Functional and technological definition of BIM-aware services to assess, predict and optimize energy performance of buildings

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Acknowledgments

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Presentation Outline

- Introduction/Problem Statement
  - Building Energy Management Systems
  - Analytics – APO Services
- BaaS Architecture
  - Overall System Architecture
  - Services Integration – APO Kernel
  - Role of Simulation
  - Building Information Modeling (BIM)
- Conclusions – Future Work
Introduction
Building Energy Management Systems

- **Field** layer sensors (temperature, humidity, interior air quality, occupancy detectors, etc.) and actuators (valves, light switches, etc.)

- **Automation** layer consists of controllers whose logical functions may range from the single input single output (SISO) closed-loop control at the base level, to plant level control and supervisory control or optimization at the upper level.

- **Management system** layer provides capabilities for monitoring and centralized management of the building. At this layer various advisory services for the people involved in daily operation such as service technicians, engineers, or facility managers. Frequently these services may take advantage of powerful cloud-based analytics, which complement the functionality delivered locally.
Introduction
Analytics – APO services

APO Services:
(A)ssessment, (P)rediction, (O)ptimization

Fault Detection & Diagnostics
• Analytics to detect and discover the root cause (diagnosis) of equipment malfunctions and faults
  • Hard faults – hardware faults; Soft faults – performance degradation monitoring
  • Faults either discovered retrospectively either by continuous monitoring to schedule optimal maintenance

Performance Monitoring
• Analytics to monitor equipment performance at various hierarchy levels
  • Identify critical levels for effective operation to schedule optimal maintenance

Control Design & Optimization
• Control-related analytics to design, monitor and optimize applied control strategies
  • Interact with FDD and EM modules
  • Design strategies based on various performance criteria and comfort constraints
Introduction
Analytics

MONITORED ASSETS
- Refrigeration
- Controllers
- HVAC
- Combustion
- Sub-metering
- Sensors

Recommended Actions
- Summary of faults
- Top 10 worst performers
- Prioritized service / maintenance actions
- Cost analysis supporting upgrades / retrofits
- Reports

BIM, system models

Modeling

Remote Data

Data Warehouse

Automated APOs

24/7

Interactive tools

On-demand Analyst

Facility Management System

Local

Local APOs

Control Hardware

Embedded APOs

24/7
System Architecture
Overall System Architecture
System Architecture

APO Kernel

✓ Manages the interconnections between all APO service components;

✓ Data Management.
System Architecture

APO Kernel Example – Module Registry

[Diagram of System Architecture]

- JMS Broker (ActiveMQ)
- Embedded Database (DataModel)
- Modules Manager Bundle
- BaaS-Developer Fragment Bundles
- OSGi System Registry
- Modules Manager Service
- Domain Objects
- DI Singleton Instances
- OSGi Service: ModuleManagerDAO
- OSGi Service: ModuleManagerDAO Impl
- DI Singleton
- Instances
- Objects
- Simple Module
- Module Logic
- Module Domain Objects
- Multithreading Module
- Multithreaded Task Executor
- Module Logic
- Module Domain Objects
- BaaS-Developer Fragment Bundles
System Architecture
The need for support of simulation models

• Fault Detection & Diagnosis:
  ➢ Comparing measured performance indices (KPIs) to simulated;

• Performance Monitoring:
  ➢ Baselining – Reference energy consumption is constructed from a validated model;

• Control Design & Optimization:
  ➢ Model-assisted control design and optimization.
Thermal Simulation Models

Supported Calculation methodologies

- Spatial and temporal comparison of whole-building simulation models
Thermal Simulation Models

Types of models used

BaaS Thermal Simulation Models

<table>
<thead>
<tr>
<th>Detailed Models</th>
<th>State-Space Models</th>
<th>Black-Box Models</th>
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| • Detailed thermal simulation models
  • Require special treatment for the co-simulation component (e.g. BCVTB)
  • Require model-reduction techniques for simulation time speedup |
| • RC-based first principles models
  • Heat and moisture balance equations |
| • System Identification based on detailed thermal models
  • Execution time speedup
  • “Just enough” accuracy
  • NARX models
  • ARX models |
Thermal Simulation Models
Simulation – State-space models: SRC

- State-space model creation and invocation

Diagram:
- Data Warehouse
- Middleware
- BIM Server
  - Raw Data
  - IFC Data
- Co-Simulation
- SRC
- APO Services Layer
  - Input Data
  - Geometry

Diagram:
- RC-Network Model
- One-Zone Building
  - 10.11
  - 6.7
  - 4.5
  - 2.9
  - 13.14
  - 8.9
  - nid
Building Information Models
Industry Foundation Classes – IFC

- Designed in Constructivity:
  - IFC2x3, IFC4 import;
  - IFC4 export.

