CALIBRATION PROCEDURE OF ENERGY PERFORMANCE SIMULATION MODEL FOR A COMMERCIAL BUILDING

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ABSTRACT

Calibration with actual data has been considered as one of the most important and difficult part for the systematic energy audit procedure. The purpose of this paper is to develop a systematic method, "base load analysis approach" to calibrate the building energy performance model with actual monthly data. The calibration procedure has been visualized as a logical flow chart and demonstrated with 26-stories actual commercial building located in Seoul. The results indicated that the developed approach provided a reliable and accurate computer model for the annual building energy performance simulations.

INTRODUCTION

Calibration procedure has been recognized as a key element to apply many energy conservation measure (ECM) and energy conservation opportunity (ECO) when they use computer model to evaluate the energy performance and their impacts for existing buildings. The calibration of computer model compares the simulated results with the actual collected data and proves to the validity of the model for further applications of the possible ECM's. A try to systematic calibration for building models has been proposed by many researchers(Diamond, Holtz, Kaplan, Pratt). A statistic method was introduced to calibrate the model with compensated hourly data(Kreider, 1994). A post processor program has been developed and provided by visual data analysis technique(McCray, 1995).

The recent research trends to develop a calibration process focus on comparing most hourly data measured with simulated because the hourly simulations represent the building dynamic energy characteristics in more accurate and reliable way(Bou-Saada, Bronson, Haberl). However, the additional expensive data loggers are required to measure the hourly data and not many buildings in Korea have been equipped with the logging system so far. Thus, the difficulties from measurement cost and extra data availability often make it very difficult to implement the hourly data to calibrate the building energy computer model although it represents the dynamics better. In general, monthly invoiced bills for electricity and gas could be easily collected and just compared in a statistical way. However, no standard way of calibrating the computer model of building energy performance based on the monthly data are not typically available for most building simulation applications.

Therefore, the objective of this paper is to develop a calibration methodology and applies it to justify the various ECM's for actual large commercial buildings with the monthly data, which could be obtained more easily than the hourly data in most Korean practice. The target building of this study would be high rise office building with high electric consumption for cooling and gas consumption for heating. The key concept of base load analysis - disaggregation - during the mid season would be introduced to calibrate the model. The simulation tool applied in this study was DOE2.1E developed by LBL(Lawrence Berkeley Lab).

CALIBRATION METHODOLOGY

A stepwise procedure to calibrate the computer model of building energy performance has to be prepared for a robust approach. Figure 1 shows all seven step process established in this study to calibrate the model with easily available monthly data. Following this process, a sound base model can be obtained and more reliable ECM evaluation can be implemented in the next stage. The process utilizes the key concept of the mid-season base load analysis, which disaggregates the energy consumption in more detailed sub-areas to examine and trace the energy use in building(Lyberg). The stepwise calibration methods are the followings :

1) Base case modeling
2) Base load analysis
3) Mid season calibration
4) Site interview and confirmation
5) Heating and Cooling season calibration
6) Validation of calibrated base model
7) Investigation of promising ECM’s

Step 1) Base case modeling:

