ESL-IC-06-11-205

Estimation of Energy Baseline by Simulation for On-going Commissioning and Energy Saving Retrofit

Masato Miyata, Harunori Yoshida, Masahiko Asada, Takuro Iwata, Youich Tanabe, Tadahiro Yanagisawa

Department of Urban and Environmental Engineering, Kyoto University, Japan
Obayashi Corporation, Japan
Department of Urban and Environmental Engineering, Kyoto University, Japan
Osaka Prefectural Government, Japan

ue.miyata@archi.kyoto-u.ac.jp

Abstract: This paper proposes a method of estimating the adjusted energy baseline using simulation models, which can calculate the energy baseline with various conditions, such as conditions of weather, occupancy and equipment operations. Especially, this paper reveals what detailed data the calibration of the model needs and the change of accuracy caused by different calibration data. Using the operational data of a middle-scale office building in Osaka Japan, the simulation accuracies of three models, which are calibrated using monthly energy consumptions of whole building (Level 1), monthly energy consumptions of subsystems (Level 2) and the detailed operational data of equipments (Level 3) respectively, are compared. The result shows that the differences of daily-integrated energy consumptions between measured value and simulated value using the model of Level 1 and 2 are not much different. The model of Level 3 is about 3% more accurate than the model of Level 1 and 2.

1. INTRODUCTION

It is important to propose an objective and rational method to evaluate energy savings caused by the implementation of Commissioning or the retrofit conducted by ESCO (Energy Service Company). Because electric power consumption, gas consumption and water usage (in this paper these are called "energy consumption" in all) of a building changes according to weather conditions and conditions of the building operation, it is necessary to adjust the energy consumption of pre-retrofit using the post-retrofit conditions in order to estimate the energy savings properly. Then, the energy savings can be determined by the difference between the post-retrofit energy consumption and the adjusted pre-retrofit energy consumption (in this paper it is called "adjusted energy baseline").

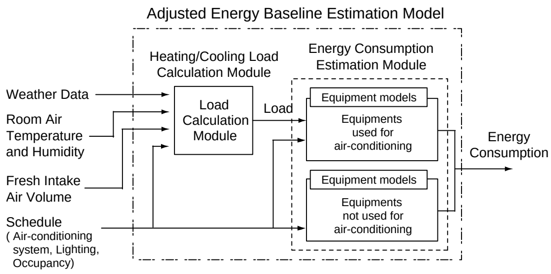


Fig. 1 Adjusted energy baseline estimation model

U.S. Department of Energy proposes four options to estimate the adjusted energy baseline, which are Option A, B, C and D described in International Performance Measurement and Verification Protocol [1]. In Japan, most energy saving companies use Option C, which estimates the energy baseline using simple regression models whose coefficients are determined using pre-retrofit monthly energy consumptions, and few companies use Option D, which estimates the energy baseline using simulation. Although Option D needs more information and manpower than Option C, Option D can estimate the energy baseline with various conditions, such as conditions of weather, occupancy and equipment operations, and can determine the baseline more properly than the other options.

In this research, Option D is applied to a real office building and the simulation model estimating the adjusted energy baseline of the building is developed. Detailed measurement of the energy consumption in the building is conducted and the simulation model is verified using the measured data. In particular, this paper focuses on necessary information and measured data used to develop and calibrate the models or to be inputted into the models, and how much the available information and measured data affects the accuracy of the simulation model.

2. ADJUSTED ENERGY BASELINE ESTIMATION MODEL

Figure 1 shows the outline of the model of estimating the adjusted energy baseline proposed in this paper. The model consists of two modules: the heating and cooling load calculation module and the energy consumption estimation module, which consists of models of energy consuming equipments in a building.

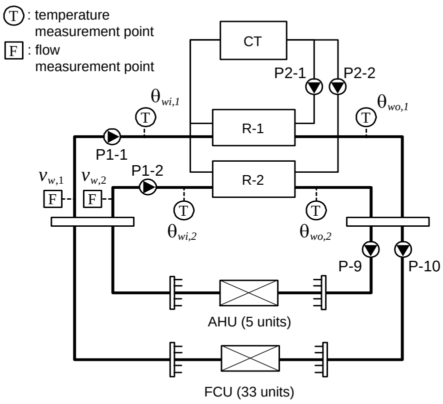


Fig 2 Air-conditioning system

Because the models' parameters are determined using design data or specification data provided by manufactures, the simulation model might not match the real performance. Therefore models should be calibrated using measured data in order to make them accurate enough. Because the accuracy calibration needs detailed operational data in general and it seems difficult to obtain such data before the implementation of commissioning or ESCO retrofit, it is important to reveal what detailed measured data the calibration needs and how the data affects the accuracy of the models.

This paper uses the following three levels of measured operational data to compare the accuracies of the simulation models.

Level 1: Assumption to get only monthly energy consumptions of a whole building. In all building energy companies measure these data certainly.

