**New Energy Saving Strategies for HVAC Control Systems**

**Report Documentation Page**

<table>
<thead>
<tr>
<th>1. REPORT DATE</th>
<th>2. REPORT TYPE</th>
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<td>26 FEB 2004</td>
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<th>4. TITLE AND SUBTITLE</th>
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<td>New Energy Saving Strategies for HVAC Control Systems</td>
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<th>5a. CONTRACT NUMBER</th>
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<th>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</th>
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12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES


14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:

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17. LIMITATION OF ABSTRACT

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18. NUMBER OF PAGES

26

19a. NAME OF RESPONSIBLE PERSON
JCI Federal Business Goal

“Help the Army Accomplish its Mission Critical Goals”

- Energy security
  - Constant power
  - Secure facilities
  - Reduce energy usage
- Base sustainability
  - Water resources
  - Infrastructure revitalization
- BRAC 2005
  - Keep SWRO installations open
  - Master planning
  - Added value to the bases
- Reduce capital budget burden
Army Systems and Services

- Energy Savings Performance Contracting
- Security Systems
- Fire Systems
- Construction Management
- Mechanical Equipment and BAS Service Contracts
- Facility Management
- Building Automation Systems
ESPC Overview

• ESPC Vehicles
  ▪ Corps of Engineers
  ▪ Department of Energy
  ▪ GSA
  ▪ MEDCOM

• ESPC Energy Conservation Measure Examples
  ▪ Energy Security
  ▪ Lighting
  ▪ Water
  ▪ Re-commissioning
  ▪ Infrastructure improvements
  ▪ Peak shaving
  ▪ Building Automation Systems - Digital controls
New Energy Saving Strategies for HVAC Control Systems

John E. Seem, Ph.D.

Agenda

• Adaptive Feedback Control
• Fault Detection & Diagnostics
• Sequencing Control
• Energy Optimization Control
Feedback Control System

Chilled Water Supply

Setpoint

Controller

Control Signal

Valve

Cooling Coil

Temperature Sensor

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**PI Controller**

\[ u(t) = \bar{u} + K \left[ e(t) + \frac{1}{\tau_i} \int_{0}^{t} e(t^*) dt^* \right] \]
Problem

Although PID Controllers are common and well known, they are often *poorly tuned*.

Åström and Hagglund (1988)
*Automatic Tuning of PID Controllers*
Adaptive Feedback Control

+ Thousands of Papers
- Hard to Develop Industrial Controller

Approaches
• Self-Tuning Control
• Model Reference Adaptive Control
• Pattern Recognition Adaptive Control
Research Objective: Adaptive Feedback Control

Develop Continuous Tuning Method for PI Controllers

Features

- Easy to Use
- Near-Optimal Performance (IAE)
  - Load Disturbances
  - Setpoint Changes
- Robust
- Low Requirements
Field Test: Static Pressure

![Graph showing static pressure over time with notes on PRAC turned on and process output setpoint.](image)

- Static Pressure (Pa)
- Time (minutes)

PRAC turned on
Process Output
Setpoint
Field Test: Cooling Coil

- Setpoint
- Process Output
- PRAC turned on
Field Test: Heating Coil

- **Setpoint**
- **Process Output**
- **PRAC turned on**

![Graph showing temperature over time with annotations for Setpoint, Process Output, and PRAC turned on.](image-url)
Field Test: Heating Coil

Controller Output (%)

Time (hours)

PRAC turned on
AHU Fault Detection

Research Objective
- Detect leaky valves, stuck dampers, ...
- No additional sensors
Approach for AHU Fault Detection

1) State Machine
   • Mode of Operation
   • Steady-State Conditions
2) Model Based Residuals
   • Mass Balances
   • Energy Balances
3) Control Performance Indices

Integrated Control, Fault Detection & Fault Tolerant Control

Process
Residual Generation

Residual = $T_{supply} - T_{outdoor} - T_{fan}$

= $55 \, ^{\circ}F - 35 \, ^{\circ}F - 1 \, ^{\circ}F$

= $19 \, ^{\circ}F$

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Simulation Results from Dr. John House

- Cooling valve 3% leakage
- Heat. valve stuck 10% open
- Heating valve 3% leakage
- Cool. valve stuck 20% open
- Normal

Residual (°C)
Split Range Control

Problem: Heating, Cooling,…

Heat Transfer

Time

Setpoint

Controller

Split Range

Feedback

Closed

Closed

Control Signal

0 0.5 1.0

Heating Valve

Cooling Valve

Open

Open

Heating, Cooling,…

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Finite State Machine

Finite State Machine

No Heating for 5 minutes & $T_{supply} > T_{set}$

No Cooling for 5 minutes & $T_{supply} < T_{set}$
Air Side Economizer

60 °F & 50%RH

75 °F & 50%RH

Closed

HC

CC

Closed

Control

55 °F
Enthalpy Economizer
Energy Optimization Economizer

- FREE COOLING
  - 100% OA

- MECHANICAL COOLING
  - 20% OA
  - 20% < OA < 100%

Return Air Conditions

Temperature (°F)

Humidity Ratio

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Simulation Results for New York

Return Relative Humidity (Percent)

Cooling Load (Btu/lb)

Enthalpy
Energy Optimization
Simulation Results for Phoenix

Cooling Load (Btu/lb) vs. Return Relative Humidity (Percent)

- Enthalpy
- Energy Optimization

Johnson Controls, Inc.
Summary

- Tune feedback controllers
- Detect & fix faulty systems
- Stop fast switching: $\text{H} \leftrightarrow \text{C} \leftrightarrow \text{H} \leftrightarrow \text{C} \leftrightarrow \text{H} \leftrightarrow \text{C}$
- Use energy optimization