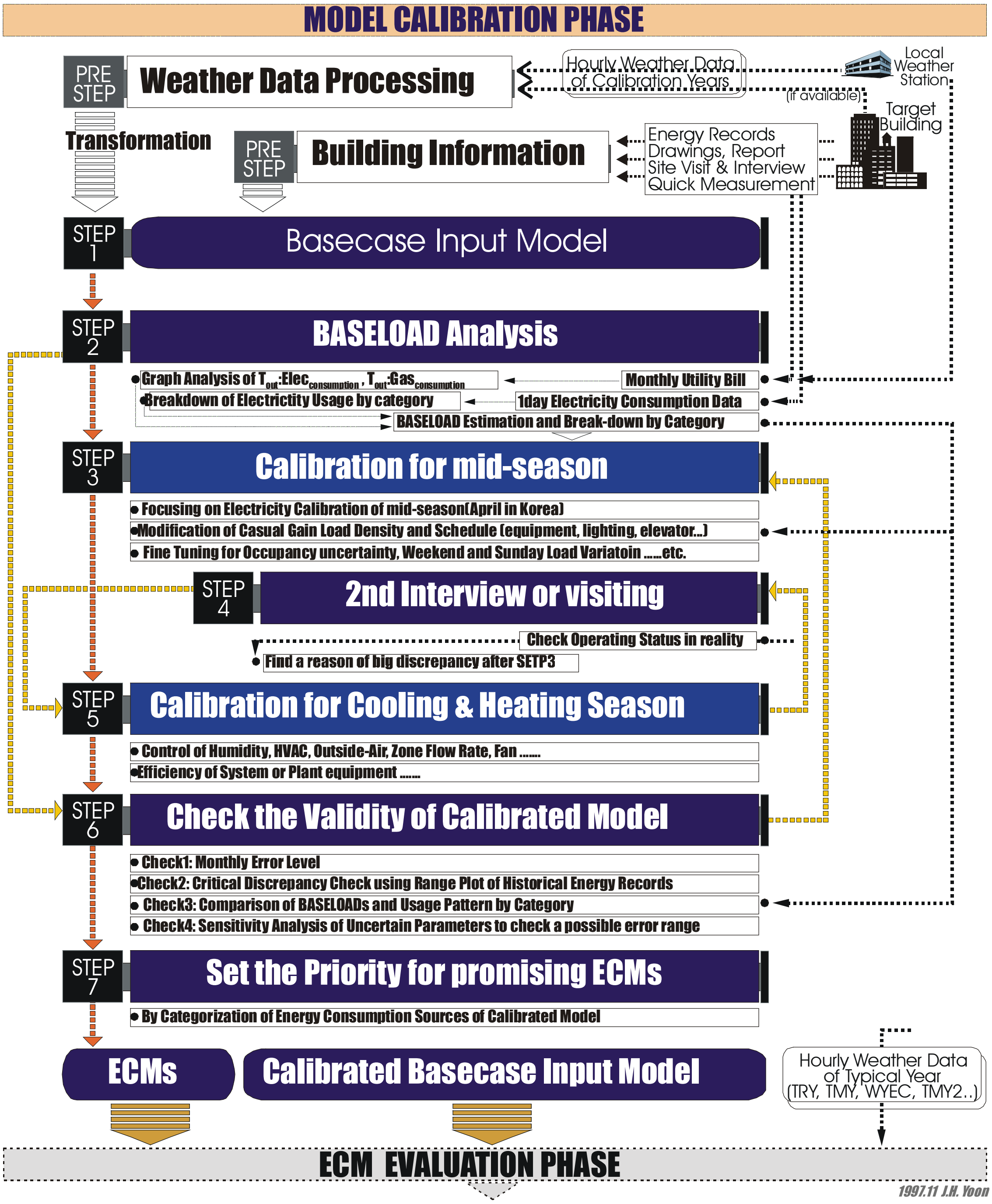


Figure 1.Seven step calibration procedure including base load analysis

The first step is to build up the building energy simulation model with one of most reliable tools. This study used a PC version of DOE2.1E - PRC DOE. This process requires all the information of building geometry, construction and operating data including drawings, reports, and HVAC system data. This also includes the site review for data soundness of uncertain variables such as thermal intensity and the schedule of internal gains. Zoning process should be carefully done based on the plan drawing and actual divider situation of core and perimeters. The model has to be prepared in sequence of building load, HVAC system and plant. The model of building geometry and zoning is of time consuming and keen to input model error. Therefore, a software like DrawBDL would help to minimize the error during the step 1 process by visualizing and checking the geometry model so far(Huang).

