# FEED-FORWARD AIR-CONDITIONING CONTROL USING A WEATHER FORECASTING DATA IN SCHOOL BUILDING IN HEATING SEASON

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## ABSTRACT

To achieve the low-carbon society, Japanese government has conducted; 1) to revise "Laws Concerning the Rational Use of Energy", 2) to manifest reducing 25 % of CO2 emission, and 3) to participate COP15 as international activity.

Various techniques have been applied for energy conservation of building individually. Recently, commissioning (Cx) that assesses whether building performance based on simulation at design stage has been often conducted recently in Japan.

There are some cases that energy efficient methods are not implemented properly and it is helpful to develop the system for monitoring and/or visualization of the information about operation and management of the HVAC control system.

This paper introduces the system which enables to solve the above problem by automatic air-conditioning control based utilizing the predicted simulation. The simulation consists of two parts: the estimation of necessary energy load based on the set temperature and usage schedule of rooms in building, weather forecasting, etc. using TRNSYS, and also the calculation of optimum driving schedule of HVAC system of the building according to the estimated heat load using GAMS.

As preliminary study, the system was installed in Regional Innovation Center (410 m2) located in Sendai National College of Technology (latitude E148deg., longitude N38deg.), Japan and verification experiment was conducted in winter.

## INTRODUCTION

It is necessary for Japanese public welfare section to reduce CO2 emission rate. The emission from the field of the public welfare in Japan is 15.5 % at this moment, and a rate of increase from 1990 to 2001 is 30.9 %. The energy consumption in buildings is one thirds of the total energy in Japan, therefore, it is important to reconsider the energy use for the air conditioning that holds a most part of the total energy in buildings. One of the most effective methods to reduce energy consumption in buildings is to install the advanced HVAC equipments and to control them properly, that is variable by influence of thermal property of the building envelope, occupants' schedule, heat generation from the OA apparatus, etc.

To achieve the target, the role of simulation is very important and it may be pursued by the embedded system including BEMS, predictive simulation and related control systems, as often mentioned in the future of the building simulation.

## CONCEPT OF THE SYSTEM

The process of the system development is as followings;
1) The simulation generally done only at design stage is executed to reproduce the present thermal behaviour of the building and to predict the optimum control continuously.
2) The data of sensors such as temperature, humidity, etc. are used for the monitoring, the direct control and the simulation.
The control is operated smoothly according to the comparison of the targeted point to the measured value.
3) The results from the optimum calculations are provided, and a result is chosen by the operator with considering CO2 reduction, energy consumption, cost and indoor thermal comfort. It is important to take the balance by varying factors daily, because of the achievement all of the index are difficult
Figure 1 shows the idea of developed system. The real time control is possible with concurrent simulation, while the system function as the cycle, "measurement → calculation → control → measurement ...", is repeated. The detail about the cycle is described in the next section.
The system user can monitor whether energy saving performance toward the target is realized and the individual energy saving device functions effectively. In addition, the system can unify existing various energy saving system and function together. It is possible to apply the energy saving technology to new construction and the existing buildings. This enables to realize the environmental assessment in practical manner considering the global environment. In addition, the management of the scale of district, i.e. the assessment of the energy saving with many

kinds of buildings and the upcoming new systems would be feasible.

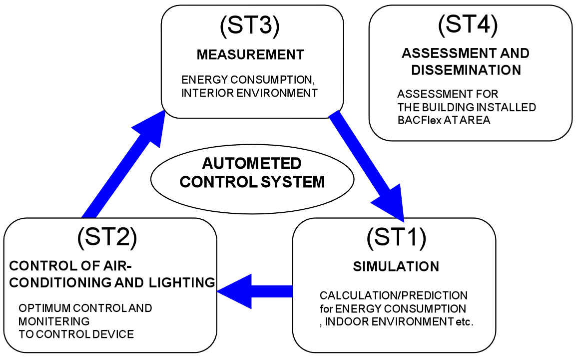



*Figure 1 Concept of the system and its development*

## THE CONSTITUTION OF THE DEVELOPMENT PROJECT

This project consists of four sub-tasks (ST) as shown in Figure 1. The work contents in 2004, the initial stage, are as the below;

1) ST1: The simulation model considered with the structure of the target building and the applied energy-saving technologies is developed.

