Implementation and Demonstration of Energy Management Systems for Terminal Buildings

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Overview

- **Introduction**
  - Smart Grid in Japanese island
  - EV & ITS project and FUSION project

- **The meta-standard concept**
  - The concept for integrating heterogeneous systems

- **The construction of the EMS**
  - Constructing an EMS in an actual operating building

- **Application of the constructed EMS**
  - Air-conditioner control application
Introduction

- **Smart Grid in Japanese island**
  - Power grid is independent from that of main land.
  - Effective use of distributed power sources and leveling of electric power of demand and supply are important.
  - To achieve these matters, Energy Management Systems and its upper layer applications for the leveling are necessary.

- **Nagasaki EV&ITS project**
  - Research about utilizing ITS technologies in island
  - Install over 100 electric vehicles (EV) to the Goto island, Nagasaki prefecture
  - Construction of Energy Management Systems (EMSs) in the Terminal Buildings
Purpose

- **Purposes of this study**
  - The construction of the EMS in the Fukue Port Terminal Building of Goto island
  - The construction of total system including hetero-subsystems using XML, which maintains interoperability
  - The demonstration of the proposed XML format for data description in the actual operating building
  - The reduction of CO$_2$ emission by controlling air-conditioner as application of EMS

This study aspires to formulate unified XML-based format for data description (system interface) to maintain interoperability and to develop upper layer application.
The meta-standard concept

**Conventional system construction**

- The total system has heterogeneity composed of various standard technologies and protocols
- Selection of standard technologies from each layer is fundamentals of system architecture

![Diagram showing system levels and standards](image)
The meta-standard concept

**In the conventional system construction**

- We need to select and combine appropriate standard technologies according to communication requirements and data semantics in order to construct the total system and upper layer application.

**Example of the conventional EMS construction**

- Existing upper layer application should consider these constraints of these standard technologies, and dedicated application software is indispensable to utilize each technologies.
The meta-standard concept

- The meta-standard concept for the system construction
  - Considering infrastructures and standard technologies as resources for operating and managing the system

A common platform and flexible protocol for data description are necessary.
The common platform for meta-standard

- The common platform with database for
  - flexible operation and management of the resources
  - treating the existing infrastructures and standard technologies in different areas as available resources

- All the interfaces (data description) is defined and unified by proposed XML-based format
The XML-based data description

- All the interfaces (data description) are defined by using XML-based message format to exchange data through the RS-PF, AP-PF, and PF-PF interfaces.
- The sample data description through the RS-PF interface

```xml
<?xml version="1.0"?>
<inms>
  <head>
    <version>1.0</version>
    <id name="device">12345abc</id>
    <timestamp timezone="JST">2011-02-24 23:13:56</timestamp>
  </head>
  <body>
    <group name="A01">
      <timestamp timezone="JST">2011-02-24 21:45:43</timestamp>
      <in name="temperature" type="room" id="ABC" action="write">Data</in>
      <in name="humidity" type="room" id="DEF" action="write">Data</in>
    </group>
  </body>
</inms>
```
The construction of the EMS

- **Site**
  - Fukue Port Terminal Building, Goto island, Nagasaki Prefecture, Japan
  - Floor area : 2330[m$^2$] Robby area : 1180[m$^2$]

- **Purpose**
  - To confirm the feasibility of the proposed XML-based common platform and data description

- **System configuration (The constructed system includes various heterogeneous subsystems.)**
  - Subsystems of environmental sensors
  - EV’s plug-in stands measurement system
  - Subsystems of EV’s information (indoor condition, running history with GPS)
  - Photovoltaic generation system
  - Power measurement system
  - Each subsystem is constructed by different 7 companies.

- **Upper layer application and service (The EMS application)**
  - Data visualization on the web
  - Air-conditioner control
  - Human behavior management using RFID tag
Installed devices

- Bringing devices produced by different companies into the actually operating environment, Fukue Terminal Building.

