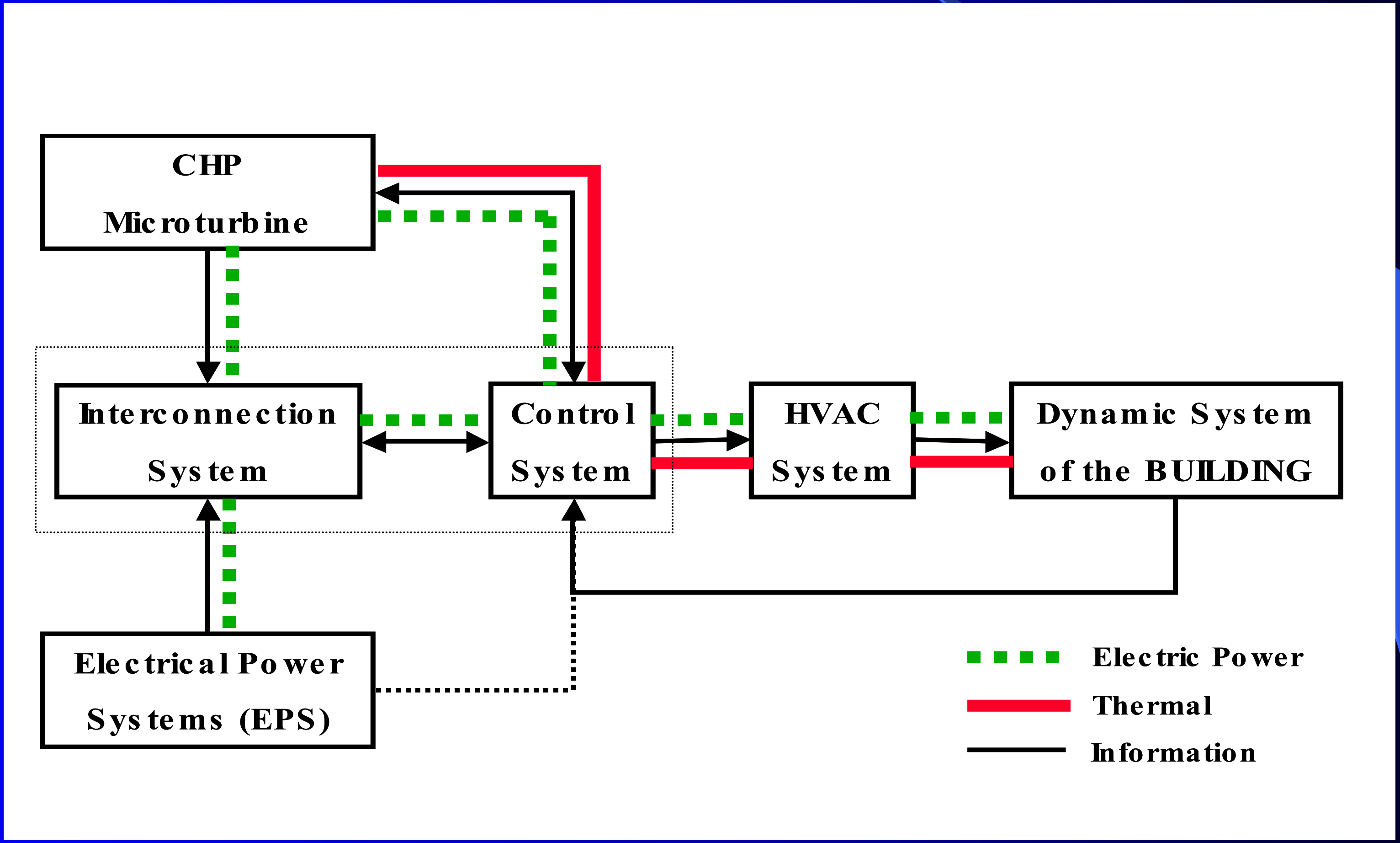
Index of Performance for Thermal Optimization

$$J = \int_{to}^{tf} [fQ_{aux}^{2} + C1(T_a - T_{set})^2 + C2(H(H_a - H_{set})^2]dt$$