Step 2) Base load analysis:

The next step is to analyze the base load by decoupling the base and the cooling heating load, that is one of the creative methods devised from this study. First, two dimensional graph of monthly average outdoor temperature and total electricity

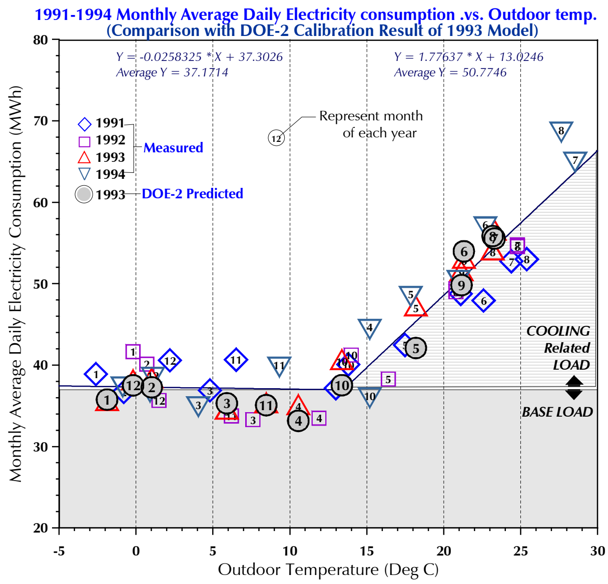


Figure 2. Base and cooling load characteristic curve

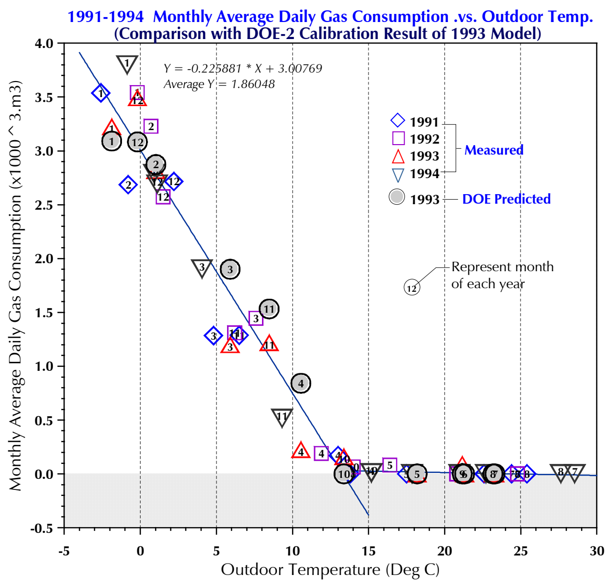


Figure 3. Building heating characteristic curve

consumption including the cooling load have to be generated as in Figure 2. It shows the base load as 37.5 MWh/day and also shows the cooling start temperature of 13ºC). The base load line which is parallel with the x-axis in Figure 2 corresponds to the non-weather-dependent electricity consumption in this building. Figure 2 shows that the cooling start point and the cooling load increases with a slope depending upon outdoor temperature rise. Figure 3 shows that heating energy requirement depending on the outdoor temperature - heating characteristic curve of the building. The base of heating is surely 0 gas consumption, but it shows both the heating start temperature as well as heating rate as function of outdoor temperature decrease. Just quick and overall estimation for base load can be done with this graph and more detailed analysis for base load estimation should be conducted with short time measurement data as in Figure 4.

A short time measurement during a period of a day or a week would be required to insecure the thermal characteristic curves. Most buildings in Korea have equipped with several wattmeters to monitor the electricity for the various usage such as lighting, cooling, plug-loads and elevator etc.. The electricity consumption components and use pattern in each drawing of electric diagram and the matching condition have to be collected through the site survey and interview with mechanical operation staffs. Data logging sheet may be used to collect the daily electricity consumption from each wattmeter. In-situ measurement with potable ampere meter would be necessary depending upon the load type of each wattmeter. It would be more desirable to observe the data from already installed with wattmeters considering the situation of measurement cost and building operation environment. Figure 4 summarized the procedure to produce the pie chart containing the categorized electricity for the different equipment loads. It shows also the worksheet for base load break-down and disaggregation process. The values of measured electricity have been obtained from fifteen wattmeters during the day of base load analysis. The electric use was again categorized into the followings: lighting, HVAC equipment load, plug-loads and elevator. The more detailed list of components measured by each wattmeter are described in Figure 4. And it could be used to tune the computer models of lighting, cooling, plug-load and elevator for the mid- season calibration. The base load, then, can be predicted in daily, weekly and monthly which would be about 1023 MWh/month. The portion of lighting, cooling, plug-load and elevator would be 31%, 16%, 41% and 12% respectively based on the collected data and spread sheet calculation. The intensity per area of the internal gains could be obtained, inputted and validated with the method.

