EXPERIMENTAL VERIFICATION OF PREDICTIVE AND OPTIMUM HVAC CONTROL SYSTEM APPLYING THE OPEN PLATFORM TO THE SCHOOL BUILDING

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ABSTRACT

One of the most effective methods to reduce energy consumption in buildings is to install the advanced HVAC equipments and to control them properly. This paper describes the optimum HVAC control system through the developed data platform, BACFlex that the simulation is executed using BEMS data, the weather forecasting, etc. The concerned targets are CO2 generation, energy consumption, comfort and cost. The brief structure of the system is explained and an example applied to the school is introduced. The accumulation of expertise of the construction, the tuning of the simulation model, the operation in many usages of buildings may offer the simplified systems.

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.
The result from the optimum control should be considered with CO2 reduction, energy consumption, cost and 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, if the management of the scale of district, the assessment of the energy saving with many kinds of buildings and the upcoming new systems would be feasible.

THE CONSTITUTION OF THE DEVELOPMENT PROJECT

This project consists of four sub-tasks (ST) as shown in figure 1. The work contents of 2004 are as the

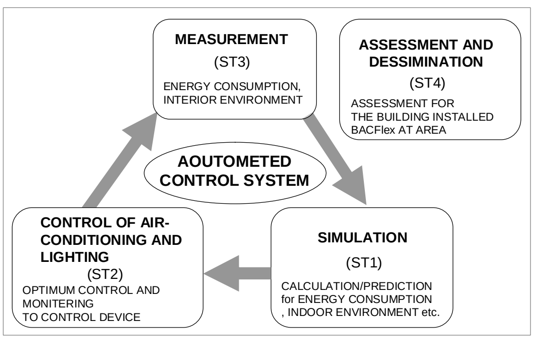

Fig.1 Concept of the system

below;
1) ST1: The simulation model considered with t
he 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 is 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 complete the making the prototype of the system, it is applied as the practical manner at the building of the collaborative technology center of Miyagi National College of Technology.

THE SUMMARY OF THE AUTOMATIC CONTROL SYSTEM

The brief structure of the developed system is shown in figure2. The system is composed from measuring equipments of the indoor environment such as temperature and humidity, the operation situation, the use of energy consumption of the devices, software and PC for building simulation of heat load, new and existing control systems, those interface and communication network, etc.
Those data flows are shown with the arrows in the figure. Also the system needs the data such as the specifications of the building to make the thermal simulation model of the building and the weather data.
The system can apply for various devices such as BEMS (Building Energy Management System), DDC (Direct Digital Control) and energy saving, etc. The communication protocol is "BAC-net" standardized by ASHRAE and other protocols are merged by customised relay control system.
The system can be installed with low cost because of using the open network protocol BAC-net that can connect various measurement equipments or control devices via internet. An example the instrumentation using BAC-net system is indicated in figure3.
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 energy saving actions to the occupants, e.g. the recommendation of the wears.