A Multi Layer of Feedforward ANN



Electrical and Thermal Systems Model



Index of Performance for Cost

$$PI(x) = \int_{ti}^{tf} \alpha\left(\underline{x}, \dot{\underline{x}}, t\right)^2 dt$$

Where

$$\alpha = \Phi_E .\left(kWh_{BLDG}(t) - kWh_{GEN}(PLR,t)\right) + \Phi_G\left(Btu_{BLDG}(t) - Btu_{GEN}(PLR,t)\right)$$

Optimization of Cost Matrix

- Cost matrix for available options

$$C_{ELEC} = \phi_{KWH} \begin{bmatrix} kWh_{BLDG}(1) - kWh_{GEN}(1) \\ kWh_{BLDG}(2) - kWh_{GEN}(2) \\ \cdots \\ kWh_{BLDG}(k) - kWh_{GEN}(k) \end{bmatrix} + \phi_{KW} \begin{bmatrix} kW_{BLDG}(1) - kW_{GEN}(1) \\ kW_{BLDG}(2) - kW_{GEN}(2) \\ \cdots \\ kW_{BLDG}(k) - kW_{GEN}(k) \end{bmatrix} + \ldots.$$

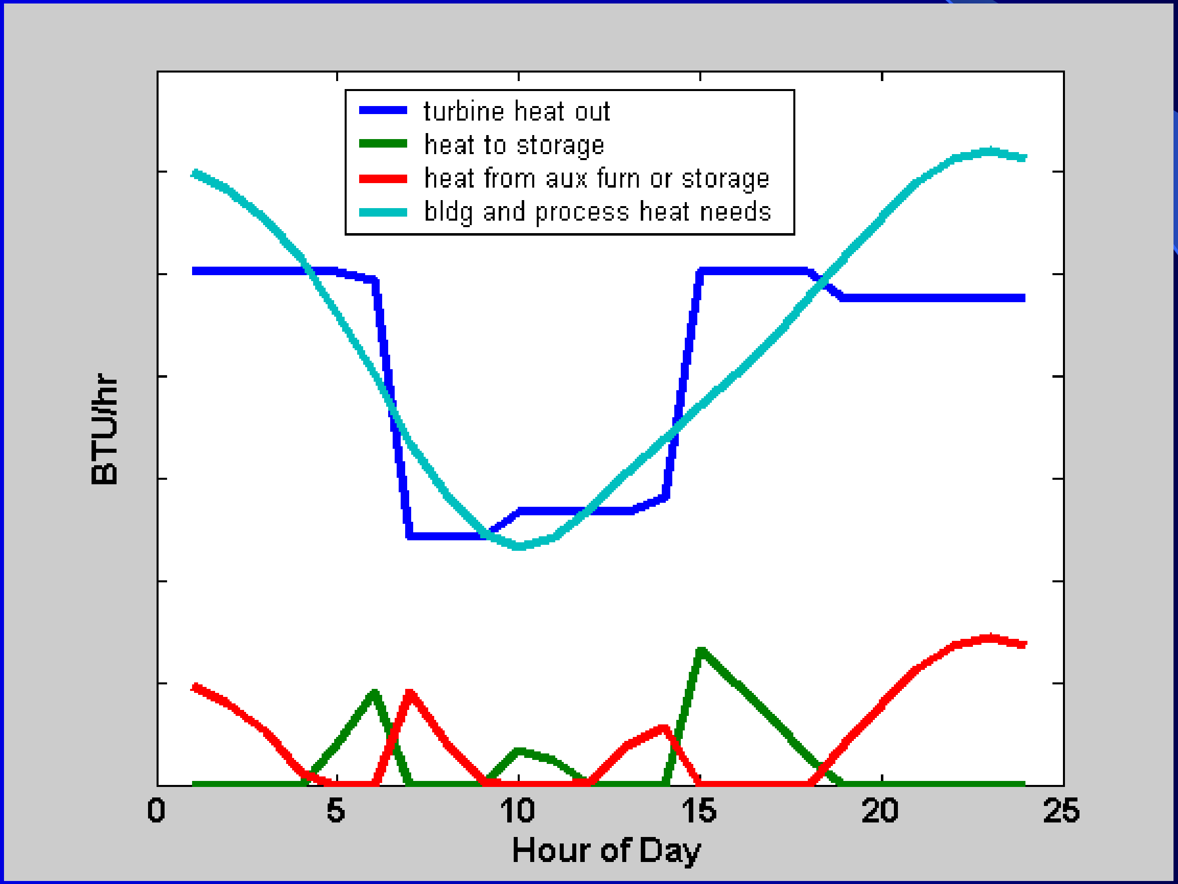
$$\ldots\ldots\ldots\ldots + \phi_{GAS} \begin{bmatrix} Btu_{BLDG}(1) - Btu_{GEN}(1) \\ Btu_{BLDG}(2) - Btu_{GEN}(2) \\ \cdots \\ Btu_{BLDG}(k) - Btu_{GEN}(k) \end{bmatrix} + \ldots.$$