Tab. 1 Energy consuming equipments

Energy	Measured systems	Equipments	Name	Rated Energy Consumption	Frequency Set Point
Electric Power	Group1	Gas-fired absorption chiller/heater	R-1	3.9 kW	-
			R-2	2.0 kW	-
		Cooling tower fan	CT	4.4 kW	-
		Pump of chilled water	P1-1	5.5 kW	60 Hz
			P1-2	3.7 kW	45 Hz
		Pump of cooling water	P2-1	11 kW	52 Hz
			P2-2	7.5 kW	59 Hz
		Monitoring instrument	-	10 kW	-
	Group2	Secondary pump (Fan-coil)	P-9	3.7 kW	-
		Secondary pump (AHU)	P-10	3.7 kW	-
		Fan of AHU (Office)	AHU-1	11 kW	38 Hz
			AHU-2	11 kW	53 Hz
			AHU-3	11 kW	57 Hz
			AHU-4	3.7 kW	51 Hz
			AHU-5	2.2 kW	33 Hz
		Fan of AHU (Computer room)	AHU-PC	3.0 kW	-
		Lavatory ventilation fan	FAN-TW	2.2 kW	-
	Group3	Water supply pump	P-L1	9.59 kW	-
			P-L2	13.1 kW	-
		Elevator	-	-	-
	Group4	Fan coil units (33 units)	-	10.22 kW	-
		Fluorescent lamps (27.5W * 344)	-	9.46 kW	-
		Fluorescent lamps (50W * 9)	-	0.45 kW	-
		Lap top PCs (50W * 273)		13.7 kW	-
		Copy machines (800W * 40)		32.0 kW	-
		Servers (14)	-	7.7 kW	-
Gas	Medium Pressure	Gas-fired absorption chiller/heater	R-1	40.9 Nm^3/h	-
			R-2	27.3 Nm^3/h	-
	Low Pressure	office use	-	-	-
Water	Air-conditioning Syste	Supply water for Cooling Tower	CT	-	-
	General	office use	-	-	-

Level 2: Assumption to get monthly energy consumptions of subsystems. These data are usually available if a building has Building Energy Management Systems (BEMS).

Level 3: Assumption to get more detailed operational data of equipments and weather data measured near the building besides the monthly energy consumptions of subsystems. These data can be obtained if short-term measurement is conducted in addition to the installation of BEMS.

3. MEASUREMENT IN A REAL BUILDING

Tab. 2 Measured data (by meters for charging)

Energy	Measured systems	Interval
Electricity	whole building	monthly
Gas	whole building	monthly
Water	whole building	monthly

Tab. 3 Measured data (measured by ESCO)

Energy	Measured systems	Interval
Electricity	Group1	10 mins
	Group2	10 mins
	Group3	10 mins
	Group4	10 mins

Tab. 4 Measured data (long term measurement)

Measured items	Interval	Instruments
Outside air temperature and humidity	10 mins	Temperature and humidity recorder
Global solar radiation	1 min	Pyrheliometer
Room temperature and humidity	10mins	Temperature and humidity recorder
Fresh air intake volume	10mins	Hotwire anemometer
Gas consumption (R-1,2)	10mins	Gas flow meter
Water flow rate of cooling tower (CT)	10mins	Water flow meter

Tab. 5 Measured data (short term measurement)

Measured items	Interval	Instruments
Inlet and outlet temperature of chilled water (R-1,2)	10mins	Thermister inserted in pipe
Flow rate of chilled water (R-1,2)	10mins	Pitot-tube flow meter
Frequency of Inverter (AHU-1,…,5, PC1-1,2, PC2-1,2, PC-9,10)	10mins	Read displays of inverters
Electric power consumption (AHU-1,…,5, PC1-1,2, PC2-1,2, PC-9,10)	10mins	Read displays of inverters

Operational data were measured in a middle-scale government office building in Osaka Japan, whose floor area is 6,169 m^2 and air-conditioned area is 3,942 m^2. Figure 2 shows the outline of the air conditioning system of the building. Table 1 is a list of energy consuming equipments in the building. The energy saving retrofit was conducted in 2003 to the building, for example the installation of inverters in fans of air handling units and pumps and the change of fluorescent lamps to high-efficiency ones. The frequencies of the pumps in secondary system (P-9, P-10) are controlled automatically at a constant pressure. The frequencies of the other pumps and the fans are set at a constant value less than 60 Hz (as shown in Table 1).

The details of measurement are shown in Table 2 to Table 5. The items listed in Table 2 are measured using meters installed by energy companies for charging. The items listed in Table 3 are measured using meters additionally installed by ESCO, which can measure the electric power consumption of four sub-systems.

The items listed in Table 4 and 5 are measured by the authors. Table 4 shows the items measured continuously from August 2005. Table 5 shows the items measured on September 12th, 13th, 14th, and 20th in 2005. In this paper, these four days is called as detailed measurement term.

Using the measured data in the detailed measurement term, cooling load is calculated by the following equation.

$$q_m(t) = c_{p,w}\sum_{n=1}^{2}\sum_{k=0}^{5}\left[v_{w,n}(t-k\Delta t)\left\{\theta_{wi,n}(t-k\Delta t)-\theta_{wo,n}(t-k\Delta t)\right\}\right] \quad (1)$$

4. HEATING/COOLING LOAD CALCULATION MODEL

Heating and cooling loads are calculated using ACSES, which is software to calculate building heating/cooling loads. ACSES can calculate the load in the actual conditions by inputting variable measured data such as room air temperature and humidity, fresh intake air volume, and operation schedules of air-conditioning systems, lighting systems and occupancy. The interval of the calculation is 1 hour.