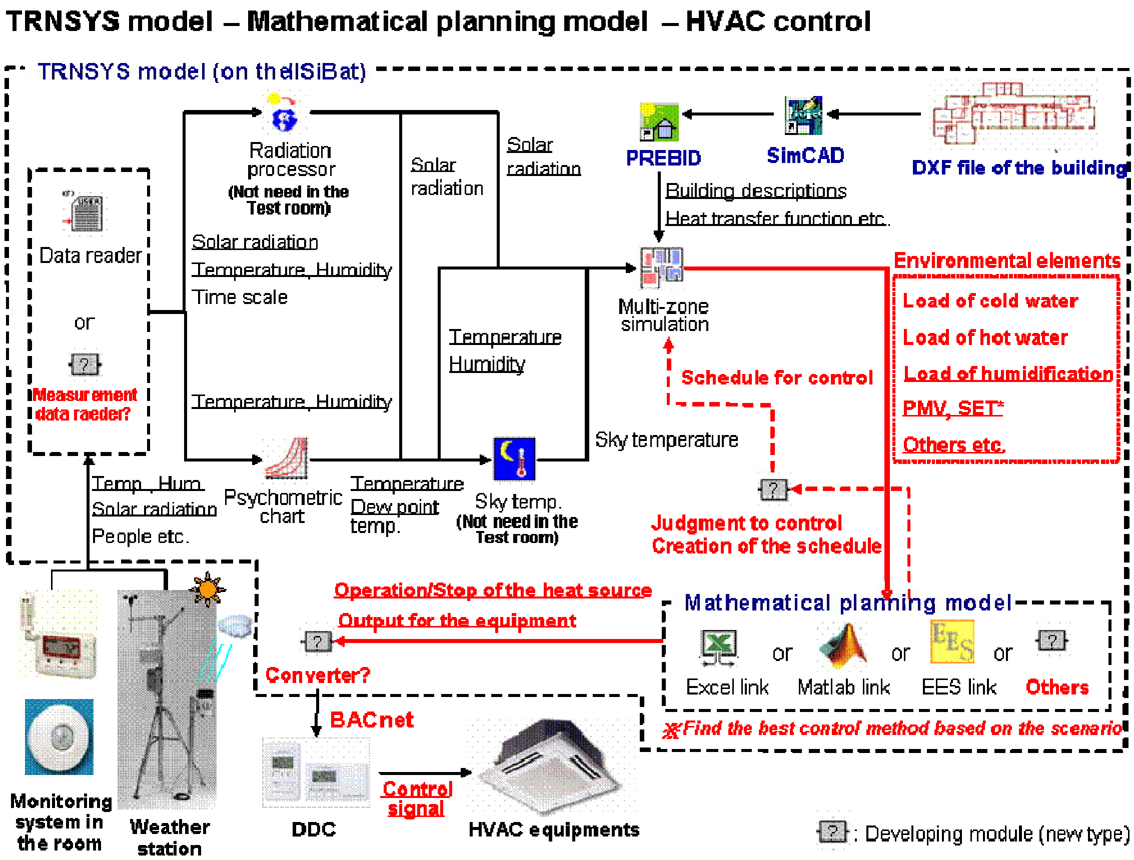

Fig.2 Automatic Control System of HVAC Equipments

DATA STRUCTURE OF THE DEVELOPED SYSTEM

The data structure and its flows, from No.1 to No.6, of the developed system in the environment is 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): management of all data with the general rule.
BACFlex Point Server: management of the individual calculation information of each device. When a data collection order is given as No.1, the data is sent to NAS as No.2, and the latest data are always accumulated in NAS.
BACFlex I-CONT Emulator: The emulator emulates the information from measurement point in the system. Actually information from BEMS is input in this part through BACFlex ICONT.
The actual interfaces in figure 4 is 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 in files accumulated in NAS are exchanged on the Internet through interfaces by TCP/IP. If the file can satisfy the contents and the format (.txt as extension, etc), the other simulation engines can incorporate it.

