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A BIM BASED DATA MODEL FOR AN INTEGRATED BUILDING ENERGY INFORMATION MANAGEMENT IN THE DESIGN AND OPERATIONAL STAGES

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ABSTRACT

Many buildings have been monitoring and collecting large amounts of data related to building energy. However, these building energy data are not being used to achieve building energy reduction in buildings under operation. In order to manage efficiently the building energy information about the building energy, this study suggests an extended data model based on a BIM based design model (gbXML). Currently, the BIM model cannot represent the dynamic information related to the building energy in the operational stage. In this study, we suggest an extended data model and integrate the model to a database and the measurement devices of a building using an external coupling program (i.e. BCVTB). A case study for an integrated data management system is performed in an actual building equipped with a building energy monitoring system. This study shows that the extended data model can manage building energy information in both design and operational stages more efficiently.

INTRODUCTION

A building's energy consumption occurs continuously during its entire life cycle; design, construction, operation, and disassembly. Buildings consume 40% of global primary energy and contribute in excess of 30% CO_2 emissions (EUROSTAT, 2008). In addition, operation and maintenance of buildings account for about 60~85% of the total life cycle costs. This indicates that the potential to save energy by applying appropriate building operation management is great (Pérez-Lombard et al., 2008).

Currently, many buildings are collecting a rich set of operational data related to the building energy from various building systems and equipments. At this time, the main issue is how to store the large amounts of data into a structured database, and how to efficiently manage the data for building energy saving. However, a scalable and structured database, which can be applied to different buildings (e.g. size and type) with different systems, is still missing (Dong et al., 2012).

These days, a BIM model has been actively adopted in architecture, engineering, and construction industries for such uses as 3D-rendering, drawing extraction, cost estimation, material, clash check, etc (Eastman, 2008). However, while there are BIM model based design tools such as Revit (Autodesk, 2011), data integration from the design stage to the operation stage is still missing (Dong et al., 2012). If data loss occurs when the data transits from design to operation, the cost is incurred to reconstitute the data, which also leads to overall reduction in data integrity (Costa et al., 2013).

Tremendous amounts of building information are gathered over the building life cycle. However, the data flow from design stage to operational stage is still not seamless and data loss may occur. In addition, there is shortage about a scalable framework to efficiently manage the information related to building energy. The objective of this study, it is the integrated management of building energy information in the design and operational stages using the gbXML based an extended data model related to building energy. This study can reduce the time spent to understand trends of building energy usage.

TECHNOLOGY APPROACH

In this paper, we proposed a gbXML based data model that can extend from the design stage to the operational stage about the building energy. This suggested data model was applied in an actual building equipped with measurement sensors. In addition, we demonstrated the data management about building energy in the design and operational stages through integration between the measurement sensors of a building and database using BCVTB as middleware. Figure 1 shows the change of application according to the extension of a BIM model related to building energy. The BIM model from the authoring tool (e.g. Revit MEP) is extended with the addition of information, such as HVAC and the information related to the building operational energy. Depending on extension of the BIM based design model, the range of application is increased, such as analysis model, energy simulation and control, etc. This study was performed by following steps:

1. Suggestion of an extended data model with gbXML for building operational information.
2. Establishment of the real-time data acquisition system to demonstrate the integrated data management in the design and operational stages.

3. Application of the real-time system in an actual building.

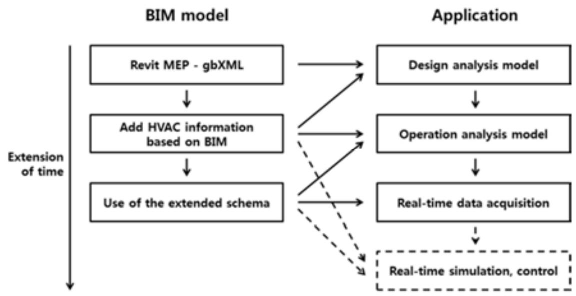

Figure 1 Extension progress of a BIM model related to the building energy

DATA MODEL FOR BUILDING OPERATIONAL INFORMATION

In this section, we suggested an extended data model for building operation based on a gbXML based design model.