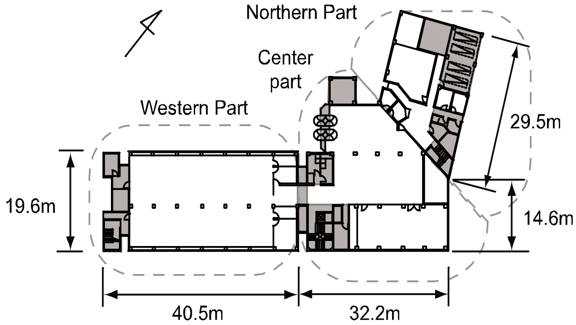


Fig. 3 Plan of the experimental building

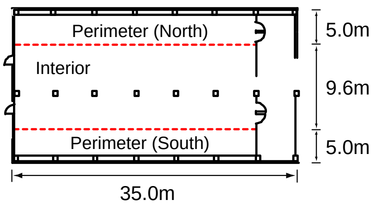


Fig. 4 Plan of Western Part

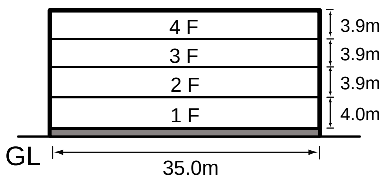


Fig. 5 Section of Western Part

4.1 Construction of Building Model

Tab. 6 Materials of the walls in Western Part

Exterior wall	mortar(20), normal concrete(150), light-weight concrete(20)
Interior wall	mortar(20), normal concrete(150), mortar(20)
Room divider	asbestos cement slate(6), plaster(9), still air(120), plaster(9), asbestos cement slate(6)
Ceiling	rock wool board(12), gypsum board(9), air(1160), normal concrete(130), mortar(30)
Ceiling (top)	rock wool board(12), gypsum board(9), air(960), styrene(25), light-weight concrete(150), mortar(30), light-weight concrete(100), mortar(30)
Floor	linoleum(3), mortar(30), normal concrete(130), air(1160), gypsum board(9), rock wool board(12)
Floor (bottom)	linoleum(3), mortar(30), normal concrete(120), mortar(30)

The building model is constructed using the design drawings. Figure 3 shows a plan of the building. Figure 4 and 5 show a plan and a cross-section of the western part of the building. Table 6 shows the materials of the walls and Table 7 is the list of internal heating loads of the western part. The number of occupants is determined from the total number of the occupants in the building (260 persons). The calorific value of lighting and office apparatus are determined by counting the number of the equipments such as fluorescent lamps, personal computers, copy machines and so on.

Tab. 7 Internal cooling loads in Western Part

Occupants			0.066 person/m^2
Calorific value of lighting			25 W/m^2
Calorific value of office apparatus	Sensible heat	4F	5.49 W/m^2
		2,3F	8.45 W/m^2
		1F	15.19 W/m^2
	Latent heat		0 W/m^2

Inputs for the load calculation are weather data (outdoor air temperature and humidity, direct solar radiation, global solar radiation, wind direction and velocity), room air temperature and humidity, fresh intake air volume and operational schedules.

These input data for three levels of calculation methods are as follows.

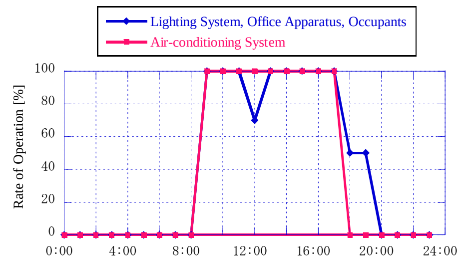


Fig. 6 Operational schedules

1) For Level 1 and 2, the weather data measured by the weather station at Osaka is used. The distance between the weather station and the building is about 20 km. For Level 3, the weather data measured near the experimental building is used. The direct solar radiation is calculated by separation calculation of direct and diffuse components from global radiation. Wind direction and velocity are set at the values of the standard weather data in Osaka.

2) For Level 1 and 2, the room air temperature and humidity are assumed to be constant at the set points (27°C, 50%). For Level 3, the temperature and humidity are set at the average of the measured data (27.7°C, 52%).

3) For Level 1 and 2, flesh intake air volume is calculated from the number of the occupants and fresh air .the measured data (2.41 m^3/m^2h) is used.

4) From the results of the investigation in the building, the operational schedules are determined as shown in Figure 6. These schedules are used in all levels calculation.

4.2 Verification of Load Calculation

Cooling load from August 6th to September 30th is calculated and the simulated load is compared with measured load. In this section, the calculation of Level 3 is conducted.

First, during the detailed measurement term, the measured hourly cooling loads $q_m(t)$ are calculated and compared with simulated values $q_s(t)$. The mean difference between $q_s(t)$ and $q_m(t)$ is about 5.1% and root mean square error (RMSE) is about 9.2%. Figure 7 shows the comparison of $q_s(t)$ with $q_m(t)$ in September 14th and 15th. From the comparison, it can be said that the simulation of the cooling load is accuracy.