Step 3) Mid-season calibration:

The verified number of the internal gains can then be used for model during mid-season calibration. The mid-season calibration reiterates and results depending upon mainly internal loads not depending upon heating and cooling loads. Therefore, the key tuning parameters would be lighting, HVAC equipment, plug load and elevator calibrated already in previous step, too. The calibration process goes to the next step - heating cooling calibration process until the value between the predicted and the measured satisfies in the specified limit. Again, the frequent site visits to confirm the data are necessary for the model validation during this step.

Step 4) Site interview and confirmation:

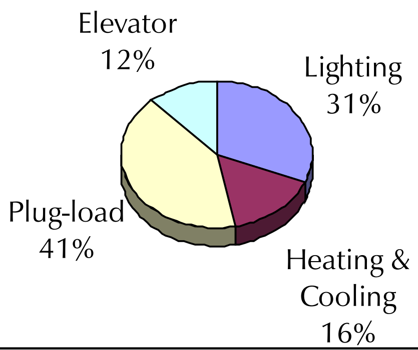
Additional site interview and data confirm are one of the most important steps because there are definitely some differences between the data in paper and in actual situation. Site interview often confirms that the real number of lighting density, OA equipment like computer and printer, the name plate(wattage) of each equipment, people number and schedule. In general, the uncertainty of the internal gain and operation schedule affects the accuracy of the model in the next step. The site review found also some

BASELOAD ANALYSIS WITH MEASURED DATA

Watt-meter No.	Measured Electricity kWh/day		Elec. Consumption Components (Site visiting and Interview with building operaters)
1	**960**		Pumps(hot water, service water, waste water, AHU etc.) : 365days 5a.m.-5p.m. (AHU Schedule ; 5a.m.-5a.m., 11.25kw/floor (7.5+3.75kw))
2	**1,550**		Package-type airconditioner (1set / every_3floors, 3phase 220V)
3	**5,350**		Lighting : Lighting Schedule 5a.m.-8p.m.(100%), -22h(60%), -24h(40%), -5h(30%) (Lighting Fixture : 300units/floor)
4	3,050	**2,950**	Plug-Load(Computer, OA etc.)
		100	Fancoil(45w*58units/floor)
5	3,600		[Plug-Load]
6	5,740	1433	Coumpter Room(8th floor) : 24hr running, monthly 43000kwh consumption.
		2667	Computer Room(3rd floor) : 24hr running., monthly 80000kwh consumption
		1680	Elevator : 35kw*8units*12h*50%
		1152	Lighting for emergency : 64W*50unit/floor*30floors*12hr(25days/month)
		936	OA, Telex, computer etc.(28086 kwh/month)
		1472	Computer, OA etc.
7	1,780		
		700	Emergency Elevator : 35kw*2units*20hr*50%
		1,080	Lighting : guide light
8	240		Computer, OA etc.
9	200		Lighting : guide light, kitchen, toilet for 27th floor
10	2,580	1680	Elevator : 35kw*8units*12h*50%
		900	AHU :11.25*(18th-27th floors)*operation_ratio
11	1,070		Pumps :Cooling tower(5kw*4units for summer), Circuration, PTC, etc.
12	3,780		[Plug-Load]
		2,650	Computer, OA etc.(around 100A --> 130kwh/hr)
		1130	Brocasting Equipment (around 80A -->47kwh/hr)
13	2,900		Lighting : Lighting Schedule 5h-20h(100%), -22h(60%), -24h(40%), -5h(30%)
14	490		Computer, OA etc.
15	690		Heat Pumps for Top floor(4hr-16hr 365days operation, 4units)
Daily Total		**33,980**	kWh/day
Monthly Total(estimate) :			*30days = **1019** MWh/month

Category of Electricity Use

Component	**Electricity C. (kWh/day)**		**Ratio**
Lighting	8,250	**10,682**	**31%**
	2,432		
Heating &	4,270	**5,270**	**16%**
Cooling	1,000		
Plug-load		**13,968**	**41%**
Elevator		**4060**	**12%**
	(SUM)	**33,980**	**100%**