The heat load, energy consumption and PMV are calculated and the automatic control system of target building is described according to the model.

2) ST2: The device control algorithm and system are developed and analyzed with measurement of heating and cooling system. Optimum control is decided by the mathematics programming.

3) ST3: The data communication environment by the measurement to evaluate system is constructed. The system can collect the data such as energy consumption rate, the air conditioning actual situation, indoor and outdoor environment, etc. and can analyze and verify the data.

4) ST4: The energy consumption data are arranged at various scales such as whole cities, towns, etc. to evaluate the effect of the energy saving by the installed of the developed system.

After the completion of making the prototype of the system, it is applied in practical field, as the building of the regional innovation center of Sendai National College of Technology.

## THE SUMMARY OF THE AUTOMATIC CONTROL SYSTEM

The brief structure of the developed system is shown in Figure 2. The system consists of measuring equipments of the indoor environment such as temperature and humidity, the operation situation, the energy consumption of the devices, software and PC for building simulation of heat load, existing control systems, those interface and communication network, etc.

The system needs the data such as the specifications

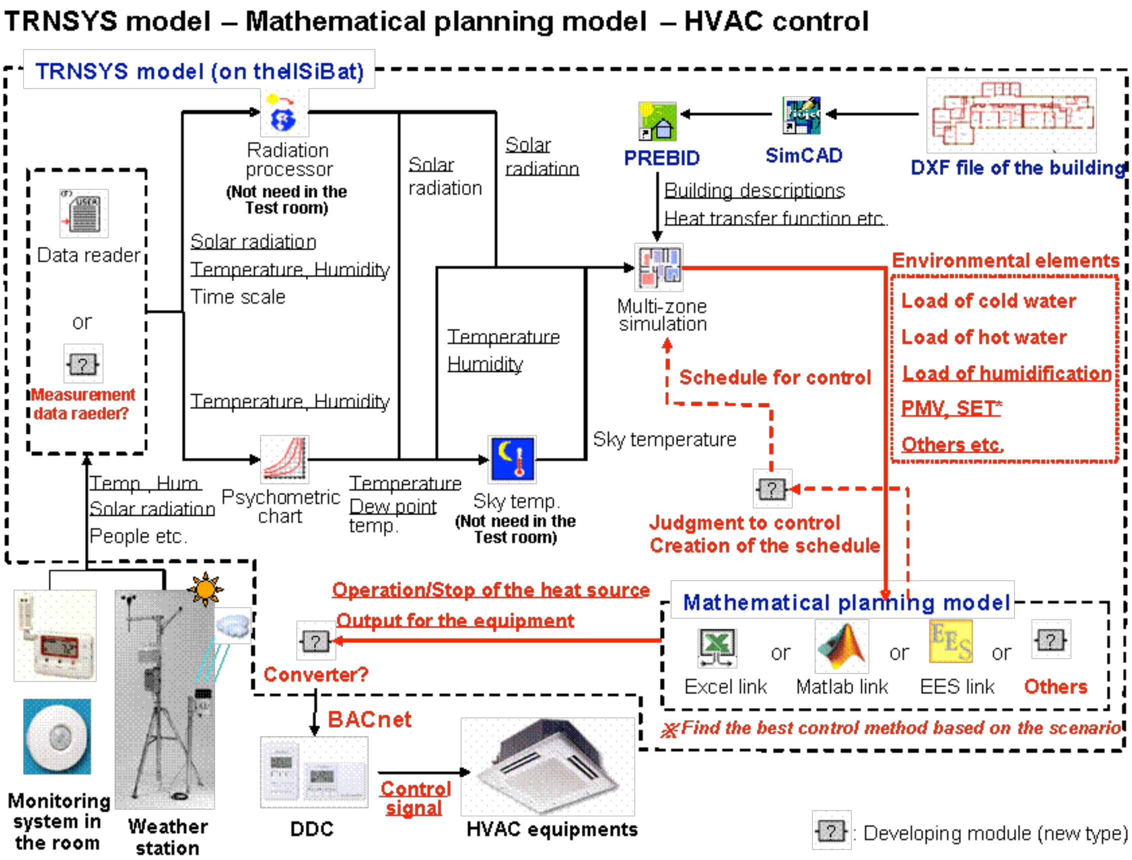



*Figure 2 Automatic Control System of HVAC Equipments*

of the building to make the thermal simulation model of the building and the weather data with the structures shown in Figure 3 and Figure 4. The data flow among the devices is shown in Figure 4 in arrows.