Next, the simulated load is compared with the gas consumption because the gas consumption is related with cooling load. In order to compare the two values, the following coefficient k_q is defined using measured data from August 6th to September 30th.

$$\sum_{i=1}^{N} Q_{s,i} = k_q \sum_{i=1}^{N} G_{R,i} \qquad (2)$$

Here, k_q is an empirical coefficient which changes G_R to Q_g and the value is 11.0 kW/Nm^3 for this system. Figure 8 shows the comparison the daily-integrated load estimated using simulation and the daily-integrated load calculated using the gas consumption. Because RMSE between Q_m and Q_s is about 18.0%, it can be said that the simulation can estimate the profile of the daily-integrated load approximately.

5 . ENERGY CONSUMPTION ESTIMATION MODELS

This section discusses the models of the energy consuming equipments [2] [3]. The equipments are divided into two groups: the equipments used for air-conditioning and the equipments not used for air-conditioning. The energy consumptions of the former equipments are related with the heating and cooling load. The energy consumptions of the latter equipments are related with the operational schedules of the building.

For the purpose of calculating energy consumptions, load factor $L(t)$ and system status of on or off δ_a, δ_b are defined as the followings.

$$L(t) = \frac{q_s(t)}{q_r} = \frac{q_s(t)}{q_{r,1} + q_{r,2}} \qquad (3)$$

$L(t)$ is the ratio of the simulated cooling load $q_s(t)$ to the sum of the rated chilled capacities of R-1 and R-2. δ_a is 1 if the air-conditioning system is on and δ_a is 0 if the air-conditioning system is off. δ_b is 1 if the building is in use and δ_b is 0 if the building is closed.

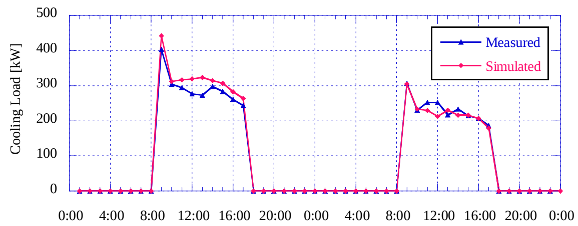


Fig. 7 Hourly-integrated cooling load

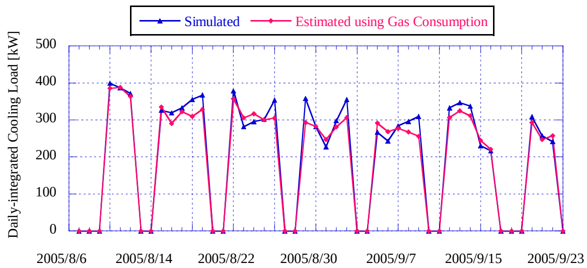


Fig. 8 Daily-integrated cooling load

5.1 Models Of Equipments Used For Air-Conditioning System

a) Gas Consumption of Gas-Fired Absorption Chiller /Heater (R-1 and R-2)

The gas consumption of the gas-fired absorption chiller and heater $g_R(t)$ is calculated as follows.

$$g_R(t) = \delta_a \left(q_{r,1} + q_{r,2}\right) k_R(t) \qquad (4)$$

$$k_R(t) = a_R + b_R L(t) + c_R L(t)^2 \quad (5)$$

$$a_R = a_{R,0} + a_{R,1}\theta_{cw}(t) + a_{R,2}\theta_{cw}(t)^2 \quad (6)$$

$$b_R = b_{R,0} + b_{R,1}\theta_{cw}(t) + b_{R,2}\theta_{cw}(t)^2 \quad (7)$$

$$c_R = c_{R,0} + c_{R,1}\theta_{cw}(t) + c_{R,2}\theta_{cw}(t)^2 \quad (8)$$

The inputs of the model are $L(t)$ and $\theta_{cw}(t)$, and the output is $g_R(t)$.

For Level 1 and 2, the parameters of the model are determined by using the specification curve provided by the manufacture. Figure 9 shows the specification curve of R-1 and R-2. For Level 3, the parameters are determined using the operational data measured during the detailed measurement term by least square method. The measured data is shown on the Figure 9 with scattered points. The figure indicates that the performance of R-1 and R-2 is about 20% lower than the specification curve.

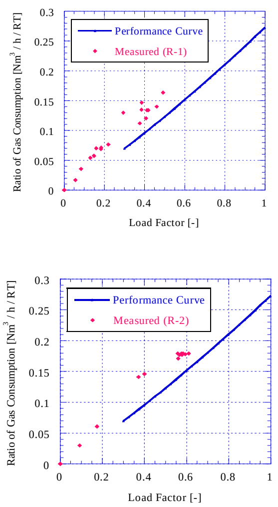


Fig. 9 Specification curve of R-1 and R-2

b) Electric Power Consumption of Secondary Pumps (PC-9 and PC-10)

Electric power consumption of PC-9 and PC-10 is assumed to have the linear relation with $L(t)$. The model is expressed as follows.

$$E_{ps}(t) = \delta_a \left(E_{r,9} + E_{r,10}\right)\left(a_{ps} L(t) + b_{ps}\right) \quad (9)$$