- Contents:
  - 2 spaces: space #2, space #3;
  - 2 levels: floor level, roof level;
  - 7 windows;
  - 2 doors.
Building Information Models
Types of Available Information

Sensor #6: Humid. sensor
Sensor #5: Humid. sensor
Sensor #3: Light sensor
Sensor #4: Temper. sensor
Sensor #8: Temper. sensor
Sensor #7: Light sensor
Sensor #9: Contact sensor
Sensor #10: Contact sensor
Sensor #1: Contact sensor
Sensor #2: Contact sensor
Sensor #1: Contact sensor

Space #2
Space #3
Building Information Models
BIM utilization – Aggregate Relations
Building Information Models
Queries – BIM server

- TNO BIMServer
  - Natively supports IFC2X3 – adapted to IFC4
  - Queries to the IFC data model
**Building Information Models**

**Query Example**

- **IfcSensor -> IfcSpace**

  **Result:**

  | Name: Sensor #4 | GUID: 2lWaYPui1AxxiWinuEGFk6 | Type: TEMPERATURESENSOR |
  | Sensor Belongs to: Space #3 |
  | Name: Sensor #7 | GUID: 3SPMQ30T16uB32WdNVpUnE | Type: TEMPERATURESENSOR |
  | Sensor Belongs to: Space #2 |
  | Name: Sensor #5 | GUID: 1BZhGaSQn7afwiHuHauLKWo | Type: HUMIDITYSENSOR |
  | Sensor Belongs to: Space #3 |
  | Name: Sensor #8 | GUID: 3iJjf30vXCF9U06SCCy_Q4 | Type: HUMIDITYSENSOR |
  | Sensor Belongs to: Space #2 |
  | Name: Sensor #3 | GUID: 2Z0n6P6ZnEag9NNLVEd6Zq | Type: LIGHTSENSOR |
  | Sensor Belongs to: Space #3 |
  | Name: Sensor #6 | GUID: 0mnOgsCz15hvyjFv8pQjEN | Type: LIGHTSENSOR |
  | Sensor Belongs to: Space #2 |
  | Name: Sensor #2 | GUID: 0DC4pKbIDF4xMQU1I_2xyj | Type: CONTACTSENSOR |
  | Sensor Belongs to: Door #1 |
  | Name: Sensor #10 | GUID: 3nu74XBHeb8B215CTgE5A | Type: CONTACTSENSOR |
  | Sensor Belongs to: Window #6 |
  | Name: Sensor #9 | GUID: 3Pyba$fBj439rpMWcA7H48 | Type: CONTACTSENSOR |
  | Sensor Belongs to: Door #2 |
  | Name: Sensor #1 | GUID: 2bJRWhcLr8c94cSsO5yq_e | Type: CONTACTSENSOR |
  | Sensor Belongs to: Window #3 |
Building Information Models
Query Example

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  - Name: Sensor #9  GUID: 3Pyba$fbj439rpMWcA7H48 Type: CONTACTSENSOR
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**Humidity Sensors**
Building Information Models
Query Example

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  Sensor Belongs to: Door #1

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  Sensor Belongs to: Window #6

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Building Information Models
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APO Services
Fault Detection and Diagnostics

• Semi-automatic configuration of APO services:
APO Services
Control Design and Optimization

Current control parameters $u_k$

Optimization Process

Controller Performance

Candidate Controller

Model

New Parameters $u_{k+1}$
Conclusions

• An architecture for delivering analytics services has been presented:
  ➢ Data Analytics (Fault Detection, Performance Monitoring)
  ➢ Control (Re-)Design and Optimization

• BIM crucial element for parameterization of services

Ongoing Work:

• Implementation and testing of such services
• Simulation-based testing
• Implementation in demonstration buildings
Additional Information

- Project Web Site:  
  http://www.baas-project.eu

- Attend the Joint C21-BaaS workshop

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