Baseload Estimation

-Daily(weekday) Consumption Error(33980-35320kWh) : - 1060MWh((4%)
-Monthly Day Number Error (28-31) : 951MWh(7%) - 1053MWh(3%)
-Weekend & Sunday Error (70%-80%) : 968Mwh -

--> Baseload Variation Range : 1023MWh +- 72MWh(7%) (951MWh - 1095MWh)

Figure 4. Disaggregation worksheet sample for building base load analysis

changes in power densities of equipment and occupancy load by observation and wattnode measurement. The conversation with mechanical staff would set up to revise the schedule of week and week-end days. The density and schedule of elevator had been checked to improve the model accuracy in this study. The more influential parameters were equipment density and schedule. In practice, the model prediction error within 10% could be accepted as a calibrated model(Kaplan, 1992 and Pratt, 1990).

Step 5) Heating/cooling season calibration:

The next step of cooling/heating calibration could be ready if the differences were less than that of the specified values in the mid-season calibration. A careful review should be made on set temperature, schedule, control mechanism, HVAC system operation characteristics, outdoor air requirement and actual control situations. The overall efficiency and the part load performance of HVAC cooling and heating machine affect on simulated results. One should check the possible default values to see any differences from the actual conditions. Otherwise, maybe another site visit would be required if the differences occurred larger than that from the base load calibration. This time of site visit should focus on plant system design and performance values in model simulated and actually measured.

Step 6) Validation of calibrated base model:

Finally, a calibrated base model could be developed from the base load and heating/cooing load analysis. Most approves that the computer model be valid and calibrated if the error would be less than 10 % during the calibration process(Kaplan, Pratt). It is quite desirable to use the numerical comparison as well as graphical comparison when one decides the base model adequacy. In general, statistical Mean Bias Error (MBE) approach has been adopted in many practices to evaluate the error between the predicted and the measured. This approach has a disadvantage of inter-neglecting effect, so called plus and minus error compensation, which might lead to zero error interpretation. Therefore, recently, Root Mean Squared Error (RMSE) approach or Coefficient of Variation (CV) of the root mean squared error values are used more frequently(Kreider). They used the following statistical index:

$$MBE = \frac{\sum_{i=1}^{n}(Q_{pred,i} - Q_{data,i})}{n\,\bar{Q}_{data}}$$

$$RMSE = \frac{\sqrt{\sum(Q_{pred,i} - Q_{datai})^2}}{n}$$

$$CV(RMSE) = \frac{RMSE}{\bar{Q}_{data}} = \frac{\frac{\sqrt{\sum(Q_{pred,i} - Q_{datai})^2}}{n}}{\bar{Q}_{data}}$$

where,

MBE	:	Mean Bias Error
RMSE	:	Root Mean Squared Error
CV(RMSE)	:	Coefficient of Variation of the root mean squared error
$Q_{pred,i}$	:	predicted value during period i
$Q_{data,i}$	:	measured value during period i
Q_{data}	:	measured avg during the period

A Box-Whisker approach, as in Figure 7, indicating the maximum, average and minimum values with actual multi year energy records would be also very effective to justify the validity for the typical year simulation model(KIER). One of uncertain factors mostly includes the area intensity such as lighting, equipment and this may lead to building load sensitivity studies to quantify its impact on the simulated energy performance results.

Step 7) Investigation of promising ECM's:

It was very important to disaggreate the energy into a pie chart form as in Figure 4. This would make energy auditor to identify effectively a promising and building specific ECM. The type and priority of possible ECM's could be devised and recommended based on the disaggregated result. Identifying the feasible ECM's in this step is prerequisite to the success of the next ECM evaluation phase. Then, another sensitivity model of the most feasible ECM can be modeled, simulated and could be evaluated before their actual construction and implementation. Also, other candidates of multiple ECM's could be considered for owner according to the priority made by the ECM simulations. Now, the seven steps calibration procedure to develop a base model and verify the model with the actual data has been described in previous. Next, this method will be demonstrated as in the following actual case study.