For level 1 and 2, a_{ps} is set at 1 and b_{ps} is set at 0 so that $E_{ps}(t)$ is $\left(E_{r,9} + E_{r,10}\right)$ when $L(t)$ is 1, and $E_{ps}(t)$ is 0 when $L(t)$ is 0. For level 3, the parameters are determined using the measured data (a_{ps} =1.042, b_{ps} =0.123). Figure 10 shows the measured $L(t)$ and $E_{ps}(t)$ with fitted curve and equation.

c) Electric Power Consumption of Equipments in Heat Source System

Electric power consumption of the heat source equipments is calculated on the assumption that the energy consumption has the linear relation with $L(t)$.

$$E_R(t) = \delta_a E_{R,r}\left(a_r L(t) + b_r\right) \quad (10)$$

$$E_{R,r} = E_{R1} + E_{R2} + E_{CT} + E_{P11} + E_{P12} + E_{P21} + E_{P22} \quad (11)$$

For level 1 and 2, the energy consumptions of the equipments are determined using the rated energy consumption. If the inverter is installed in the equipment, its energy consumption is calculated using the following equation.

$$E_k = E_{k,r}\left(\frac{f_k}{60}\right)^3 \quad (12)$$

For level 3, the energy consumptions of the equipments are determined using the measured data.

This system has two heat source systems and the system whose total running time is shorter is operated. The other is switched on if the load of the main system is over 90%. Therefore a_r is 0 and b_r is 0.5 when $0 < L \le 0.45$, and a_r is 1 and b_r is 0 when $0.45 < L \le 1$ for all calculation levels.

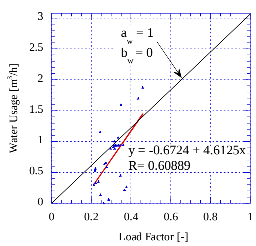


Fig. 10 Energy consumption of PC-9 and 10

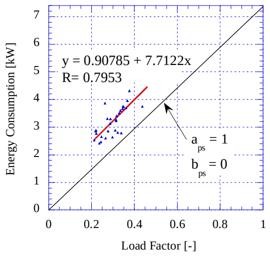


Fig. 11 Supplement water usage of CT

d) Supplement Water Usage of Cooling Tower

The supplement water usage is also assumed to have the linear relation with $L(t)$.

$$w_{ct}(t) = \delta_a k_{ct} v_{wr} \left(a_w L(t) + b_w \right)$$

(13)

For level 1 and 2, a_w is set at 1 and b_w is set at 0. For level 3, a_w is set at 1.500 and b_w is set at –0.219 fitted using the measured data. Figure 11 shows the measured $L(t)$ and $w_{ct}(t)$.

e) Electric Power Consumption of Terminal System

In this building, the fans of the air handling units and the exhaust fans in lavatory are on whenever the air-conditioning system is on, and the electric power consumptions are constant. These electric power consumptions are calculated as follows.

$$E_{ac} = \delta_a \left(\sum_{n=1}^{5} E_{a,n} + E_{tw} \right) \quad (14)$$

For level 1 and 2, $E_{a,n}$ are determined using the rated consumptions and the set point of the inverters using equation (12). For level 3, $E_{a,n}$ is determined using the measured data.

5.2 Models Of Equipments Not Used For Air-Conditioning

f) Electric Power Consumption of Intermittent Equipments (P-L1, L2 and Elevator)

For level 1 and 2, the electric power consumptions of the water supply pumps and the elevator are calculated as follows.

$$E_i = \delta_b (E_{pl} + E_{ev}) \quad (15)$$

$$E_{pl} = r_{pl} E_d \quad (16)$$

$$E_{ev} = n_{ev} \frac{k_{ev} m_{ev} v_{ev}}{860} \left(\frac{h_y}{n_d h_d} \right)$$

(17)

From the manufacture's specification data [6], k_{ev} is 0.025, m_{ev} is 750 kg, v_{ev} is 60 m/s and h_y is 2000 hours. In the building, n_{ev} is 1, n_d is 240 days and h_d is 9 hour/day. In this condition, E_{ev} is 1.21 kW. For level 3, E_i is calculated from the measured data of electric power of group 3, and E_i is determined at 2.37 kW.

g) Electric Power Consumption of Receptacle and Lighting System

For level 1 and 2, the electric power consumptions of lighting system and receptacle are determined using the general electric power consumption rate $r_e(t)$ determined from the investigation results of some government office buildings as shown in Figure 12. $r_e(t)$ is the hourly rate of the electric power consumption and the daily-integrated value of $r_e(t)$ is 1. $E_c(t)$ in weekday is determined using the sum of the rated energy consumptions of the equipments in lighting system and receptacle E_{cr} (=73.31 kW) and $r_{e,d}$, which is the average of $r_e(t)$ from 9:00 to 16:00 and the value is 0.0814.

$$E_c(t) = \frac{r_e(t)}{r_{e,d}} E_{cr} \quad (18)$$

$E_c(t)$ in weekend is determined using $r_{e,n}$, which is the average of $r_e(t)$ from 0:00 to 5:00 and the value is 0.0098.

$$E_c(t) = \frac{r_{e,n}}{r_{e,d}} E_{cr} \quad (19)$$

For level 3, $E_c(t)$ is determined using the average of the measured data of group 4. The comparison with the measured data and the estimated data by Level 1 and 2 is shown in Figure 13.