- Control device
- Power measurement device
- Photovoltaic generator
- Environmental sensors
- Server

Fukue port Terminal Building
Measurement items of the system

- Various information should be included to demonstrate data description format and common platform. Measurement items are as follows.
  - Consumed power of receiving point, air-conditioner, and distribution board
  - Photovoltaic generated power
  - Environmental data (Temperature, Humidity, Motion, Air velocity, Illuminance)
  - Information of fast charger of EV (EV’s plug-in station)
  - Driving history of EV

- We have 2,000,000 sampling data for 1 day storing in the common platform (database).

- These information are described by using proposed XML-based format.

- In this presentation, consumed power and environment data are mainly shown.
Upper layer application and service

- Examples of possible upper layer application of the EMS
  - Air-conditioner control using head-count conjecture
  - Air-conditioner control considering indoor environment
  - Demand control using EV’s battery pool
  - ITS application for EV and tourism
  - Data visualization on the web

- These applications uses information from the resources such as
  - Motion sensor, RFID reader, environmental sensor, power measurement sensor, GPS, EV’s plug-in stand, etc.

  These information can be accessed as desired on the common platform.

- Though this study is mainly focused on air-conditioner control and data visualization, the total system should be prepared for future expansion.
  - The common communication platform
  - Proposed XML-based format for data description
Constitution of the EMS

**Fukue Port Terminal Building, Nagasaki, Japan**
- Sensors
  - Temperature
  - Humidity
  - CO₂
- RFID Reader
- Specified Low Power Radio
- Air-Conditioning Control
- Resource Management Server

**Fukue Island, Nagasaki, Japan**
- Solar Panels
- EV Plug-in Station

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**Keio University, Yokohama, Japan**
- Resource Management Server

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**Infrastructure**
- LAN (100BASE-TX)
- L2SW
- L3SW
- AP
- WiFi
- 3G
- RS485
- XML-C
- Data

**Networking**
- IP-VPN

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**Communication**
- About 1000 km

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**Confirmation of system operation**

- Tendency of consuming energy is conjectured to have correlation with ship departure.
- Control of electrical devices, especially air-conditioner can be conducted using scheduling method.
Demand side application

- General outline of the demand side application implemented in the site

**Common Platform (PF)**

- Database
- Environmental data
- Resource state data
- Consumed power data

**Control**

- XML
- Data Acquisition

**Response** (Required data)

- XML
- Command

**Application (AP)**

- Static AC control
- Dynamic AC control
- Receiving power leveling with battery

**Resource (RS)**

- Air-conditioning equipment
- Battery
- Sensor

AC : Air-conditioning equipment
Control targets of the application

- In this research, AC control is conducted as an application of the constructed EMS.
- Control targets of the application
  - 12 electrical air-conditioning equipment
AC control method

- **Static AC control**
  - The operation schedule of the AC is prepared based on configured reduction rate.
  
  Ex) Operation schedule for an AC(control target) with configured reduction rate (CRR) 10%

  ![Operation Schedule](image)

  
  - **Dynamic AC control**
    - The control schedule varies according to the reduced CO₂ emission.
    - Turn off which AC and how long would be different according to the situation.

  Ex) Reduced CO₂ of an AC(control target) and operation decision

  ![Operation Schedule](image)

  \[
  \text{Actual reduced CO}_2 \text{ rate (ARR) = Reduced / (CO}_2 \text{ emission + Reduced)}
  \]

  ![Operation Schedule](image)

  Compare ARR and target rate (TR)

  Environmental situation

  - which AC?
  - how long?
Dynamic AC control flow chart

- Start
  - Get HVAC On/off state
  - Calculate PMV of each room
  - Turn off HVAC based on PMV and cut rate
  - Calculate RP
  - HVAC state
  - Environmental data
  - Consumed power of HVAC
  - HVAC : Air-conditioning equipment
  - RP : Reduced power
  - TRP : Target reducing power
  - End of experiment?
  - Decision: TRP <= RP
  - Decide control parameters