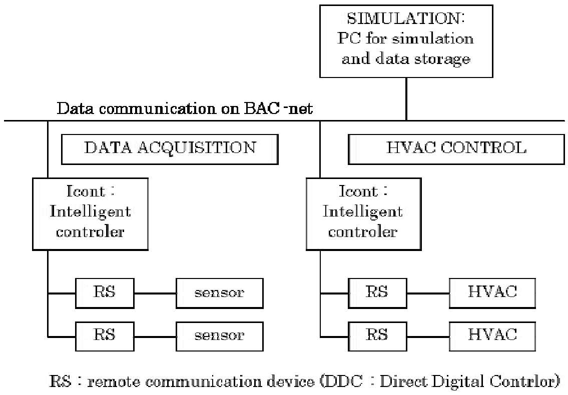

Fig.3 Automatic Control System on the BAC-net

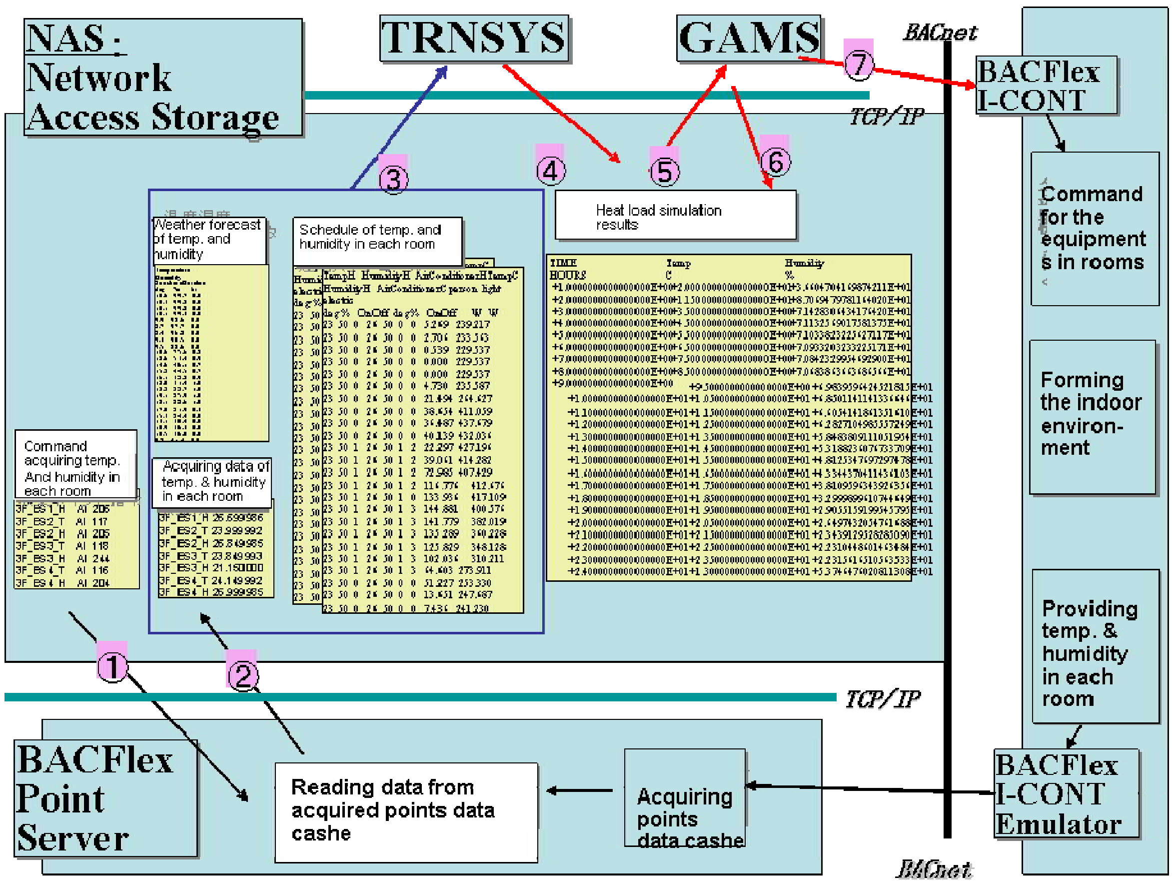

Fig.4 Brief structure of the developed system

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 setting temperature, humidity and air changing rate, an operation schedule such as occupants, electric device, lighting 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 whole system 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, CO_2 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 which are changed by some options such as indoor set temperature, etc. by system operator are simulated. (The calculated data and scenario data in No.1 and 2 are transferred to No.3 in Fig 4.)
(2)Creation of the list of simulation results;
The list according to the options is created based on the simulation results such as energy consumption, CO_2 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 to the air-conditioning system operator based on the evaluation;
The created list is shown on the monitor to the operator who decides an optimum scenario from some scenarios. Actually, there is the interface device, PC, between NAS and the operator.
(4)Delivery to the control side of the data based on the choice of the operator;
After the choice of a scenario, all information concerned 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