h) Electric Power Consumption of Continuously Working Equipments

Monitoring instruments and the air-conditioners placed in computer servers' room are working all day. For level 1 and 2, these electric power consumptions are determined using the rated energy consumption (13.0 kW). For level 3, the value is determined using the measured data (11.8 kW).

i) Gas Consumption by General Use

The gas consumption by general use is determined using the general gas consumption rate $r_g(t)$ determined from the results of the investigation of some government office buildings.

$$g_g(t) = r_g(t)\, g_d\, S_b \quad (20)$$

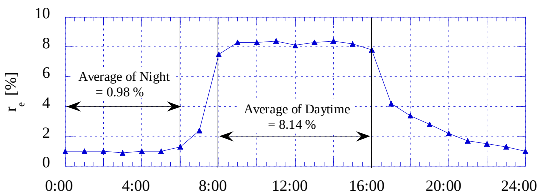


Fig. 12 Electric Power Consumption ofReceptacle and lighting system

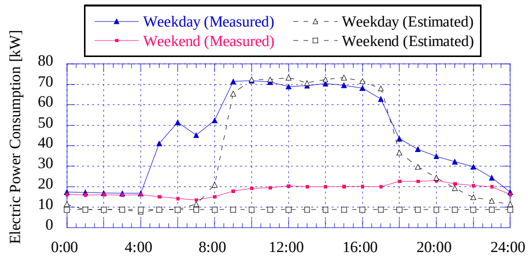


Fig. 13 Comparison of measured $E_c(t)$ with estimated $E_c(t)$ using $r_e(t)$

For level 1, g_d is 0.0035 Nm^3/m^2/day that is the average value of the general government office buildings. For level 2 and 3, g_d is 0.0028 Nm^3/m^2/day determined using the measured data.

j) Water Usage by General Use

The water usage is determined as follows.

$$w_g = \delta_b w_r S_o \quad (21)$$

For level 1, w_r is 0.00089 m^3/m^2/hour that is the average value of the general government office building. For level 2 and 3, w_r is 0.00096 m^3/m^2/hour determined using the measured data.

Fig. 14 Comparison of simulated electric power consumption with measured value

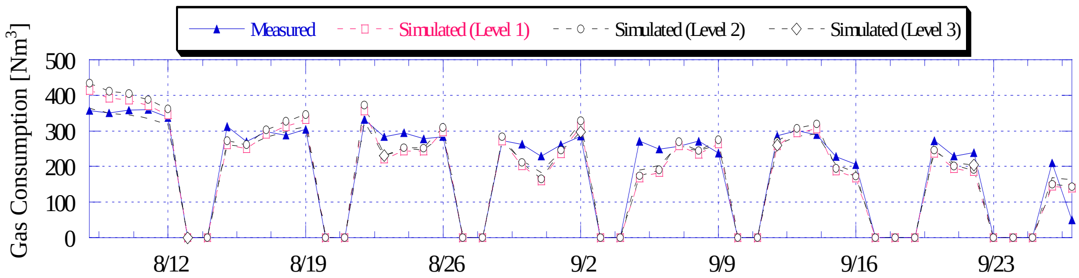


Fig. 15 Comparison of simulated consumption of medium-pressure gas with measured value

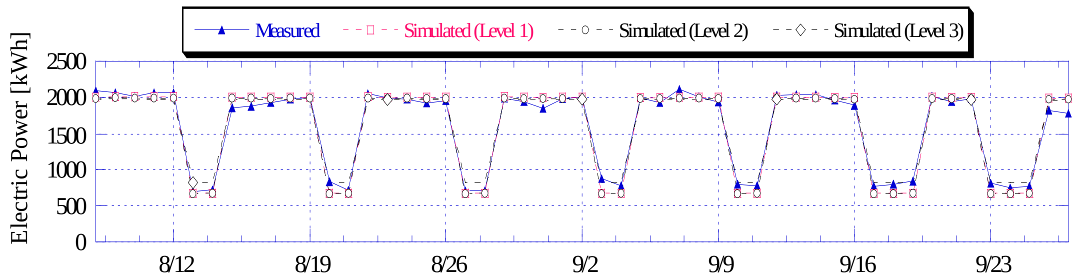
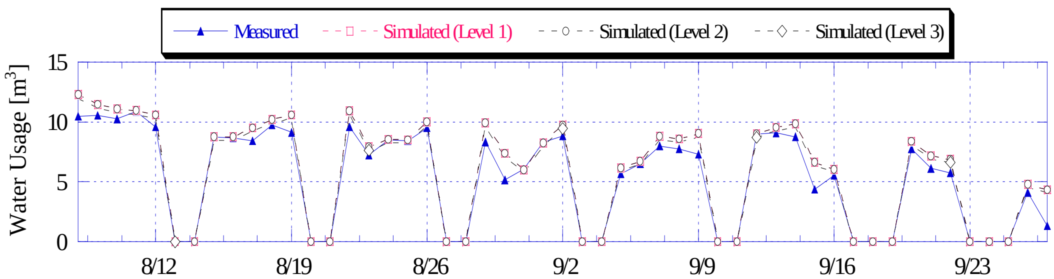