Required data types related to building energy in the operational stage

Building operational information consists of four data types. Features of the required four data types are as follows:

1. Monitoring data, it refers to the information measured that relates to building energy. This data includes information about building operation schedule, weather, occupancy, etc.,
2. Forecasting data, it contains the predicted information about weather and occupancy. These data can construct the building environment in the next time step,
3. Control data, it pertains to the information about the building control signals. This control signal is applied to an actual building,
4. Simulation data, this data includes the results from simulation programs. It can be used to calibrate the simulation model, and can be used for the building control based on the simulation.

Figure 2 shows the data relationship for a building's operation. The monitoring data is used to produce a simulation model, or generate the data in the next time step. The forecasting data provides the environment of the simulation. The control data is generated through algorithms. This data directly controls the operation of building. The measured data about the building operational status is repeatedly stored as the monitoring data. The simulation data is used for the calibration and building control. The calibration is performed by comparing the simulation results to the measured building energy data. This calibration can improve the accuracy of the simulation model.

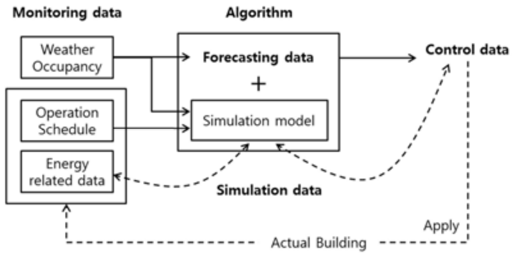

Figure 2 Data relationship for building operation

Structure of the data types

We suggested structures of the four data types. Each data structure is as follows:

'Monitoring' is classified into three child data types; 'Environment', 'BuildingSystem', and 'Resource'. 'Environment' includes general information, such as temperature, humidity, pressure, flow rate, etc., that can be measured inside and outside of building. 'BuildingSystem' can describe the measured information about major and sub equipment of the building system. In addition, 'Resource' is able to store information about the price and consumption of each fuel used in the building system. Figure 3 shows the architecture of monitoring data.

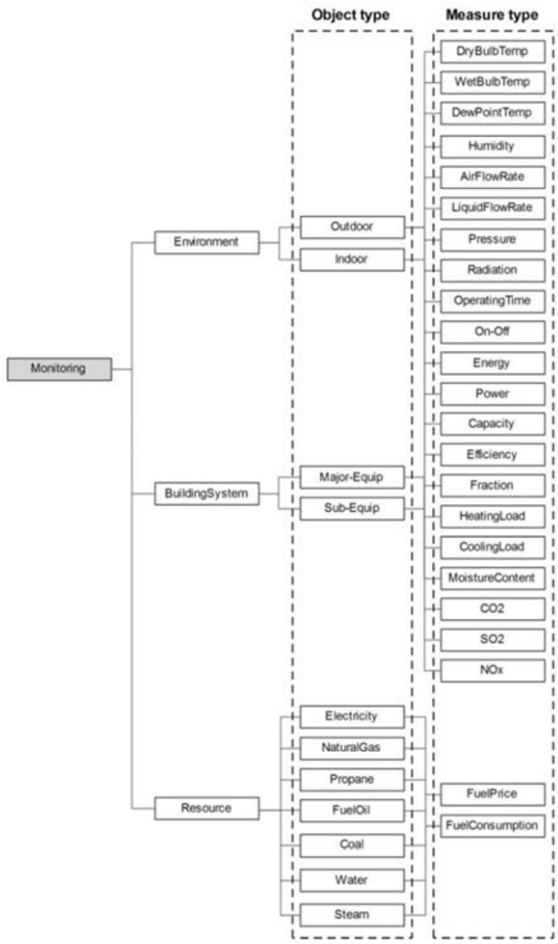

Figure 3 Architecture of monitoring data

‘Forecasting’ is categorized into two child data types, ‘WeatherData’ and ‘OccupancyData’. ‘WeatherData’ data type includes the nine inputs required to generate a .epw file; temperature, humidity, precipitation, wind speed, etc. This file is the weather file used for the energy simulation in EnergyPlus. In addition, ‘OccupancyData’ data type can store information about the predicted occupancy pattern in each zone.