CASE STUDY

A case study to demonstrate the methodology has been performed for a large commercial building located in down-town Seoul. The target building has 26 stories, 4 underground floors, all floor area of 3,920m^2. Centrifugal chiller with ice storage system has been equipped for cooling and LNG gas boiler was used for heating, The system and the plant was modeled with DOE2.1E program and the actual data from 1991 to 1994 were used to calibrate the model. The real weather data of the year 1993 was used and converted into the form of TRY to use DOE2.1E

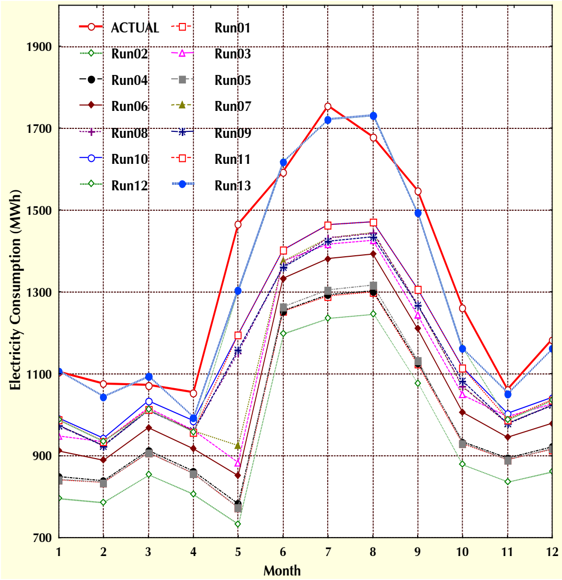


Figure 5. Thirteen sensitivity simulations for base model development

weather input file(Kim). The base load analysis approach was used to tune the model. Figure 2 and 3 show again that cooling and heating base load and rate curves depending upon the outdoor temperature. Figure 4 indicates the disaggregation results of measured data as described in previous. A careful review has to be conducted again for internal density and schedule in week day and week-end days. A number of iterations need to match the prediction and the key measured elements.

Figure 5 shows the results of thirteen sensitivity simulations to develop a valid and sound base model. Run1 was the result from first try as run2 was with elevator load correction and run3 was with plug load

Table 1. Thirteen sensitivity simulations for base model development

RUN #		Error Type	Electricity	Gas
(1)	**RUN01**	MBE	24.9%	-115.6%
		CV	24.9%	120.0%
(2)	RUN02	MBE	28.7%	-115.6%
		CV	28.7%	120.0%
(3)	RUN03	MBE	16.3%	-103.2%
		CV	16.3%	107.6%
(4)	RUN04	MBE	24.5%	-116.4%
		CV	24.5%	120.8%
(5)	RUN05	MBE	24.5%	-113.2%
		CV	24.5%	117.7%
(6)	**RUN06**	MBE	19.4%	-101.3%
		CV	19.4%	105.7%
(7)	**RUN07**	MBE	15.6%	-95.5%
		CV	15.6%	99.9%
(8)	**RUN08**	MBE	14.2%	-84.4%
		CV	14.2%	88.8%
(9)	**RUN09**	MBE	14.3%	-68.3%
		CV	14.3%	72.8%
(10)	**RUN10**	MBE	12.0%	-107.6%
		CV	12.0%	112.0%
(11)	**RUN11**	MBE	12.5%	-15.8%
		CV	12.5%	22.7%
(12)	**RUN12**	MBE	5.7%	-15.8%
		CV	6.7%	22.7%
(13)	**RUN13**	MBE	**2.3%**	**-15.8%**
		CV	**3.6%**	**22.7%**

MBE: Mean Bias Error = Sigma(Qpred-Qdata)/nQdata_avg
CV: Coefficient of variation of RMSE = RMSE/Qdata_avg

