ASSISTED CALIBRATION IN BUILDING SIMULATION–ALGORITHM DESCRIPTION AND CASE STUDIES

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ABSTRACT

Building simulation must be calibrated to fit the customer's bill before applying energy saving measures. However, existing calibration methods are usually too complex to be included in building simulation software.

The author has developed and implemented in DOE2.1E based building simulation software a calibration method which assists the software user in the calibration process using built-in engineering rules as well as optimization algorithms based on Marquardt-Levenberg non linear least square method.

The article presents an overview of the calibration module's functionalities and two case studies. For the first case study, the calibration process reduced the maximum error on the monthly electrical bill from 143% to 14%. For the second case, the maximum error was reduced from 40% to 11%. For this latter study case, the availability of hourly consumption data shows a need for schedule adjustment prior to calibration.

INTRODUCTION

Energetic building simulation is now widely used for retrofit evaluation. However, building simulation softwares usually require a large number of entries leading to a high risk of error. Calibration of the model is therefore essential.

There are two different views on calibration procedure. The first, as described by Waltz (1992) and Yoon & Lee (1999), relies mainly on the user's knowledge and experience. It therefore cannot efficiently be used by less or inexperienced users. The other class of calibration procedures is based on a mathematical approach. Carroll and Hitchcock (1993) presented an interesting calibration method. However, such a technique, as mentioned by Sun & Reddy (2006), requires a huge amount of simulations and can hardly be implemented within complex simulation software.

The author has developed a calibration method that allies both approaches. The resulting calibration module is now integrated inside a user friendly interface for DOE2.1E simulation software. The module helps the user to adjust parameters so that the monthly electrical consumption and peak power demand fits that of the utility bill. This calibration procedure still requires knowledge of building services and simulations and should not be used by completely inexperienced users. However, the calibration module includes a pre-calibration algorithm that will help in the identification of parameters that could have an erroneous value. For non-expert users that are familiar with building services and simulations, this could significantly reduces the number of parameters to calibrate leading therefore to a fewer simulation runs. The calibration requires four simulation runs per parameter and each simulation takes approximately 9 to 16 seconds to be completed. A previous article (Lavigne & Millette, 2008) indicated that, in some cases, the pre-calibration could reduce the number of runs up to 55%.

Nevertheless, the calibration module shows some limitations. First, as mentioned earlier, it can only be used to adjust monthly consumption and peak power demand. It is also limited to electricity for now and schedules cannot be adjusted with the tool. Finally, the calibration procedure can be simplified as a simple mathematical optimization problem with multiple solutions. Since no exhaustive search of the minimum is done (e.g. Monte Carlo or Latin Hypercube designs), one could end up with a solution that has no real physical meaning. However, this is mitigated by the pre-calibration and by ranges of values imposed to the parameters.

The present article presents an overview of the calibration procedure as well as two case studies.

METHODOLOGY

The calibration process is realised using monthly electrical energy consumption and peak demand and is not intended for schedule adjustments. Other energy sources are not considered for now. The process requires local weather data corresponding to the period of measurements. Standardized weather files are not used. The calibration module is divided into two algorithms: pre-calibration and calibration.

Pre-calibration

When the user selects the calibration module from a tool menu, the pre-calibration algorithm is first launched. This algorithm does not require any further simulation run. It simply exploits the results of the initial simulation. More specifically, monthly measured (bill) and simulated electrical consumptions are plotted against external temperature. A five-variable energetic model (see figure 1) is then fitted through each data set (one regression for the measured data and one for the simulated data). A previous study (Lavigne & Millette, 2008) has helped to link a subset of DOE2.1E simulation parameters with the variables of the model (b_0, b_1, and b_2). b_0 refers to baseline charges such as plug loads and lighting density. b_1 is the "heating slope"; it gives the amount of energy or power required by unit of temperature during winter time. Its opposite, b_2, is the "cooling slope". It gives the amount of power/energy required by unit of temperature during summer days. b_1 and b_2 are usually associated with envelop parameters such as insulation but also with systems parameters such as heating and cooling efficiencies. The impact of a parameter depends on its influence on the monthly output values (energy and power). A larger scale study (Lavigne & Millette, 2008) has allowed determining in which conditions a given parameter is susceptible to be important. Pre-calibration compares the variables (b_0, b_1, b_2) for the measured data regression and the simulated data regression.