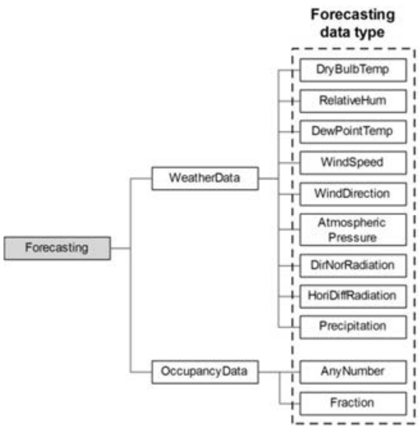

Figure 4 Architecture of forecasting data

‘ControlPlan’ is categorized into two child data types, ‘MechanicalEquip’ and ‘ElectricEquip’. ‘MechanicalEquip’ includes the planning information about how to control the mechanical equipment of the building system. ‘ElectricEquip’ can describe the plan to control the power load and lighting in the next time step. When control signals are applied in the building, they are used in a specific approach of a control target (e.g. Door – on/off, Equipefficiency - fraction).

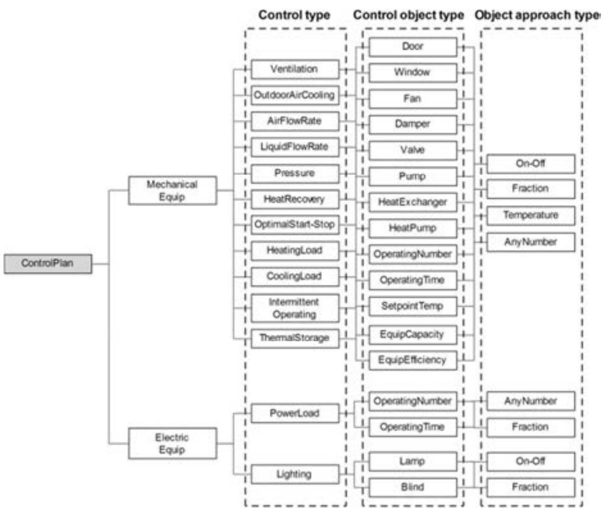

Figure 5 Architecture of control plan data

‘SimulationResults’ is classified into two child data types, ‘IndoorSim’ and ‘SystemSim’. ‘IndoorSim’ can store the simulation output about temperature, humidity, etc. In addition, ‘SystemSim’ includes the simulation output related to the building system. Figure 6 shows the architecture of simulation results data. In order to compare with monitoring data, the structure of figure 6 is similar to ‘Monitoring’ structure.

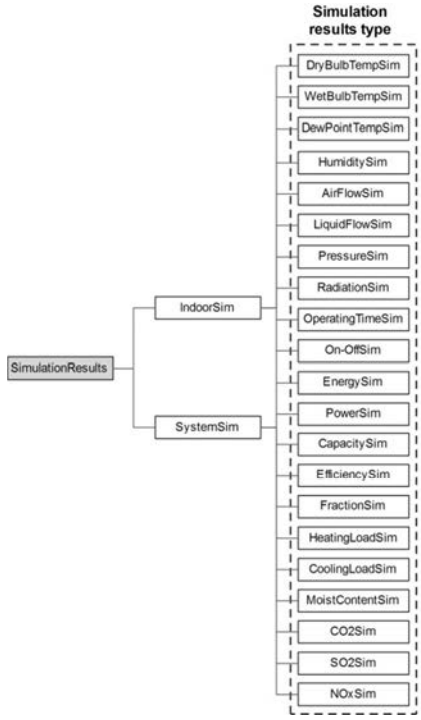

Figure 6 Architecture of simulation results data

Construction of an operational schema

An extended schema in the operational stage consists of four high-level elements according to the each data structure; ‘Monitoring’, ‘Forecasting’, ‘ControlPlan’, and ‘SimulationResults’. By default, each element is defined using ‘id’ attribute. The four high-level elements can choose the time step of the data storage using ‘timeStepType’ attribute (1, 5, 10, 15, 30, and 60 minutes).