The system can be applied to existing various devices and systems, such as BEMS (Building Energy Management System), DDC (Direct Digital Control) and energy efficient devices, etc. The communication protocol is "BAC-net" standardized by ASHRAE and other protocols can be merged by customised relay control system.

The system can be installed with lower cost than conventional customised system because of using the open network protocol BAC-net that can connect various measurement equipments or control devices via internet. The instrumentation using BAC-net is indicated in Figure 3.

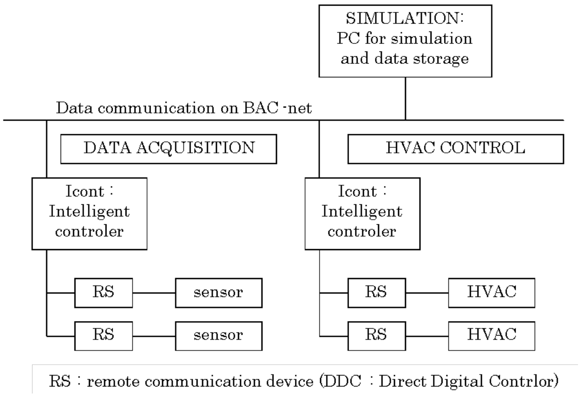



*Figure 3 Automatic Control System on the BAC-net*

The system can predict the effect of the application of energy saving technologies such as new air conditioning system, new lighting bulbs, etc. Also the system suggests many scenarios that describes the possible energy saving actions to the occupants, e.g. the recommendation of the wearing for the thermal comfort.

## DATA STRUCTURE OF THE DEVELOPED SYSTEM

The data structure and its flows, from No.1 to No.6, of the developed system are shown in Figure 4.

The system consists of the following parts;

TRNSYS: executing the simulation of the heat load of the building using measured and given predicted data.

GAMS: making machinery control data based on the individual energy management methods and calculated data by TRNSYS.

NAS ((Network Access Storage): the management of all data with the general rule.

BACFlex Point Server: the management of the individual monitoring data of each device.

For the data flow in Figure 4, the data collection starts at No.1, the data is sent to NAS as No.2, and