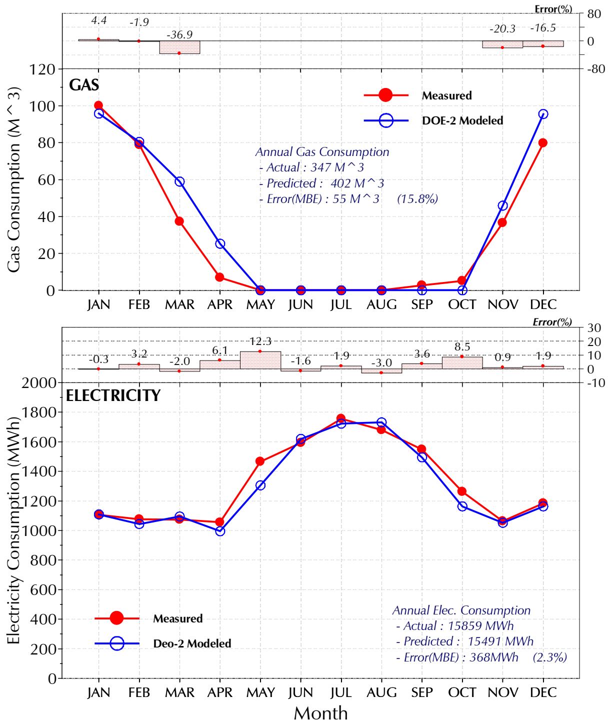


Figure 6. Base model justification with monthly data for the case study

and schedule change. Run4 changed the lighting load and run5 corrected the internal occupancy density and schedule item by item. Run6 was the case of all changes made from run2 to run5 simultaneously. Run7 considered the schedule of weekend, while run8 did model the shopping mall in the underground during the year of calibration. Run9 modeled the value of fresh air introduction rate and run10 modified the air flow rate per each HVAC zone to match the model with the actual data more closely. Run11 included the effect of actual humidity control status and Run12 considered the efficiency of cooling system. Finally, base model was developed from run13 case with heating load calibrated. The base model was justified with monthly gas data and electric data as in Figure 6. Table 1 summarizes the impact of those 13 changes on annual energy consumption in terms of MBE and CV(RMSE). Their final values are about annual errors of 2.3%(MBE) and 3.6%(CV).

Run11 indicated that the impact of no humidity control reduced the error significantly. The values of MBE 15.8% and CV 22.7% were the lowest we could reach for gas calibration due to the uncertainties of boiler maintenance schedule. The heating performance model in spite of higher error values could be used because the model predicted the actual data very closely in peak heating months. The errors occurred during the transition months of boiler maintenance and replacement period, which could not be considered in computer model.

Table 2. Model verification and validation with measured and predicted disaggregated data

Measured Electricity (March)				Simulated Electricity	(March)			(April)		
Component	kWh/ day	Ratio		Component	MWh/ month	Ratio		MWh/ month	Ratio	
Lighting	10,682		**31%**	**Area Lights**	332		**30%**	320		**32%**
Plug-load	13,968	41%	**53%**	**Misc Equip**	527		**48%**	508		**51%**
Elevator	4060	12%								
Heating & Cooling, Equipment	5,270		**16%**	**Space Heat**	115	11%	**22%**	48	5%	**16%**
				Pumps & Misc	9	1%		8	1%	
				Vent Fans	112	10%		108	11%	
SUM	33,980		100%	SUM	**1095**		100%	**991**		100%
Baseload Range : **1023MWh**+-7%				Baseload Difference.	7%			-3%		

Figure 6 shows the comparison and error bound of monthly measured and predicted data of gas and electricity consumption. The model could be said as sound and valid because it has less than 3% error even in July and August cooling season and all less than 10% except May. It predicts very closely in March and April of mid season error less about 2% and 6%. According to the electricity comparisons in March and April, the model predicted 1095MWh for March and 991MWh for April, which is less than the error bound of 7% of 1023MWh as shown in Table 2. Table 2 compares the monthly measured and the simulated electricity of base load. The percentage of the base load components used in a day and in a month appear to be consistent, 31% of lighting, 53% of plug and elevator and 16% of HVAC equipment. The model also predicts the key internal load such as lighting and plug-load well within the allowable error range.