‘Environment’, ‘BuildingSystem’, and ‘Resource’ child elements of ‘Monitoring’ can decide what should be measured using various attributes (location, object, and measure type).

‘Forecasting’ consists of two child elements, such as ‘WeatherData’ and ‘OccupancyData’. Firstly, in ‘WeatherData’ element, ‘date’ attribute is used as a time stamp that represented the predicted nine data in the next time step. Secondly, in ‘OccupancyData’ element, ‘occupancyInputType’ attribute selects the storage method (number and fraction) of the predicted occupancy data.

‘MechanicalEquip’ and ‘ElectricEquip’ elements of ‘ControlPlan’ are classified depending on the facility type. These elements define the control plan calculated from the control algorithms, using various attributes (control, control object, and object approach type). In addition, using ‘ControlCondition’ element, control reference values can be represented.

‘IndoorSim’ and ‘SystemSim’ elements of ‘SimulationResults’ can select the kind of simulation results using ‘~SimResultsType’ attribute.

'Monitoring' and 'SimulationResults' upper elements have a '~IdRef' attribute to share the information of each other. '~IdRef' attribute can refer to the information of the specific element through 'id'. Using this attribute, it is easy to compare both upper element values to each other. Figure 7~11 shows the schema of each element for building operation.

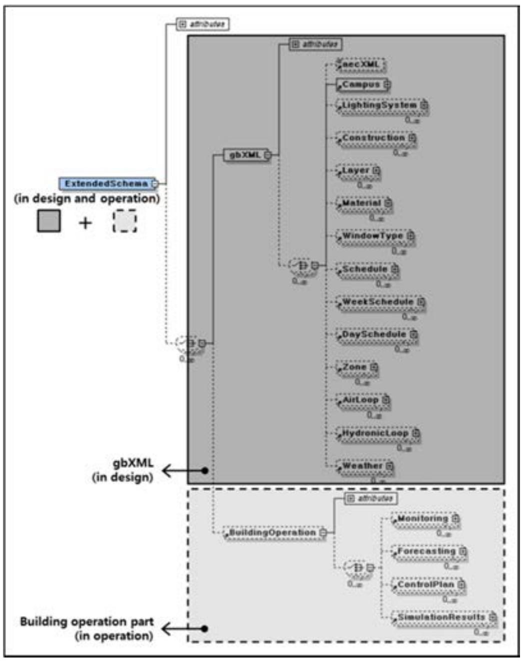

Figure 7 Extended schema for design and operation