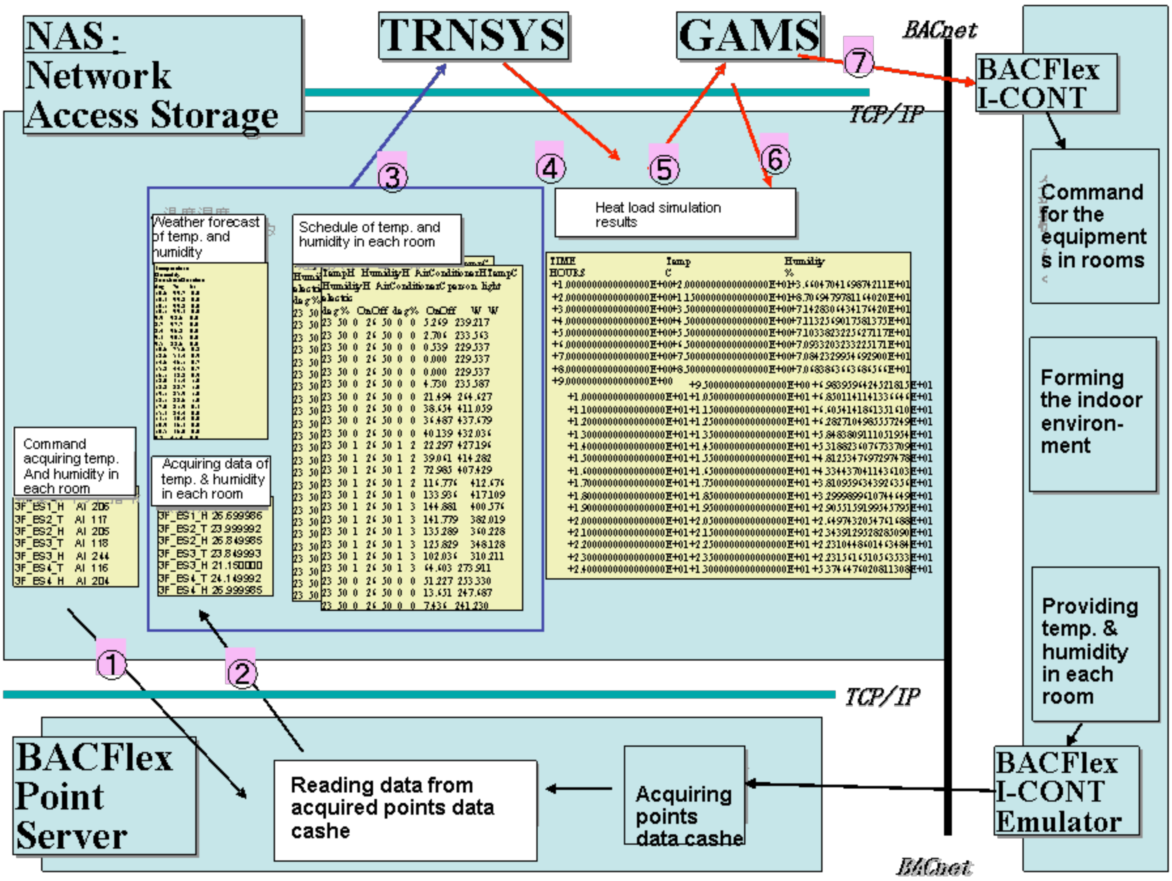



*Figure 4 Brief structure of the developed system*

the latest data are always accumulated in NAS.
BACFlex I-CONT Emulator: the emulating of the information from measurement points in the system. When operating, information from BEMS is input in this part through BACFlex ICONT.
The actual interfaces in Figure 4 are as following;
(1) the boundary between two simulation engine (TRNSYS, GAMS) to control the thermal energy devices and NAS, (TCP/IP).
(2) the boundary between BACF1exPointServer and NAS, (TCP/IP) .
(3) the boundary between BACF1exPointServer and I-CONT (emulator) to input and output data to each device, (BAC-net)
The data accumulated in NAS is exchanged on the Internet through interfaces by TCP/IP. If the files have necessary contents and satisfy the format (.txt as extension, etc.), the other simulation engines can incorporate it.
For the data of NAS and its treatment are as follows;
(1) Measurement data: 6 rooms at each floor in this case, the inside temperature and humidity at many locations.
(2) Data for simulation: the outside temperature and humidity and weather forecast data
(3) Data based on a scenario: the set temperature, humidity and air changing rate, an operation schedule such as occupants, electric devices, lightings, etc.
(4) Data by the simulation: the simulation result of the heat load.

## THE OPERATION AND THE DATA FLOW OF THE SYSTEM

Operation of the system in the building follows the selected scenario by the operator. The control of the air-conditioning system is operated by the optimum scenario considered with four indexes (energy consumption, CO2 emission, comfort, cost) selected by the system manager.
The process of the making the scenarios and the operation including the actual data transfer flow, No.1 to No.6 in Figure 4 is as the bellow;
(1) Run of simulation based on the input data;
The measurement data and simulation data as prediction are received from NAS; Various conditions including some options such as indoor set temperature, etc. decided by the system operator are simulated. The calculated data and scenario data in No.1 and 2 are transferred to No.3 in Figure 4.
(2)Creation of the list of simulation results;
The list of cost, etc. according to the options is created based on the simulation results such as energy consumption, CO2 emission, cost and comfort (PMV) by TRNSYS and GAMS. The result data is transferred to NAS as No.4 and GAMS receives necessary data in No.5 and the result data is returned as No.6.
(3)The presentation of scenarios based on the evaluation to the operator;
The list is shown on the monitor to the operator who chooses and decides an optimum scenario from some scenarios. Actually, there is the interface device, PC, between NAS and the operator.
(4)Delivery of the data to the control side based on the choice of the operator;
After the choice of a scenario, all information concerned to the control is delivered to control side and the control based on the scenario is operated. The control information is delivered from GAMS to ICONT through BAC-net as No.7.