The input data and target building are as the followings. The input data is shown Table.1. The target building is collaborative technology center of (410 m2) located in Miyagi National College of Technology (latitude E148deg., longitude N38deg.) ,Japan (Fig.5). The building model is divided into 23 zones including of 1st laboratory floor, 2nd laboratory floor, 3rd laboratory floor, technical consulting room, community hall, multi-function meeting room, etc.
For the conditions of the tuning of the building model.
(1) Three cases of whole one day; dates are 3rd Sep 2008, 12th Sep 2008, 7th Oct 2008
(2) Pre-running term for the calculation; the simulation condition with the extra-running term considered heat storage in building body is shown in Table2. This improves the simulation model of the building.
(3) Adjustment for set temperature of supply air; the adjustment for set temperature of supply air is necessary because actual temperature in the occupied zone may not satisfy the target temperature indicated at the control panel in rooms.
The adjustment of degree for each room is shown in Table.3.

RESULTS AND DISCUSSION

(1) The influence by the extension run period for heat storage;
The simulated and measured of indoor temperature and humidity in multipurpose meeting room is shown in Fig.6.
The averaged difference between prediction and measurement from 8:00 to 18:00 in cooling operation

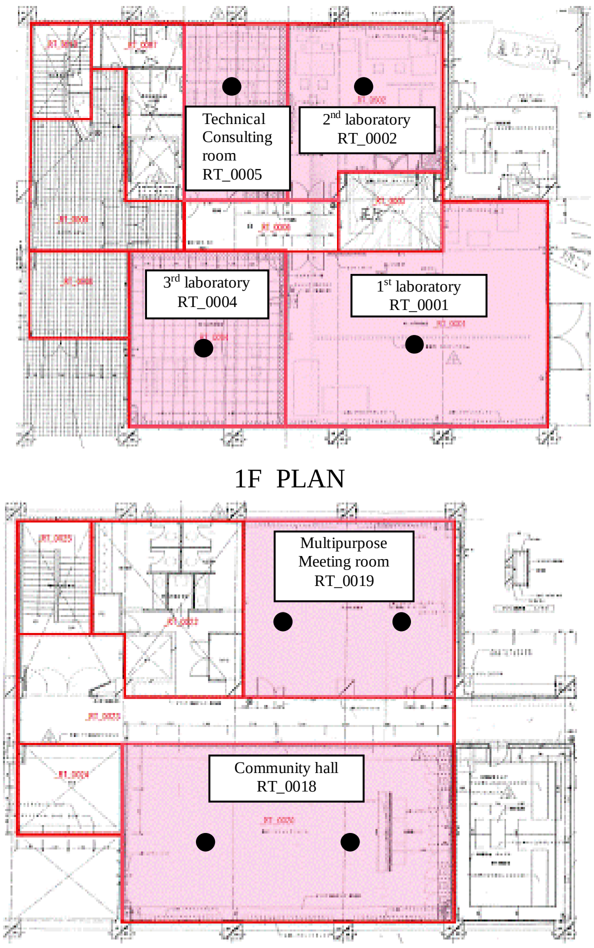

Fig.5 Regional collaboration techno center

term is calculated.

The difference between Case2 and Case5 is 3.8 degree in temperature and 19% in humidity. As a result, the simulated result approximated the measurement data better as run period extends longer as expected. In this case, the term of 28 days may be enough.

(2) The difference of the set temperature to the air supply temperature;

In the multipurpose meeting room on 3rd Sep without adjustment case, the temperature is shown in Fig.7. In the multipurpose meeting room on 12th Sep with adjusted case, the temperature is shown in Fig.8. The differences of 3rd Sep without adjustment and 12.Sep with adjustment are set. The differences between 3rd Sep and 12th Sep is 1.7 degree in temperature and 2% in humidity.

As the result, the values with adjusted case approximated the set temperature with the adjustment of -1.0 degree from set temperature. The differences seem to be consistent in each room.