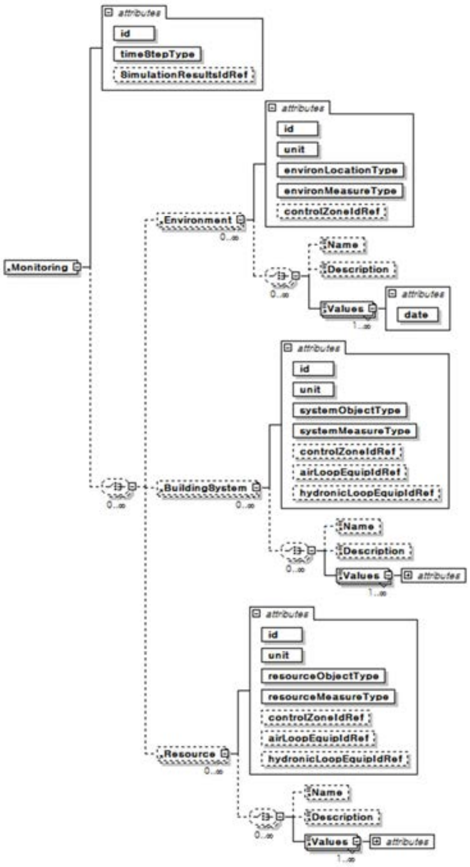

Figure 8 Monitoring schema

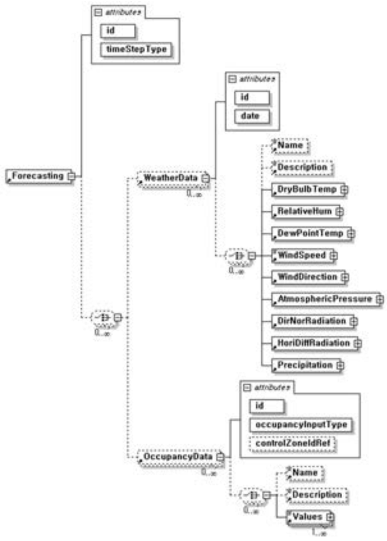

Figure 9 Forecasting schema

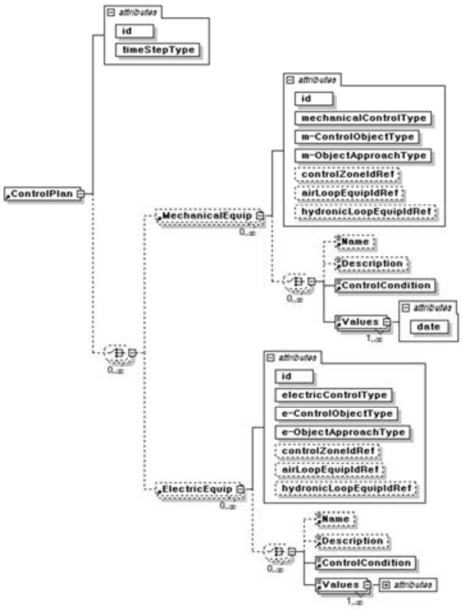

Figure 10 Control plan schema

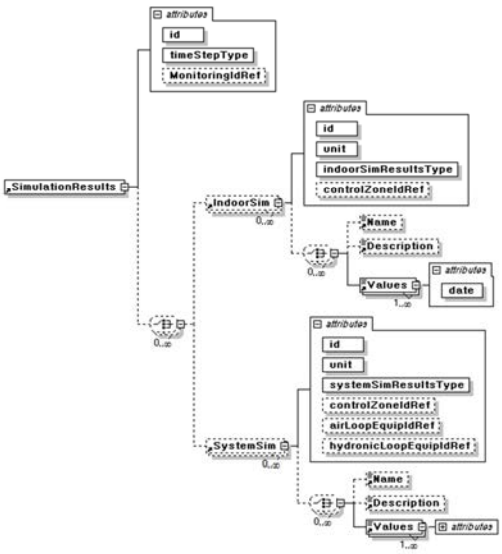

Figure 11 Simulation results schema

All four upper elements, which are suggested for building operation related to the energy, have the child element 'Values'. The stored data of 'Values' is dynamic. The data is accumulated continuously according to the time stamp from the 'date' attribute. The remaining elements, except 'Values', of the extended schema are used to describe the 'Values' data. These elements contain static information.

Connection with the BIM based design model

The BIM based design model has the information related to building energy in the design stage, such as building geometry, construction, zone, schedule, internal load, HVAC, etc. The extended schema for building operation can be connected with the information of zone and HVAC systems in the BIM based design model.

In order to share the existing information, the extended schema is connected with 'Zone', 'AirLoop', and 'HydronicLoop' elements related to the building energy in the BIM based design model. Each child element of the four upper elements (Monitoring, Forecasting, ControlPlan, and SimulationResults) refer to the BIM based design model using '~IdRef' attributes about zone and HVAC system part in gbXML. Figure 12 shows the connection structure between the extended schema and gbXML.

