Development and application of smart control and management algorithms in hospitals

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  • Energy saving potential, the Fan coil (paediatric department)
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Development and application of smart control and management algorithms in buildings towards nearly zero energy buildings

- Energy saving in existing buildings towards ZEB
- Implementation and evaluation of BOC algorithms in different systems using Internet based techniques.
SCENARIO

Hospitals are large energy consumers because of:
- 24/7 operability
- medical imaging equipment
- special requirements for clean air and disease control

Energy consumption per square meter in hospitals is much higher than in many other types of buildings.

A typical hospital building is designed for long term use and, in practice, is often utilised for longer periods than its builders ever intended.

High interest proved by the high number of documents produced by public organizations and private companies.
Energy consumption in Hospitals

HOSPITAL ENERGY CONSUMPTION BREAKDOWN

Source: white paper on Healthcare by TAC – Schneider Electrics
OBJECTIVE

Green@Hospital acts on ICT devices and infrastructures converting them from energy intensive systems to drivers for energy efficiency.

The expected result is a 15% consumption reduction in the involved areas operating on:
- heating and cooling generation
- lighting
- ventilation
- data center

The main output of the project is a Web-based Energy Management and Control System (Web-EMCS) which integrates model based energy saving algorithms.

A Maintenance Energy Service, specifically developed and integrated in the Web-EMCS, helps to maintain optimal energy efficiency after initial efforts.
Pilot Hospitals (Green@Hospital project)

Hospital Virgen de las Nieves of Servicio Andaluz de Salud
Area: 134,000 m²
Beds: 915

Hospital de Mollet
Area: 27,000 m²
Beds: 160

Azienda Ospedaliero Universitaria – Ospedali Riuniti di Ancona
Area: 100,000 m²
Beds: 756

Hospital of Chania
Area: 50,000 m²
Beds: 450

Selected solution sets
- HVAC Emergency room
- HVAC Surgery room
- Chillers of data center

Selected solution sets
- Surgery room HVAC
- Heating & cooling plant

Selected solution sets
- Artificial lights
- Chillers of data center

Selected solution sets
- Artificial lights
- Fan coils
Case study  Hospital of Chania: “Saint George Hospital”

Work performed:

• Outdoor air temperature prediction

• Building and optimization control algorithm for HVAC

• Control algorithm for artificial lights
Control algorithms

Development phase

Input

Local controller

Output

Test phase

Local controller

TrnSyS/Radiance model
Controller

The controller is giving a new command every **15 min.**

In SGH the controller is changing the state of:
- Fan coil’s fan speed
- Fan coil’s valve
Controller

System Fan coil control: 1 inputs, 2 outputs, 5 rules

Temperature error

Coil change

Fan change

Fan coil control

(mamdani)

5 rules

Input

Output

Rules

If (Temp-error is NE) then (Coil-change is Up)(Fan-change is Plus-Two) (1)
If (Temp-error is SNE) then (Coil-change is Up)(Fan-change is Plus-One) (1)
If (Temp-error is Z) then (Coil-change is Zero)(Fan-change is Zero) (1)
If (Temp-error is SPO) then (Coil-change is Zero)(Fan-change is Minus-One) (1)
If (Temp-error is PO) then (Coil-change is Down)(Fan-change is Minus-One) (1)
Hospital of Chania: “Pediatric department”

Pediatric department of Saint George Hospital
Development of dynamic thermal model for fan coil operation

Thermal dynamic model
• Simulation software: TrnSyS version 17
• Geometry: Hospital’s floor plans, section & views
• Fan coil specs: Datasheet
• Internal gains information: Collected from hospital
• Outdoor conditions: Meteonorm weather file
Measurements collection

Data available from 26/08/2013 to 08/09/2013

- Indoor air temperature
- Fan coil energy consumption (thermal & electrical)
- Artificial lights operation
- Windows position
- Outdoor conditions (temperature, humidity, radiation)
Development of dynamic thermal model for fan coil operation – Model validation
Methodology followed

Control algorithms

Development phase

Input

Local controller

Output

Test phase

Local controller

TrnSyS/Radiance model

Optimization algorithms

Past

Future

\[ t \quad t+1 \quad t+p \]
Optimization process

\[
\min \left( \sum_{t=1}^{32} \text{Cost of operating the fan coil} + \text{Error of temperature} \right)
\]

so that

- fan of the fan coil is operating only when fan coil valve is open
- when fan coil operates, windows must be closed
Outdoor air temperature prediction - Strategy
Outdoor air temperature prediction – Results

**4 hours predictive horizon**
- $R^2 = 0.982$
- $\text{rmse} = 0.781$

**8 hours predictive horizon**
- $R^2 = 0.9655$
- $\text{rmse} = 1.1109$

**12 hours predictive horizon**
- $R^2 = 0.9696$
- $\text{rmse} = 1.0529$

**24 hours predictive horizon**
- $R^2 = 0.9637$
- $\text{rmse} = 1.1370$
Identification algorithm

<table>
<thead>
<tr>
<th>Input</th>
<th>Hidden layer</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
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<td>5</td>
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Architecture of identification algorithm: Artificial Neural Network