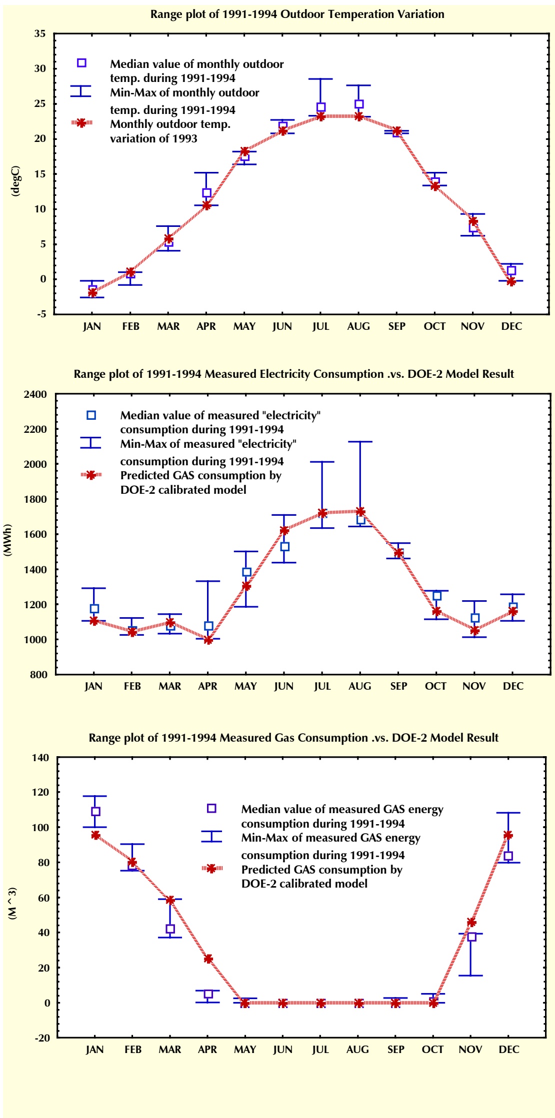


Figure 7. Statistical verification of base model using multi year energy consumption records

Figure 7 shows the justification of the final calibrated model whether to use the model for simulating the annual energy performance for the years like those four years. The data with solid vertical line and box show that the range of maximum, minimum and mean value of the outdoor temperature and electricity and gas consumption measured during four years. Outdoor temperature curve of Figure 7 shows the model to use the simulated data within the range of the collected measured data. The model based on the data of year 1993 predicted the electricity and gas consumption properly within the range of the other four years as observed in Figure 7. Electricity and gas consumption of Figure 7 illustrates the model justification to represent a calibrated base model for further sensitivity simulations. Thus, a calibrated computer model for a future ECO study could be developed based on the seven step approach. The more detail calibration process and results were included in a KIER (Korea Institute of Energy Research) technical report(KIER).

CONCLUSIONS

The number of energy audit projects on larger buildings in Korea gets increased because many buildings were constructed in the middle of 1970's. The key element of the energy audit and retrofit process is the quantification of the energy saving through the audit. The process sometimes requires the quantification of the saving according to international standard protocol such as IPMVP (International Performance Measurement Verification Protocol). The calibration process developed and demonstrated from this study could be very useful according to the requirement or sometimes options they agreed based on the international standard protocol. One of the options is to use computer model to quantify the savings from the retrofit - one of the ECO's. They could use this calibration approach too develop and apply the base and ECO model at least suggested by this paper.

This paper also found major impact parameter like the internal gain on commercial building energy performance through the base load sensitivity simulations. The impact has been confirmed and visualized again with the actual measured data from the building site. The unique way of calibrating the computer model specially with the base load, non-weather dependent, has been proposed and justified from this study. Due to the relative complexity and difficulty of the hourly measurement, the calibration with monthly data has been proposed and justified with the actual case study for a building located in Seoul. This method could be considered as a more realistic way using the typical wattmeter equipped in most buildings of Korea.

Korea now starts to focus on the business of energy consulting to overcome the economic crisis in 1998. Government provides Energy Service Company (ESCO) fund policy to support the energy saving business in Korea. One option for government policy requires a computer simulation to quantify the energy savings from the promising ECO’s. The proposed calibration method would be used effectively to justify the estimated savings for the base and the selected ECO conditions.

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