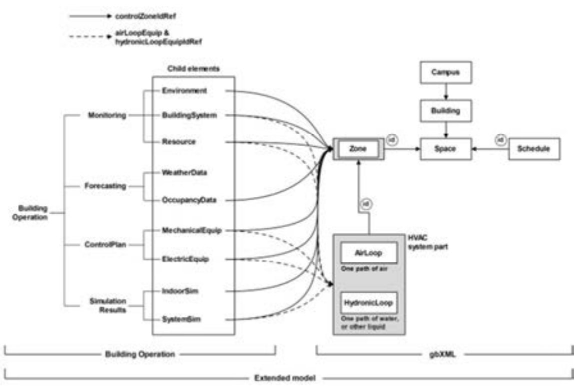

Figure 12 Connection structure between the extended schema and gbXML

REAL-TIME DATA ACQUISITION

Using the extended data model, a database can be produced real-time monitoring data related to building energy. In this study, using BCVTB as middleware, we established a data acquisition system that can connect the real-time monitoring data and the database based on the suggested data model.

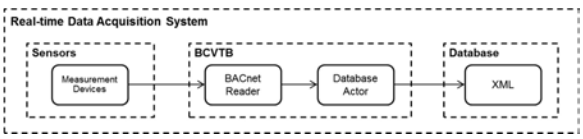

Figure 13 Construction of real-time data acquisition

BCVTB plays an important role in establishing the integrated real-time data acquisition system to efficiently use the operational data. The suggested system links hardware for a building's energy management and a database based on the extended schema. Figure 13 shows the configuration of real-time data acquisition system (Measurement devices, BCVTB, and Database).

Sensors integration

Recently, there are many modern commercial buildings equipped with devices that can measure operational building data. Open protocols, such as BACnet (a data communication protocol for networks of building information), enable sensors to transmit the measured data to the subsystems of a building. The BACnet reader actor in BCVTB can read input data through BACnet from sensors and the BACnet writer actor can write the control signal to subsystems (e.g. BEMS) of building. The two BACnet actors require configuration files (.xml) to specify the BACnet devices, object types and property identifiers (Wetter, 2011).

Database integration

A database is integrated through BCVTB to record all exchanged data in time series. This study used a XML database based on the suggested data model. BCVTB supports the connection with the XML database through the database actors (e.g. 'DatabaseManager', 'SQLstatement'). The database stores monitored data from the measurement devices, control actions in the integrated system.

DEMONSTRATION

To evaluate the feasibility of the suggested schema, this study establishes the extended XML data model based on building energy operation model about an existing building. This model can be used to efficiently manage the building energy monitoring data.

Building facts

The selected building has a rectangular shape with two stories. The first floor is used as a dining space, and the second floor is used as a living space for children. Figure 14 shows the outside view of the building, and table 1 provides a summary of the building.

Figure 14 Outside view of the existing building

Table 1 Building summary

ELEMENT		DESCRIPTION
Location	Latitude	37.39°
	Longitude	127.02°
Principle use		Children-care building
Number of stories		2 floors
Total floor area		393 ㎡
Heating system		2 night storage boilers & Radiant floor heating system
Floor heating system area		290.27 ㎡

This building is equipped with a radiant floor heating system containing two night storage electric boilers (heating capacity: 30kW, thermal storage capacity: 2700ℓ, efficiency: 93%). Figure 15 shows the structure of the heating system.

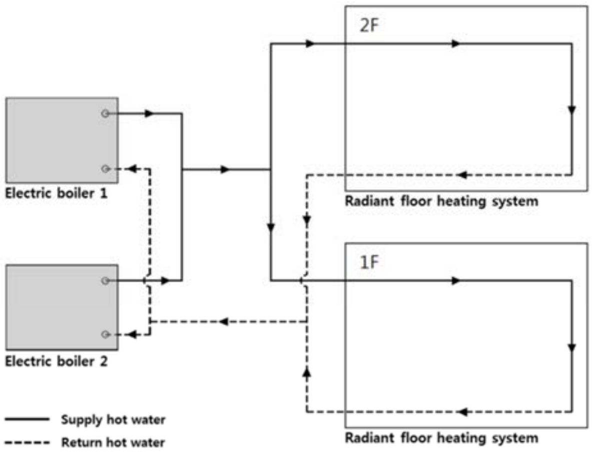

Figure 15 Architecture of the heating system

Many measurement devices were equipped in this demonstration building. Using BACnet, a lot of data can be transmitted regarding the building operational information. The transmitted data is related to the outdoor condition (outdoor dry-bulb temperature and relative humidity), the building energy system (e.g. boilers, hot water heaters, and earth tube system). These data can be sent to the server PC every 1 minute through BACnet protocol.