$$\ldots\ldots\ldots\ldots + \phi_{CRED}\left[\sum kWh_{GEN}\right] + \phi_{O\&M}\left[kW_{INST} + \sum kWh_{GEN}\right]$$

Fast Response Heat Storage to Improve Utilization

- Heat storage provides a means to improve overall energy utilization efficiency.
  - Shift the heat to times where it is needed rather than wasting it.
  - Storing and recovering the heat quickly increases its value over conventional thermal storage.

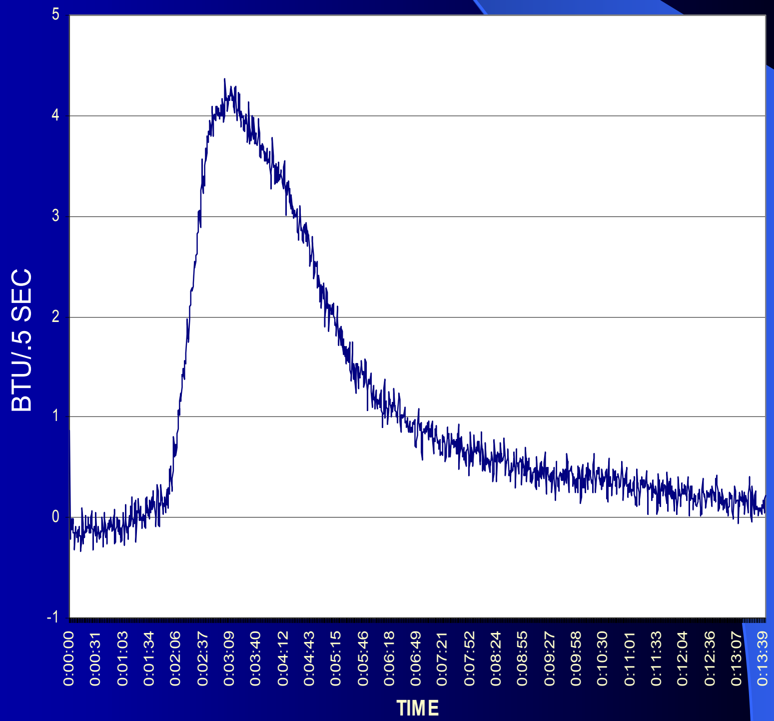
Commercial Building Winter Heat Utilization Example



Fast Response Low Temperature Eutectic Heat Storage Test Unit

Fast Response High Temperature Heat Storage Test Unit

- To improve overall efficiency it is necessary to use as much heat as is possible. Heat storage can significantly improve heat utilization and hence the overall efficiency and viability of CHP.
- Plastic phase change material in a fluidized bed configuration
  - Changes phase at 176 F