Fig. 16 Comparison of simulated water usage by air-conditioning system with measured value



Tab.8 Calibration Coefficients of the model of Level 1

Month	Electric Group Consumption			Gas Consumption			Water Usage		
	Measured [kWh]	Simulated [kWh]	Coeff. [-]	Measured [Nm^3/h]	Simulated [Nm^3/h]	Coeff. [-]	Measured [m^3/h]	Simulated [m^3/h]	Coeff. [-]
Aug.	47254	37803	1.25	5197	3906	1.33	583	613	0.95
Sep.	51686	41029	1.26	7252	5047	1.44	723	723	1.00
Oct.	45409	35489	1.28	4349	2998	1.45	674	614	1.10

Tab 9 Calibration Coefficients of the model of Level 2

Month	Gas Consumption (Medium Pressure)			Gas Consumption (Low Pressure)			Water Usage (Cooling Tower)			Water Usage (By General Use)		
	Measured [Nm^3/h]	Simulated [Nm^3/h]	Coeff. [-]	Measured [Nm^3/h]	Simulated [Nm^3/h]	Coeff. [-]	Measured [m^3/h]	Simulated [m^3/h]	Coeff. [-]	Measured [m^3/h]	Simulated [m^3/h]	Coeff. [-]
Aug.	4857	3559	1.36	340	278	1.22	-	165	-	-	480	-
Sep.	6892	4644	1.48	360	323	1.11	-	231	-	-	529	-
Oct.	3990	2666	1.50	359	258	1.39	166	164	1.01	508	483	1.05

Month	Electric Group Consumption (Group 1)			Electric Group Consumption (Group 2)			Electric Group Consumption (Group 3)			Electric Group Consumption (Group 4)		
	Measured [kWh]	Simulated [kWh]	Coeff. [-]	Measured [kWh]	Simulated [kWh]	Coeff. [-]	Measured [kWh]	Simulated [kWh]	Coeff. [-]	Measured [kWh]	Simulated [kWh]	Coeff. [-]
Aug.	11380	10260	1.11	6936	7052	0.98	1046	517	2.02	27892	19974	1.40
Sep.	13125	10695	1.23	8171	7852	1.04	1081	576	1.88	29309	21906	1.34
Oct.	10179	9612	1.06	6630	8610	0.77	1031	484	2.13	27568	18882	1.46

6. CALIBRATION OF ADJUSTED ENERGY BASELINE ESTIMATION MODEL

From the above discussion, the energy consumptions of the building are defined as follows.

$$E_b(t) = E_{ps}(t) + E_R(t) + E_{ac} + E_i + E_c(t) + E_{cn}$$

(22)

$$G_b(t) = g_R(t) + g_g(t)$$

(23)

$$W_b(t) = w_{ct}(t) + w_g$$

(24)

For the purpose that the simulation results can match the real performance, the model must be calibrated using the measured data. In this paper, using the monthly-integrated energy consumption data, the model is calibrated in order to make the simulated monthly-integrated energy consumption match the measured value. For example, the calibrated baseline of electric power consumption $E_{b,c}$ is calculated as follows.

$$E_{b,c}(t) = k_e E_b(t)$$

(25) $$k_e = \frac{\overline{E_b(t)}}{\overline{E_{b,m}}}$$

(26)

k_e is the calibration coefficient determined using the monthly-integrated measured data. The calibration coefficients of the gas consumption and water usage k_g , k_w are determined by the same way.

The monthly-integrated measured data used to calibrate the model are determined as follows for each level. $E_{b,c}$, $G_{b,c}$ and $W_{b,c}$ are the adjusted energy baseline, which are the outputs of the adjusted energy baseline model.

1) For level 1, the coefficients are determined using monthly energy consumption data of the whole building. Table 8 shows the calculation results of the coefficients.

2) For level 2, the coefficients are determined using monthly energy consumption data of the subsystems. Table 9 shows the calculation results of the coefficients of subsystems. Though the coefficient of the electric power consumption of group 3 is about 2.0, which is not very accurate, it dose not influence much because the consumption of group 3 is smaller in the electric power

consumption.

3) For level 3, the coefficients are also determined using monthly energy consumption data of the subsystems. Table 10 shows the calibration results of the coefficients. Because the model by level 3 is developed using the detailed measured data, the calibration coefficients are nearly 1.

7. VERIFICATION OF ENERGY BASELINES

Tab. 10Coefficients of the model of Level 3

	Electric Power				Gas		Water	
	Group1	Group2	Group3	Group4	R	Gene.	CT	Gene.
Aug.	1.11	1.04	0.97	1.04	0.97	1.22	-	-
Sep.	1.22	1.08	0.97	1.01	1.08	1.11	-	-
Oct.	1.06	1.08	1.02	1.08	1.03	1.39	1.26	1.05

Tab .11.RMSE of the models

	Level 1	Level 2	Level 3
Electric Power	5.66%	5.59%	4.50%
Gas (Middium Pressure)	15.91%	16.12%	12.92%
Water (Air-conditioning System)	14.18%	14.18%	11.69%

The accuracy of the adjusted energy baseline estimation model is verified using the measured data. Figure 14 to 16 show the comparison with measured daily-integrated energy consumption and the simulated daily-integrated energy consumption. The consumption of low-pressure gas and the water usage by general use are not measured and cannot be compared. Table 11 shows the RMSE between simulated value and measured value. From the results, the model of level 1 and level 2 have almost the same accuracies about 5% to 16%. The accuracy of the model of level 3 is 1 to 3 % better than that of level 1 and 2.