The common platform
- Resources data
  - XML
  - AC
  - Sensors

Keio Univ. West Lab
CO₂ saving experiment during winter

- Experiment term: January 13\textsuperscript{th}, 17\textsuperscript{th}, 19\textsuperscript{th}, 21\textsuperscript{st} of 2011
  - The experiment was conducted as operation confirming and preliminary survey.
  - We set the day with AC control and without AC control alternately.
- CO₂ saving method
  - Static AC control: Turning off the AC based on predefined constant operation schedule

- Evaluation of the experiment
  - Reduced CO₂ emission calculated from reduced consumed power of the AC
    - CO₂ – Electric power coefficient: 0.375[t- CO₂/1000kWh]
  - PMV (environmental index) change during AC control
  - Questionnaire to evaluate deterioration of environmental condition because of AC control
    - Participators: 22 workers of the building
    - Participators answer comfort level they felt
    - Comfort level is valued 0 as normal
    - The questionnaire was took place during July.

Discomfort because of cold  Discomfort because of hot
-2 -1 0 1 2
Temperature dropped about 1°C in maximum.

The control influences indoor condition.

We conducted questionnaire to estimate environmental effect.
# Experimental result

<table>
<thead>
<tr>
<th>Date</th>
<th>2011/1/13</th>
<th>2011/1/17</th>
<th>2011/1/19</th>
<th>2011/1/21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside temperature[℃]</td>
<td>3.4</td>
<td>3.7</td>
<td>4.9</td>
<td>5.8</td>
</tr>
<tr>
<td>AC CO₂ emission sum[kg]</td>
<td>38.86</td>
<td>38.36</td>
<td>31.24</td>
<td>30.00</td>
</tr>
<tr>
<td>Reduced sum[kg]</td>
<td>9.11</td>
<td>20.99</td>
<td>26.40</td>
<td>36.44</td>
</tr>
<tr>
<td>Result of questionnaire※</td>
<td>-0.41</td>
<td>-0.52</td>
<td>-0.19</td>
<td>-0.19</td>
</tr>
<tr>
<td>PMV※</td>
<td>-0.48</td>
<td>-0.44</td>
<td>-0.43</td>
<td>-0.29</td>
</tr>
<tr>
<td>CRR[%]</td>
<td>10</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>ARR[%]</td>
<td>6.61</td>
<td>16.03</td>
<td>8.37</td>
<td>10.84</td>
</tr>
</tbody>
</table>

※Average value of no-control day is **-0.37**, PMV is **-0.41**

- System can see reduction of the CO₂ emission about 13% at most.
- Result of questionnaire value shows close inclination between control and no-control day.
- The influence to the environment by air-conditioner control doesn’t be felt so much by demand side.
- More reduction of CO₂ emission can be anticipated by raising configured cut rate.
CO₂ saving experiment during summer

- **Experiment term**: Weekday of the July and August, 2011 (2 months)
  - We set the day with AC control and without AC control alternately.

- **CO₂ saving method**
  - Static AC control: Turning off the AC based on predefined constant operation schedule
  - Dynamic AC control: Turning off the AC on the fly based on target value of reducing CO₂ emission

- **Evaluation of the experiment**
  - Reduced CO₂ emission calculated from reduced consumed power of the AC
    - CO₂ – Electric power coefficient: 0.375[t- CO₂/1000kWh]
  - Questionnaire to evaluate deterioration of environmental condition because of AC control
    - Participators: 22 workers of the building
    - Participators answer comfort level they felt
    - Comfort level is valued 0 as normal
    - The questionnaire was taken place during July.
### Experimental result