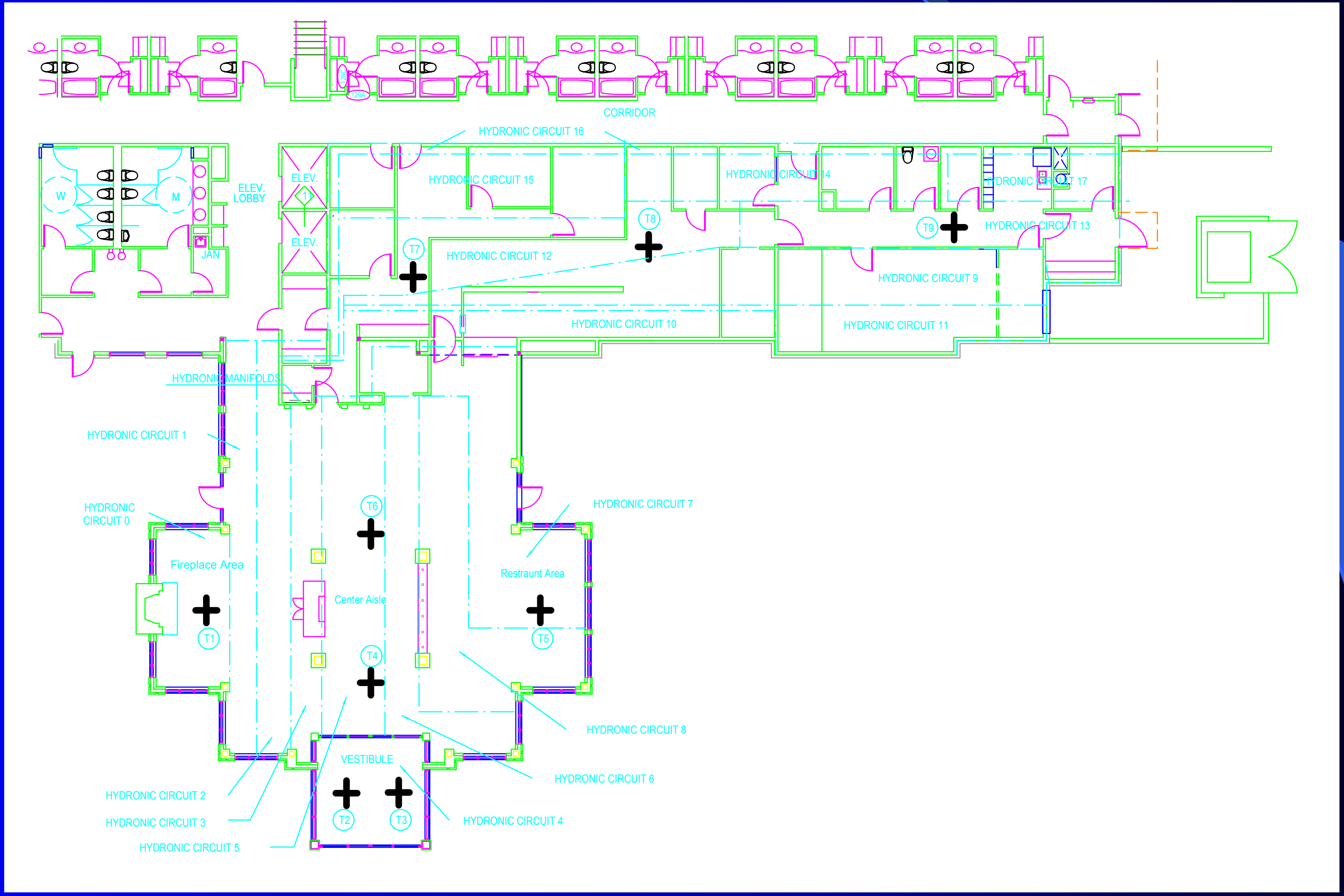


Building Thermal Time Constants

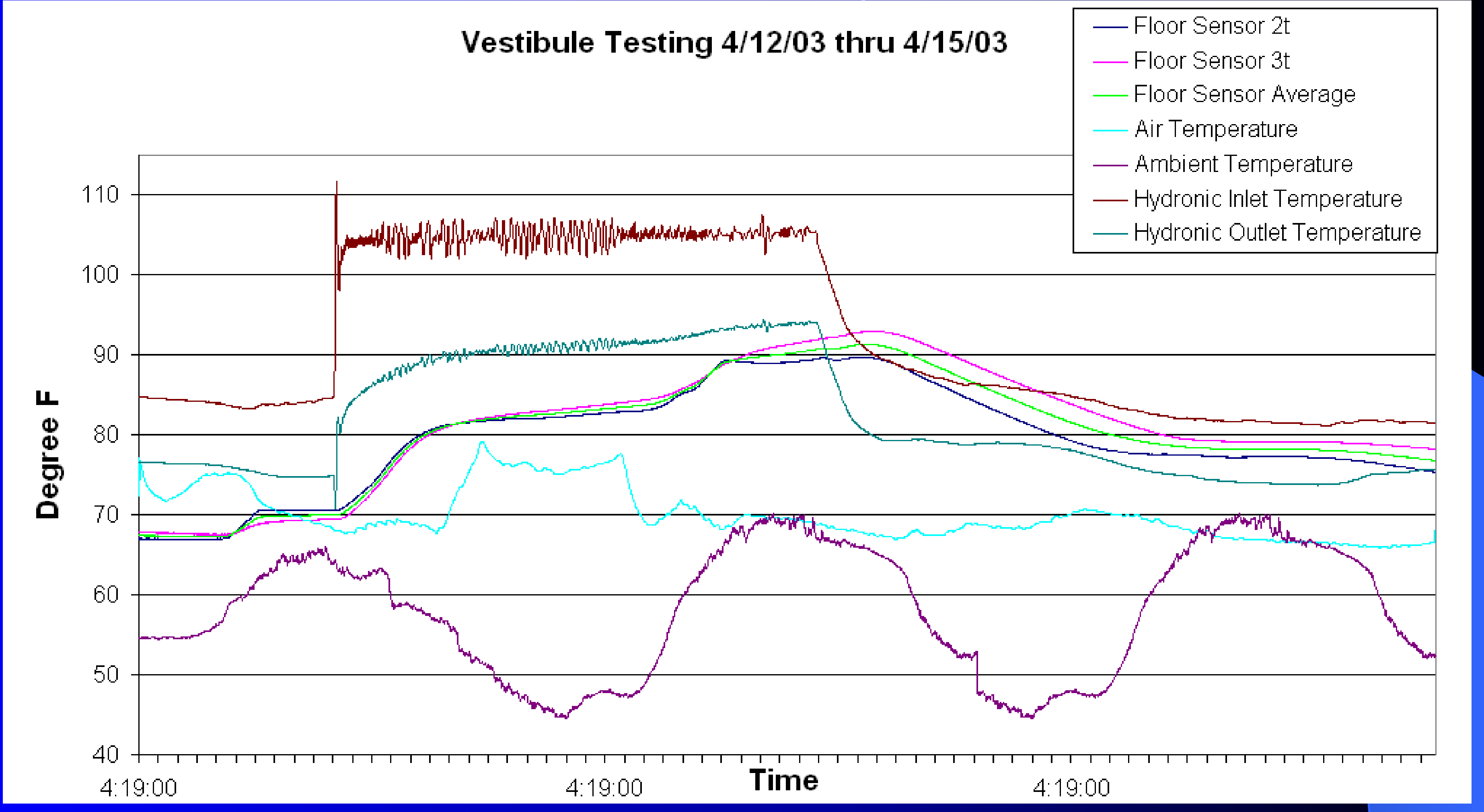
- The rate at which the temperature of various regions of the floor changes temperature is needed for input to the optimizing energy model.
- During construction calibrated TIDs were placed in the floor at various locations.
- Time constants for the various floor regions was determined for various combinations of the hydronic heating system.