Topology of identification algorithm: Elman Neural Network

Construction of the model: Grey box

Performance function/indicator: “Mean square error”

Size of initial train data set: 1000

Number of epochs: 3000

Number of maximum fails: 3000

Predictive horizon: 1 step (15 min)
Indentification algorithms - Results

• Statistical comparison between measured temperature and predicted:
  0.15 < R-square < 0.81
  Root mean square error < 0.6 C
Optimization algorithm - Results

Inputs:
- Valve position
- Fan coil’s speed

Optimization algorithm
(SGH - Paediatric department)

Cost of each gene

Cost function

Graphs showing:
- Time steps vs. Indoor temperature (°C)
- Time steps vs. Outdoor temperature (°C)
The building optimization and control algorithm - Results
The building optimization and control algorithm - Results

EMBER
Energy Management In the Built Environment Research Unit

<table>
<thead>
<tr>
<th></th>
<th>Heating (kWh)</th>
<th>Cooling (kWh)</th>
<th>Total (kWh)</th>
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</thead>
<tbody>
<tr>
<td>Current condition</td>
<td>4494.05</td>
<td>961.46</td>
<td>5455.5</td>
</tr>
<tr>
<td>Matlab BOC</td>
<td>1428.1</td>
<td>2073.28</td>
<td>3501.4</td>
</tr>
<tr>
<td>% Energy saving</td>
<td>68.22 %</td>
<td>-115.6 %</td>
<td>36 %</td>
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</table>
Methodology followed

Control algorithms

Development phase
Input

Local controller

Output

Test phase

Local controller

TrnSyS/Radiance model

Optimization algorithms

Past Future

t t+1 t+p

Implementation phase

Local controller/Optimization

Green@Hospital

Energy Management in the Built Environment Research Unit
The building optimization and control algorithm - Strategy

1. **Begin of BOC algorithm (SGH-Fan coils)**
2. **Read:**
   - Presence
   - Windows position
   - CO₂ Sensor
3. **Repeat every minute for 15 minutes**
4. **In presence off or windows contacts off for 15 min and CO₂ level below 1000 ppm**
5. **Switch fan coil off**
6. **Read indoor air temperature value**
7. **Compare measured temperature to set point**
8. **Fuzzy controller**
9. **Load previous values**
10. **Change of fan’s speed state and valve position**
11. **Set valve’s position and fan’s speed**
12. **Save new values**
13. **Begin of BOC algorithm (SGH-Fan coils)**

**Inputs:**
- Valve position
- Fan coil’s speed

**Load outdoor temperature prediction**

**Optimization algorithm (SGH—Pediatric department)**

**Cost function**

**Selection of indoor temperature set-points**

**Controller**
Development of a Web-EMCS
Artificial lights - Model development and validation

<table>
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<tr>
<th>Dept</th>
<th>Room</th>
<th>R²</th>
<th>rmse</th>
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<tbody>
<tr>
<td>Ped</td>
<td>Patient’s room</td>
<td>0.9095</td>
<td>119.5 lux</td>
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<tr>
<td></td>
<td>Doctor’s room</td>
<td>0.7762</td>
<td>163.9 lux</td>
</tr>
<tr>
<td></td>
<td>Doctors’ rest room</td>
<td>0.2949</td>
<td>122.6 lux</td>
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</table>
Artificial lights – Model output
Development of the BOC algorithm

- Begin of BOC algorithm (SGH-Artificial lights)
  - Read: Presence sensor
    - Store presence sensor value
    - Repeat every minute for 35 minutes
  - Read: Presence sensor
    - Store presence sensor value
  - Load previous presence sensor values
  - Is presence OFF for more than 15 min?
    - NO
    - Load required illuminance level
      - Compare illuminance level to the required one
      - Fuzzy controller
        - Switch art. lights off or set to minimum level
        - Load previous dimming level of artificial lights
          - Apply equation for converting dimming to lights switching
          - Add previous dimming level of artificial lights and required change
          - Apply new dimming level
          - Store new dimming state of artificial lights
Connection between Matlab and Radiance

Current approach
Radiance currently connects with BCVTB only in Linux environment

Our proposal
Energy saving potential: 58 %
Preliminary conclusions

- Energy saving (> 15%) can be achieved using ICT in hospitals
- Control and optimization algorithms contribute to the energy performance of the systems
- Further improvements can be accomplished by fine-tuning the BOC algorithms
Publications

**Journals**


**Conferences**

- Cubi, E., **Papantoniou, S.**, Cesarini, D. N., Arbol, J., Maria Fernandez, J., & Salom, J. (2014). Potential benefits in terms of thermal comfort and energy use of adding a control loop to an existing multizone Air Handling Unit in a hospital setting. In **eSim 2014**, Otawa - Canada
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Thank you
Questions?