<table>
<thead>
<tr>
<th></th>
<th>AC Control method</th>
<th>Static / Dynamic CRR / TR[%]</th>
<th>Days</th>
<th>AC CO₂ emission sum[kg]</th>
<th>AC CO₂ emission per day[kg]</th>
<th>Reduced sum[kg]</th>
<th>ARR[%]</th>
<th>Average outdoor temperature [℃]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Jul.</strong></td>
<td>Static</td>
<td>5</td>
<td>5</td>
<td>294.98</td>
<td>59.00</td>
<td>14.53</td>
<td>4.70</td>
<td>30.60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>4</td>
<td>204.71</td>
<td>51.18</td>
<td>20.42</td>
<td>9.07</td>
<td>29.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>5</td>
<td>235.62</td>
<td>47.12</td>
<td>59.47</td>
<td>20.15</td>
<td>31.00</td>
</tr>
<tr>
<td></td>
<td>With control sum</td>
<td>14</td>
<td>735.31</td>
<td>52.52</td>
<td>94.43</td>
<td>11.38</td>
<td></td>
<td>30.45</td>
</tr>
<tr>
<td></td>
<td>Without control sum</td>
<td>17</td>
<td>874.06</td>
<td>51.42</td>
<td>0.00</td>
<td>0.00</td>
<td>29.94</td>
<td></td>
</tr>
<tr>
<td><strong>Aug.</strong></td>
<td>Dynamic</td>
<td>5</td>
<td>4</td>
<td>236.46</td>
<td>59.11</td>
<td>16.66</td>
<td>6.58</td>
<td>31.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>5</td>
<td>283.77</td>
<td>56.75</td>
<td>46.38</td>
<td>14.05</td>
<td>31.20</td>
</tr>
<tr>
<td></td>
<td>With control sum</td>
<td>9</td>
<td>520.23</td>
<td>57.80</td>
<td>63.03</td>
<td>10.81</td>
<td></td>
<td>31.48</td>
</tr>
<tr>
<td></td>
<td>Without control sum</td>
<td>22</td>
<td>1321.09</td>
<td>60.05</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
<td>30.50</td>
</tr>
</tbody>
</table>

- The dynamic AC control can reduce the CO₂ emission more effective.
- The CO₂ emission saving can be anticipated in both control method.
Questionnaire result

Questionnaire result of July, 2011 (static AC control experiment).
✓ Most answered comfort level was “0” means comfort as usual.
✓ The result also shows close inclination between with control and without control day.
✓ It can be said that the control of AC doesn’t always cause environmental deterioration at the demand side.

<table>
<thead>
<tr>
<th>Comfort level</th>
<th>2</th>
<th>1</th>
<th>0</th>
<th>-1</th>
<th>-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRR : 5%</td>
<td>2.00</td>
<td>8.80</td>
<td>8.80</td>
<td>1.20</td>
<td>0.2</td>
</tr>
<tr>
<td>CRR : 10%</td>
<td>1.75</td>
<td>6.75</td>
<td>11.75</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>CRR : 15%</td>
<td>3.20</td>
<td>8.00</td>
<td>10.00</td>
<td>0.20</td>
<td>0</td>
</tr>
<tr>
<td>Without control</td>
<td>1.71</td>
<td>6.86</td>
<td>10.71</td>
<td>0.64</td>
<td>0</td>
</tr>
<tr>
<td>Sum of people</td>
<td>57</td>
<td>207</td>
<td>291</td>
<td>16</td>
<td>1</td>
</tr>
</tbody>
</table>

Answered number of people per day

- Most answered comfort level was “0” means comfort as usual.
- The result also shows close inclination between with control and without control day.
- It can be said that the control of AC doesn’t always cause environmental deterioration at the demand side.
I know you could do it. 3% of energy is reduced.
I know you could do it. 3% of energy is reduced.
I know you could do it. 3% of energy is reduced.
Conclusion

- System including heterogeneous subsystems is constructed by using the common platform and unified XML-based format.
- The AC control application was developed as application of the constructed EMS.
- The result showed the system (application) can reduce 13% of CO₂ emission in the winter and 20% in the summer at most.

Future work

- Continue operation of constructed system to show availability of the formulated connection data.
- Study control algorithm considering comfort of demand side by utilizing result of this study.
Thank you for listening.