## CASE STUDY

(1) Conditions for simulation and experiment
Conditions for simulation and experiment are shown in Table 1. There are two applied control procedures, the conventional one equipped as the original and ‘smart control’. The procedure “smart control” generates the signal for ON/OFF of the equipment every 30 seconds and is expected to contribute the energy saving caused by overheating and overcooling. Also it can make the air temperature very close to the set temperature.
The targeted area 50 m2 is a multi-purpose room in second floor, regional innovation center, Sendai National college of technology floor (latitude E148deg., longitude N38deg.) shown in Figure.5. The building model consists of 23 divided subzones including the office, laboratory, technical consulting room of 1st floor, community hall, multi-function meeting room of 2nd floor, etc. The location of the temperature and humidity sensor for measurement is height of 3.0 m (Picture 1), the sensor for control is height 0.7 m (Picture 2) on the desk.
(2) A term for simulation and experiment
The terms classified by control method are as following;
・Conventional Control:
2011/02/04, 2011/02/08－09（3 days）
・Smart Control:
2011/02/10－11, 2011/02/15（3 days）

*Table 1 Conditions for simulation and experiment*

| Operate Condition | Operate Time (h) | Occupant | Cooling・Heating | Winter season Room Temperature (°C) | Winter Humidity (%RH) | $CO_2$ (ppm) |
|---|---|---|---|---|---|---|
| Multiple Meeting Room | 8～21 | 3 | Switing Cooling and Heating | 22 | not controled | under 1000 |

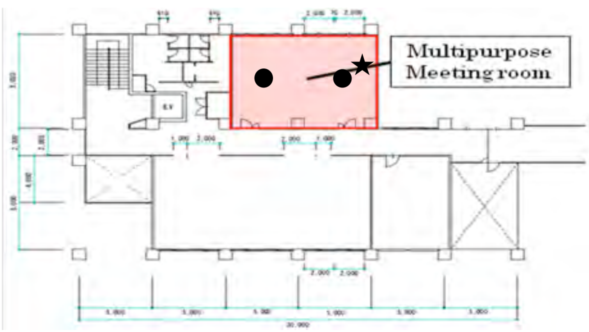
## RESULTS AND DISCUSSION

The results of measurement /simulation of electricity consumption by two control procedures are shown in Figure 6 for conventional one and in Figure 7 for smart control.

The trend of result between simulation and measurement according to each control method is almost similar. However, in any case, the simulation result is higher than the measurement.

It is necessary that initial data of insulation and heat load in building model are adjusted to improve the accuracy for simulation result.

In this time, the result was significant because of inadequate data by instable collecting data function on the system.




2F PLAN

● :Sensor for measurement

★ :Sensor for control

*Figure 5 Regional innovation center 2F*

*Picture 1 Sensors for measurement*

*Picture 2 Sensors for control*

Therefore, continuous measurement might be needed to make the result significant.

Validation for effect of energy conservation by building multi air-conditioning control

Trend of indoor temperature under the conventional control and smart control are shown in Figure 8.Conventional control holds the air temperature 4 degrees higher than smart control, because conventional control checks the air temperature at air exhaust device every 5 to ten minutes where overheating cannot avoid in this case. Smart control