Temperature sensor locations for time constant values

- + indicates location of calibrated TID in Hotel lobby area



Time constant data for vestibule area

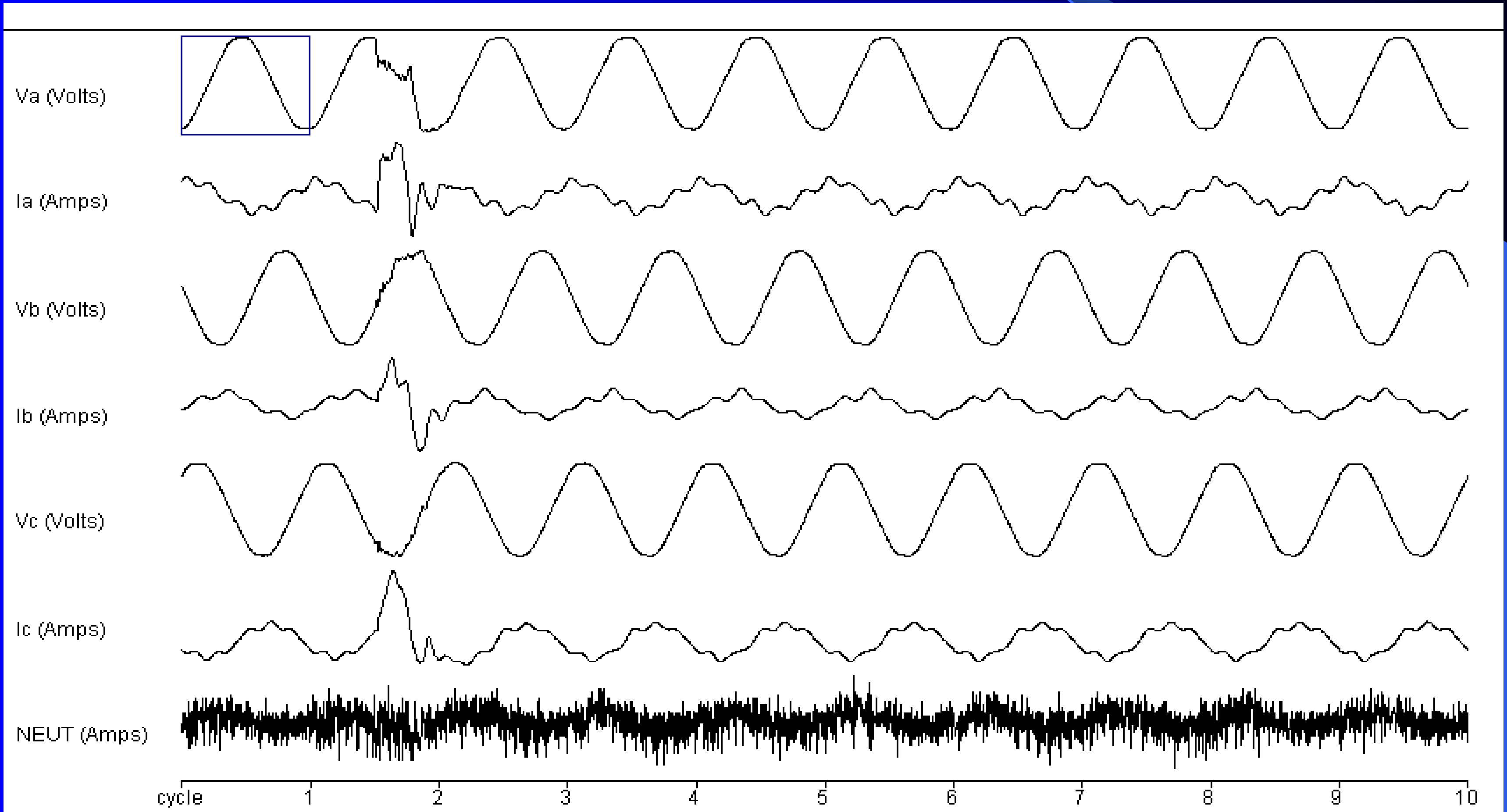


Power Quality Issues

- The quality of power at the CHP - hotel bus was monitored continuously
  - Inverter issues at the hotel
    - Inverter PQ and harmonics
    - Interactions with hotel equipment
    - Interactions between inverters
  - Disturbances from the grid
    - Impact on CHP system

Typical PQ Trigger Incident

- Transient on electric grid from thunderstorm tripped the CHP system.



Solar Cell Installation

- Three solar panels and associated electronics are being tested for inclusion in the energy system.
  - Improve understanding of how a renewable resource might be included in the optimization process.

Project Timeline

Phase	Description	Project Year	Status
1	Initiate design and construction of initial test system 1. Design and develop a program targeted to develop a BCHP packaged product for wide use in the hotel industry. 2. Install various BCHP systems in the hotel during construction 3. Build and operate a BCHP energy center adjacent to the hotel that will house CHP equipment as well as a research office/experimental area. 4. Test various equipment configurations and control approaches	**1**	**complete**
2	Realize "whole building" system optimization and interface and integration with the electric grid by considering: 1. Architecture and design 2. Building heat and power system concepts with artificial intelligence 3. Advanced controls, and interconnection with the larger grid	**2**	**finishing**
3	Finalize the development of the various systems and interfaces into a prototype BCHP package for use in the hotel industry. 1. Synthesize the experience and information gained during the prior two phases. 2. Develop a viable BCHP product prototype for the hotel industry.	**3**	**starting**

Milestones Completed

- **This project will optimize energy usage, creating energy and economic savings, and provide a reliable energy system for hotels. The intent is to develop a packaged CHP system for the hotel industry.**
  - Completed construction and installed initial CHP test system at Hotel in Chesterton, IN.
  - Integrated the system into the building and hotel operations
  - Initiated activities to optimize energy value and utilization