Fig.9 and Fig 10 are shown measurement and simulation data of electricity consumption of AC outdoor unit on 1 floor and 2 floor at the techno-center (Assumption of COP as 2.0 in summer period, 2.5 in winter period). The simulation result by the tuned model is indicated same trend to the measurement result. As the represented room temperature is set 2-degree low, energy consumption

Table.2 Condition of pre-running term

Measurement Date		Content of extra run term for heat storage	Total extra run term for heat storage [day]
07.Oct	Case1	measured 1 day (07.Oct only)	0
	Case2	fixed data of 14 days (00:00, 07.Oct) +measured 1 day (07.Oct)	15
	Case3	fixed data of 14 days (00:00, 01.Oct) +measured 7 days (01.Oct to 07.Oct)	21
	Case4	fixed data of 14 days (00:00, 24.Sep) +measured 14days (24.Sep to 07.Oct)	28
	Case5	fixed data of 14 days (00:00, 08.Sep) +measured 30days (08.Sep to 07.Oct)	44

Table.3 Adjustment to set temperature

date	Adjustment to set temperature [°C]		
	1st Laboratory	2nd laboratory	3rd laboratory (Office)
03.Sep.2008	-	-	-
12.Sep.2008	-	-	-1.0
	technical consulting room	community hall	multipurpose meeting room
03.Sep.2008	-	-	-
12.Sep.2008	-1.0	-2.0	-1.0

Table.1 Input Schedule (CASE 2)

Cooling (Set Temprature 26 degree) [-]

room name	file name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1st laboratory	RT_0001																							
2nd laboratory	RT_0002																							
3rd laboratory (Office)	RT_0004								1	1	1	1	1	1	1	1	1	1						
Technical consulting room	RT_0005								1	1	1	1	1	1	1	1	1	1						
Community hall	RT_0018												1	1	1	1								
Multipurpose meeting room	RT_0019								1	1	1	1	1	1	1	1	1	1						

Natural Ventilation [air change / hour]

room name	file name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1st laboratory	RT_0001																							
2nd laboratory	RT_0002																							
3rd laboratory (Office)	RT_0004																							
Technical consulting room	RT_0005																							
Community hall	RT_0018																							
Multipurpose meeting room	RT_0019																							

Machinary Ventilation [air change / hour]

room name	file name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1st laboratory	RT_0001																							
2nd laboratory	RT_0002																							
3rd laboratory (Office)	RT_0004								1	1	1	1	1	1	1	1	1	1						
Technical consulting room	RT_0005								1	1	1	1	1	1	1	1	1	1						
Community hall	RT_0018								1	1	1	1	1	1	1	1	1	1						
Multipurpose meeting room	RT_0019								1	1	1	1	1	1	1	1	1	1						

Occupant [person]

room name	file name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1st laboratory	RT_0001																							
2nd laboratory	RT_0002																							
3rd laboratory (Office)	RT_0004								5	5	5	5	5	5	5	5	5	5						
Technical consulting room	RT_0005								5	5	5	5	5	5	5	5	5	5						
Community hall	RT_0018												15	15	15	15								
Multipurpose meeting room	RT_0019																							

Lighting[KW/m2]

room name	file name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1st laboratory	RT_0001																							
2nd laboratory	RT_0002																							
3rd laboratory (Office)	RT_0004								30	30	30	30	30	30	30	30	30	30						
Technical consulting room	RT_0005								30	30	30	30	30	30	30	30	30	30						
Community hall	RT_0018												30	30	30	30								
Multipurpose meeting room	RT_0019																							

Others (Electric Device etc) Unit [KW]

room name	file name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1st laboratory	RT_0001																							
2nd laboratory	RT_0002																							
3rd laboratory (Office)	RT_0004								1500	1500	1500	1500	1500	1500	1500	1500	1500	1500						
Technical consulting room	RT_0005																							
Community hall	RT_0018	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420
Multipurpose meeting room	RT_0019	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150

is reduced 12% in summer period, 13% in winter period respectively.

However, there is a difference between measurement and simulation result. To improve the simulation model, some factor must be considered with the leak of heat load by comings and going by occupants accidentally opened opening and over energy consumption by over time working

By this treatment, the occupants can be aware of the relation between their comfort and the set temperature in their room. This means the viewer that provides the information to the related people is necessary. For example, the operation status in room is for the occupants, the energy consumption rate of the HVAC system is for the operator.