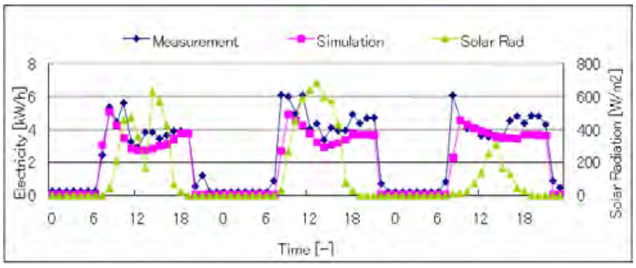



*Figure 6 The result of electricity consumption by conventional control*

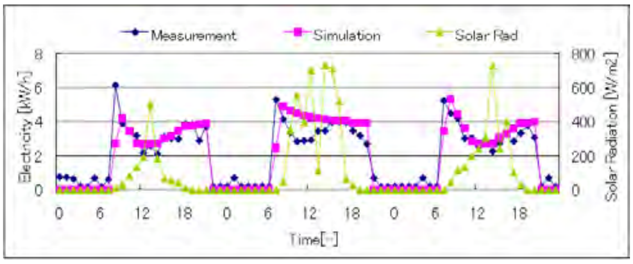



*Figure 7 The result of electricity consumption by smart control*

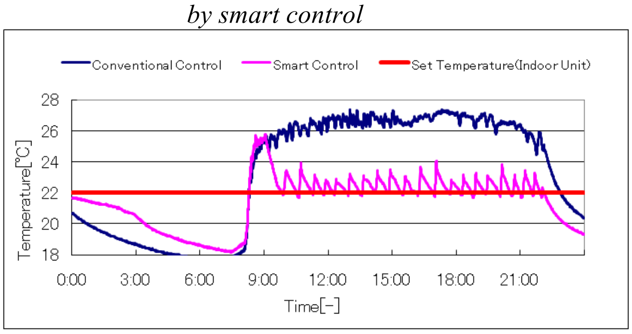



*Figure 8 Trend of indoor temperature under the conventional control and smart control*

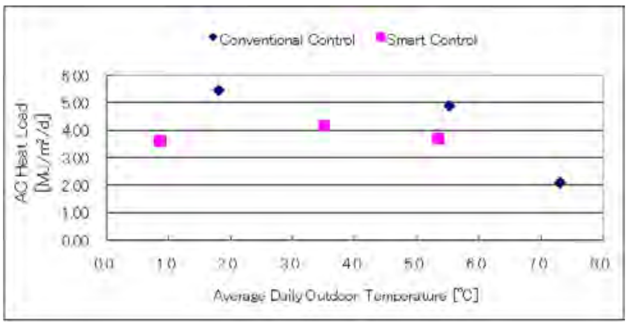



*Figure 9 The relation between heat load by air-conditioning and the average outdoor temperature*

keeps indoor temperature within 1 degree to the set temperature. The relation between heat load by air-conditioning and the average outdoor temperature in each day is shown in Table 2 and Figure 9. The energy saving by smart control was 26-34% compared to conventional control.

## CONCLUSION

(1)The simulation result by each control method is closed the measurement result, however in some parts, the simulation result is higher than measurement result caused of initial heat supply.
(2)The indoor temperature under smart controlling was controlled about 1 C degree to setting temperature.
(3)The energy saving by smart control was 26-34% of energy consumption by conventional control.
(4)The heat load by air conditioning to daily average outdoor temperature by smart controlling was below the result of conventional control.

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## REFERENCE

Malkawa, A. et al. (2004), Advanced Building Simulation. Spon Press, 2004, pp.4-24.

Utsumi, Y. et al.(2006), Development of the HVAC Control System by the Concurrent Simulation, 2006EPIC AIVC2006, 013#179, pp.1-6.

*Table 2 The result of electricity consumption by conventional and smart control*

| Date | Control Method | Set Temperature [℃] | Average Outside Temperature in Operating Air Conditoner [℃] | Average Inside Temperature in Operating Air Conditioner [℃] | Standard Deviation to 22℃ | Total Actucal Electricity [kW/day] | Calculated Electricity [kW/day] | Potential of Reduction Heat Load [%] |
|---|---|---|---|---|---|---|---|---|
| 2011/2/4 | Conventional Control | 22 | 7.3 | 26.1 | 4.3 | 54.5 | 43.9 | 19.4 |
| 2011/2/8 | Conventional Control | 22 | 5.5 | 26.4 | 4.7 | 69.0 | 50.6 | 26.6 |
| 2011/2/9 | Conventional Control | 22 | 1.8 | 25.6 | 4.3 | 64.5 | 51.5 | 20.1 |
| 2011/2/10 | Smart Control | 22 | 0.9 | 22.7 | 0.8 | 51.7 | 46.2 | 10.6 |
| 2011/2/11 | Smart Control | 22 | 3.5 | 22.6 | 0.7 | 52.9 | 57.5 | 0.0 |
| 2011/2/15 | Smart Control | 22 | 5.4 | 22.4 | 0.6 | 50.0 | 49.7 | 0.6 |