  - Developed system to quantify benefits of CHP system from real time data to meet hotel owners needs
  - Completed initial design and started efforts to implement advanced controls for energy system
  - Operated the CHP system as part of hotel operations to gain knowledge for the developmental process

Planned Milestones

- **Phase III**
  - Finalize the development of the various systems and interfaces into a prototype BCHP package for use in the hotel industry. The goal of this phase will be to synthesize the experience and information gained during the prior two phases into a viable BCHP product prototype for the hotel industry.

Impacts on DEP Goals

- Combined heat and power holds the promise to be an important part of the energy supply mix of the future.
  - This project is intended to optimize energy usage, creating energy and economic savings, and provide a reliable energy system for hotels. The intent is to develop a packaged CHP system for the hotel industry.
    - Advanced control schemes employing dynamic control technology have been developed that increase the value of CHP systems by integrating the CHP system into the building design as well as its energy control scheme.
      - Based upon experience from field tests of CHP systems that started approximately 6 years ago, this project is attempting to develop a packaged CHP system for application to the Hotel industry.
      - This work has produced recommendations for optimizing CHP designs that increase the benefit spread and hence increase the fraction of projects that are technically and economically viable for use of CHP.
      - Recommendations for optimizing CHP system designs were made.

Summary

- The current effort is developing technology, designs, and operating strategies to optimize CHP utilization in the hotel industry.
- Techniques include:
  - Intelligent dynamic control with neural networks and fuzzy logic
  - Developmental activities include an operating hotel
  - Theory iteratively blended with field experience
- Current efforts are proceeding during the second year of the three year program to meet the the overall goal of developing a technically and economically viable packaged CHP unit for use in the hotel industry.

Contact Information

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Thank You