gbXML based building reference model

The building consists of 11zones; 1F has 3zones and 2F has 8zones. A gbXML based design model, including the building architectural information (e.g. building geometry, building material, space and zone), was generated using Revit MEP. Figure 16 shows the BIM model from Revit MEP. HVAC system model is created based on the actual HVAC systems of the building. The HVAC information related to the heating system (two electric boilers and radiant floor heating) can be entered into the HVAC system part (e.g. 'HydronicLoop' element) of gbXML.

The measured data is received from BACnet gateway through BACnet/IP from the actual sensors. The transmitted data is stored in a database based on the extended schema.

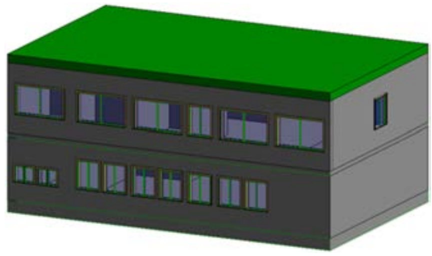

Figure 16 A BIM model from Revit-MEP

Extended XML model for building operation

In order to understand the dynamic information in the operational stage, the static data needs to describe the dynamic information. This study established an extended XML model based on the suggested schema. The extended XML model includes the information (e.g. location and measurement type) of monitoring devices in the building. In addition, this XML model can refer to the information of the BIM based design model, such as zone and HVAC system. The extended XML model can be applied to the database used in a real-time data acquisition system. Figure 17 shows an extended XML model for building operation.

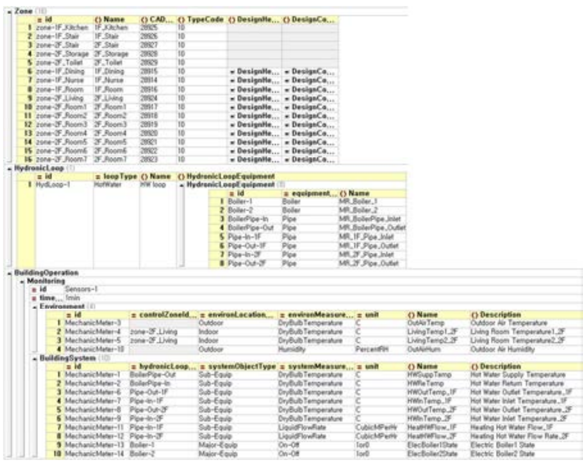

Figure 17 Extended XML model for building operation

Real-time implementation of the data acquisition

The BCVTB was installed in a separate PC that connected the measurement devices. The BACnet reader actor collects the sensor data for the real-time data acquisition such as outdoor dry-bulb, outdoor relative humidity and heating system nodes. The real-time data acquisition system can recognize the sensor data, which varies depending on time. The sensor data is sent to the database through the query language in BCVTB. The received data are stored according to the extended XML model. Figure 18 shows the real-time data acquisition system using BCVTB.

Results

The real-time data acquisition system received the information related to the building heating system (two electric boilers and radiant floor heating) from the measurement devices. The data from each sensor is entered into the XML database based on the extended data model. The XML model of database can integrate the building energy information in the design and operational stages. The measured data are the information related to the indoor and outdoor conditions (temperature and humidity), the heating system (e.g. boiler status, hot water temperature, and hot water flow rate). The stored data refers to the zone and HVAC information of the existing BIM based design model using '~IdRef' attributes regarding zone and hydronic loop information in gbXML.

Moreover, the data sent to the sensors is stored dynamically in 'Values' child element according to the time stamp. The other elements describe the 'Values' data using the static information of the building. Figure 19 shows the static and dynamic information in the extended XML model.