CONCLUSION

The optimum automatic control platform, BACFlex, of HVAC system was introduced. It consists of the HVAC control protocol, the simulation, the optimum control, etc.

With the installation and operation at the existing building;

(1) The pre-running term of the simulation was discussed. Twenty eight days may be enough for the target building in this case.

(2) The differences between set temperature and the temperature in the occupied zone are consistent in each room. It is necessary to provide the viewer of the controlled space to the occupants.

ACKNOWLEDGEMENT

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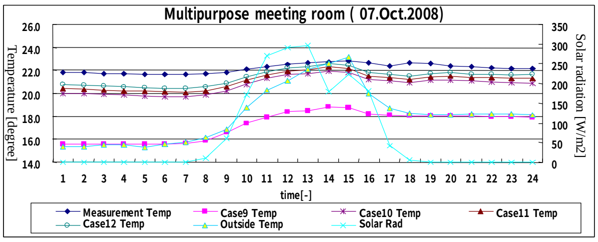

Fig.6 Influence by the pre-running period (Temperature)

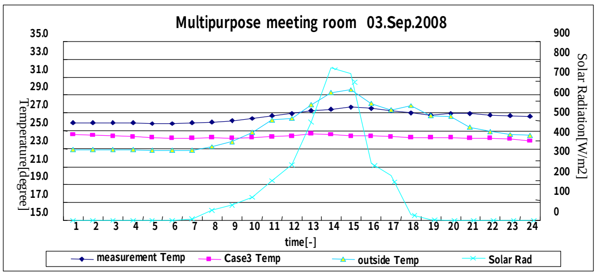

Fig.7 Influence by Adjustment set temp (3.Sep Temp)

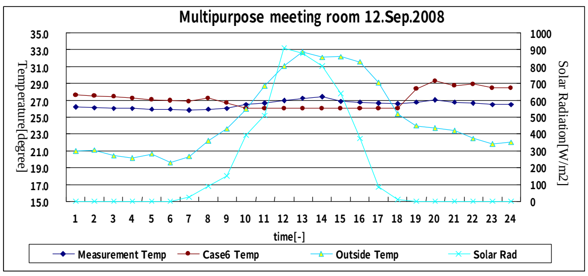

Fig.8 Influence by Adjustment set temp (12.Sep Temp)

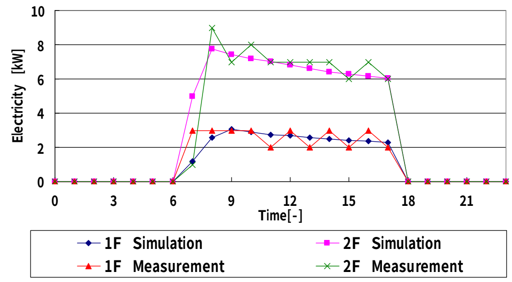

Fig.9 Measurement and Simulation of electricity consumption of AC outdoor unit (6.Mar)

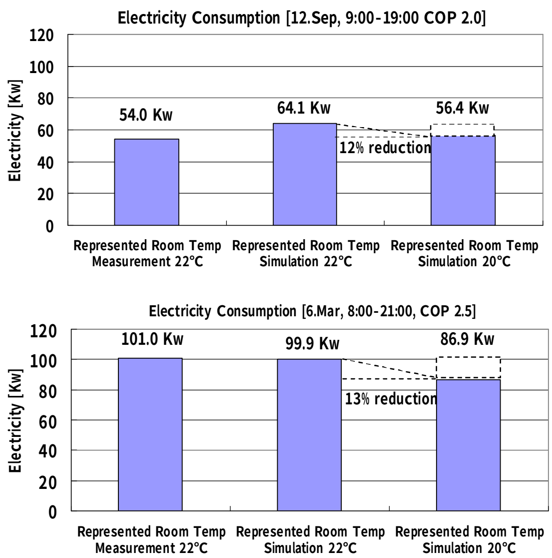

Fig.10 Electricity consumption by BACflex control in summer day(12.Sep) and winter day(6.Mar)