8. CONCLUSIONS

This paper proposes a method of estimating the adjusted energy baseline using simulation models. Based on the above discussions, the following conclusions can be drawn.

1) The model of estimating the cooling and heating load of a real building is developed and is verified using the measured data. The result shows that the RMSE of the hourly-integrated cooling load is about 9.2% and the RMSE of the daily-integrated cooling load is about 18.0%, which shows that the model can estimate the cooling load accurately.

2) The model of estimating the adjusted energy baseline using the simulated loads is developed and is verified using the measured data. The model calibrated using monthly energy consumption data has almost the same accuracy as the model calibrated using detailed measured data. The accuracy of the model calibrated using detailed measured data is improved about 1 to 3 %.

NOMENCLATUR

$c_{p,w}$: Specific heat of water [J/g/K]

E_k : Electric power consumption [kW]

($k = R$: Heat source system, AHU : Air-handling Units, i : Intermittent equipments, c : Receptacle and lighting system, ps : Secondary pumps, ac : Terminal system, cn : Continuously working equipments, $R1$: Chiller R-1, $R2$: Chiller R-2, CT : Cooling tower CT, $P11$: Pump P1-1, $P12$: Pump 1-2, $P21$: Pump P2-1, $P22$: Pump P2-2, $P9$: Pump P-9, $P10$: Pump P-10)

g_d : Gas consumption of general usage in general government buildings (=0.0035) [5] [$Nm^3/m^2/day$]

g_R : Gas consumption of chillers [Nm^3/h]

g_g : Gas consumption by general use [Nm^3/h]

G_R : Daily-integrated gas consumption of chillers [Nm^3]

h_d : Running time of elevators per day [hour/day]

h_y : Average running time of building [hour]

k_{ct} : Ratio of supplement water to cooling water [-] (=0.0123) [2]

k_{ev} : Coefficient determined by control of elevators [-]

k_R : Gas consumption ratio of chiller[$Nm^3/h/RT$]

L : Load factor [-]

m_{ev} : Rated live load of elevators [5] [kg]

n_d : Effective working days of building [day]

n_{ev} : Number of elevators [-]

q_m : Measured cooling load [kW]

q_s : Simulated cooling load [kW]

$q_{R1,r}$: Rated chilled capacity of R-1 [kW]

$q_{R2,r}$: Rated chilled capacity of R-2 [kW]

Q_g : Cooling load calculated using G_R [kW]

Q_m : Daily-integrated value of q_m [kWh]

Q_s : Daily-integrated value of q_s [kWh]

S_b : Floor area of building [m^2]

S_o :Air-conditioned floor area of building m^2]

v_{ev} : Rated velocity of elevators [5] [m/s]

v_{wr} : Rated flow rate of cooling water [m^3/h]

$v_{w,n}$: Flow rate of chilled water [kg/s]

($n=1$: R-1, $n=2$: R-2)

w_{ct} : Water usage of cooling tower [m^3/h]

w_g : Water usage by general use [m^3/h]

w_r : Water usage by general use in general government buildings (=0.00089) [5] [m^3/m^2/hour]

θ_{cw} : Cooling water temperature [^{o}C]

$\theta_{wi,n}$: Inlet water temperature [^{o}C]

($n=1$: R-1, $n=2$: R-2)

$\theta_{wo,n}$: Outlet water temperature [^{o}C]

($n=1$: R-1, $n=2$: R-2)

δ_a : System status of air-conditioning system[-]

δ_b : System status of building [-]

REFERENCES

[1] IPMVP New Costruction Subcommittee: Concepts and Options for Determining Energy and Water Savings Volume I, International Performance Measerment & Verification Protocol, 2002.3

[2] Masato Miyata, Harunori Yoshida, et al : Fault Detection and Diagnosis Method for VAV Terminal Units, International Conference of Enhanced Building Operation, 2004. 10

[3] Masato Miyata, Harunori Yoshida, et al. : Estimation of Excessive HVAC Energy Consumption Due to Faulty VAV Units, Building Simulation 2005, Ninth International IBPSA Conference, pp. 777- 784, 2005. 8

[4] SHASE handbook, Part 2, pp. 470-485, 1995

[5] Toshio Ojima: Unit requirement of energy consumption in buildings, Waseda University Press, 1995

[6] Kunikatu Ide: Calculation method of energy consumption of elevators, Japan Building Equipment and Elevators, No.46, pp. 36-42, 2003. 9

[7] Giebler, T., M. Liu, and D. E. Claridge: Evaluation of Energy Conservation Measures by Model Simulation, The Eleventh Symposium on Improving Building Systems in Hot and Humid Climates Proceedings, 1998.1

[8] Kreider, J.F. and Haberl, J.S.: Predicting Hourly Building Energy Usage: The Great Predictor Shootout -- Overview and Discussion of Results, ASHRAE Transactions Vol. 100, 1998.1