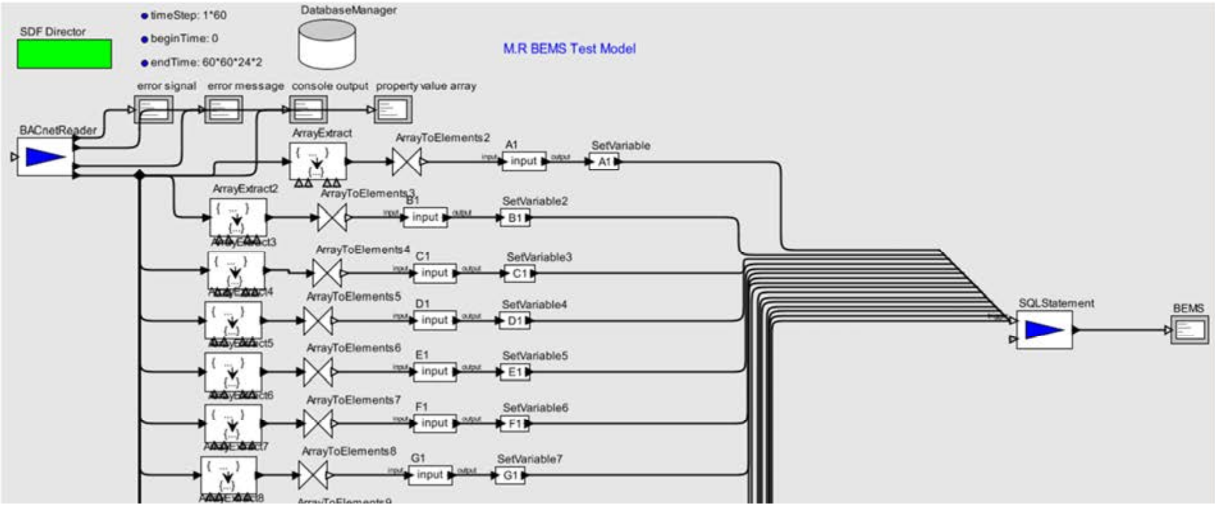

Figure 18 Real-time data acquisition system with BCVTB

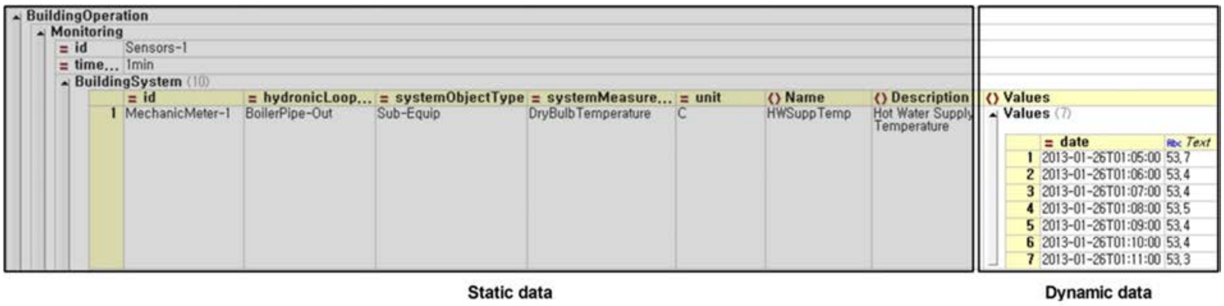

Figure 19 Static and dynamic information in the extended XML model

CONCLUSION

This paper studied on a BIM based extended data model and integrated it to a building energy information management system, which can be used in design and operational stages. A demonstration of this study was performed to validate our approach. The key findings are as follows:

1. An efficient building energy data management

   This study suggests the integrated data management in the design and operational stages. This data management system can reduce data loss through integration of the information of the BIM based design model and building operation data. This approach also can reduce the time spent to identify and manage the building operational energy information,

2. An effective use of building energy data

   The suggested data management system supports functions of sorting the required data to compare and analyse building energy data. This advantage can be used for the FDD (Fault Detection and Diagnosis) in existing buildings. In addition, the operational data can be used for better building control with a simulation approach.

In conclusion, the use of the extended data model can enhance an efficient and seamless management of building energy data in the design and operational stages.

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