If b_0, b_1 and/or b_2 significantly differ, among the related subset of simulation parameters, the pre-calibration will point out to the user those which are susceptible of having a large impact on the simulation. This is a pre-selection of parameters to be calibrated. The complete list of calibration parameters is presented in table 1.

Table 1
Description of calibration parameter and related DOE2 code-word

PARAMETER	**RELATED CODE-WORD DOE2.1**	**DESCRIPTION**
walls insulation	THICKNESS	RSI value for the entire wall construction (adjusted by modifying the thickness of the insulation layer in the wall construction)
windows insulation	GLASS-CONDUCTANCE	Window insulation (inversely proportional to DOE2's heat conductance)
roofs insulation	THICKNESS	RSI value for the entire roof construction (adjusted by modifying the thickness of the insulation layer in the roof construction)
floor insulation	U-EFFECTIVE	Floor insulation (inversely proportional to the effective coefficient of heat transfer of the slab or basement)
sensible heat gain/pers	PEOPLE-HG-SENS	Maximum sensible heat gain per person
latent heat gain/pers	PEOPLE-HG-LAT	Maximum latent heat gain per person
lighting density	LIGHTING-W/SQFT	Maximum overhead lighting energy use (W/ft²)
Plug loads	EQUIPMENT-W/SQFT	Watts of equipment energy per square feet of floor area
outside air (OA) flow rate/pers	OA-CFM/PER	Flow rate of outside air (in standard, or sea level, cfm) per zone occupant at peak occupancy
HVAC cooling efficiency	COOLING-EIR	Inverse of the Electric Input Ratio (EIR) at ARI rated conditions
Plant cooling efficiency	Chillers E-I-R	Electric input to nominal capacity ratio is expressed as ratio= electric power input to electric auxiliaries (Btu/hr) / nominal capacity of equipment being defined (Btu/hr)
HVAC fans static pressure	SUPPLY-STATIC	Total pressure increase produced across the system supply fan at design flow rate
heat recovery efficiency	RECOV-EFF	Fraction of heat that may be recovered from the return air and exchanged to the outside air stream using heat wheel, air/air exchanger, or run around coils
minimal relative humidity	MIN-HUMIDITY	Lowest allowable relative humidity (R.H.) in the zone(s) served by the system
HVAC total air flow	SUPPLY-CFM	Design capacity (in standard, or sea level, cfm) of the system air supply fan
HVAC maximum heating temperature	MAX-SUPPLY-T	Highest allowed diffuser temperature.
HVAC minimum cooling temperature	MIN-SUPPLY-T	Lowest allowable temperature for air entering the zone(s), that is, the lowest allowed diffuser temperature
HVAC preheating temperature	PREHEAT-T	Minimum temperature of air leaving the preheat coil

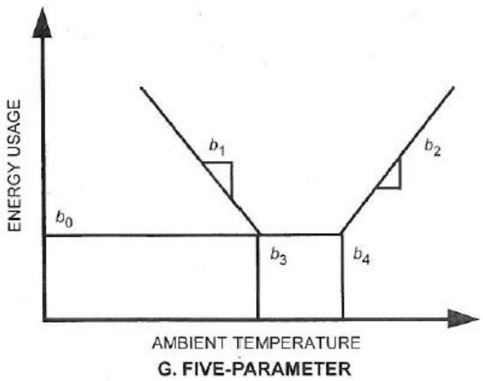

Figure 1-Five-variable energetic model [AHSRAE Fundamental, 2001]

The user may accept this pre-selected list or can add/remove parameters. The user must also impose a range a value for each of the selected parameters (the default range is ± 20% from the initial value). The calibration may then be launched.

Calibration

The calibration process, as described by Lavigne and Millette (2008), must minimize the following objective function:

$$S(\vec{x}) = \sum_{j=1}^{m} \left[f_j(\vec{x}) \right]^2 \quad (1)$$

with $$f_j(\vec{x}) = y(j, \vec{x}) - y_j \quad (2)$$

Where f_j is the jth of the m outputs (electrical monthly energy and power) and $\vec{x}$ is a vector of dimension n containing the set of simulation parameters to adjust. Therefore, $y(j, \vec{x})$ is the value of the jth output obtained with the parameters set $\vec{x}$ and y_j is the measured output j. Marquardt-Levenberg's method has been implemented to solve the following system:

$$\left(\hat{J}^T \hat{J} + \lambda \hat{D}^2 \right) \vec{\delta} = -\hat{J}^T \vec{f} \quad (3)$$

Where $\vec{\delta}$ is the variation that must be imposed to the simulation parameters and λ is an adjustable damping factor ensuring calculation stability. $\hat{D}$ is a diagonal matrix. Nash's method (1990) has been selected for the diagonal elements value:

$$D_{ii}^2 = \left(\hat{J}^T \hat{J} \right)_{ii} + \phi \quad \text{with} \quad \phi = 1 \quad (4)$$

$\hat{J}$ is the jacobian matrix of $f(\vec{x})$.

The calculation of the jacobian matrix is the most complex and time expensive step of the calibration method. Since the functions $f_j(\vec{x})$ are unknown, more simulations are required to calculate the jacobian.

A complete factorial analysis applied to different building simulations showed that, for all monthly electrical energy consumptions and power peak demands, interactions between the parameters could be neglected without affecting the validity of the model. In fact, no interaction seemed to contribute for more than 5% to the model. They were therefore ignored. The most adequate model that could be applied to the parameters was a quadratic one:

$$y(j, \vec{x}) = \left(A_1 x_1^2 + B_1 x_1 + C_1 \right) + \cdots + \left(A_i x_i^2 + B_i x_i + C_i \right) + \cdots + \left(A_n x_n^2 + B_n x_n + C_n \right) \quad (5)$$

or,

$$f_j(\vec{x}) = y_j + \left(A_1 x_1^2 + B_1 x_1 + C_1 \right) + \cdots + \left(A_i x_i^2 + B_i x_i + C_i \right) + \cdots + \left(A_n x_n^2 + B_n x_n + C_n \right) \quad (6)$$

The determination of coefficients A, B and C requires three equations. One is obtained with the initial simulation, but, for each parameter, two more simulations are required. The parameter range specified earlier is used to determine the value of the parameter for those two simulations. Two more simulation runs are conducted at mid-range in order to obtain a better caracterization of the parameter's behavior. Each simulation takes between 9 to 16 seconds to be completed. Therefore, one should expect a mean calculation time of 48 seconds per chosen parameter.

A sensitivity analysis is also performed for each parameter over the simulations' range. The sensitivity of the jth output to the ith parameter is given by:

$$SC\left(y_j(\vec{x}) \right)_i = \frac{\Delta y_j(\vec{x})}{y_j(\vec{x})} \frac{x_i}{\Delta x_i} \quad (7)$$

If the sensitivity is inferior to a certain threshold for all the m outputs, the parameter is neglected for the calibration. Otherwise, the coefficients A, B and C are calculated using Lagrange polynomials.

The functions $f_j(\vec{x})$ as well as their first and second derivatives are calculated for the initial set of parameters $(\vec{x}_0)$. Consequently, all the $f_j(\vec{x}_0)$ are known. In order to determine $f_j(\vec{x})$ at a point $\vec{x} = \vec{x}_0 + \Delta\vec{x}$, Taylor series is used:

$$f_j(\vec{x}) = f_j(\vec{x}_0) + \Delta\vec{x}^T \frac{\partial f_j(\vec{x}_0)}{\partial \vec{x}} + \frac{1}{2} \Delta\vec{x}^T \hat{H} \Delta\vec{x} + \mathrm{O}\left(\left| \Delta\vec{x} \right|^3 \right) \quad (8)$$

Where $\mathrm{O}\left(\left| \Delta\vec{x} \right|^3 \right)$ is truncation error and $\hat{H}$ is the hessian matrix. Interaction between parameters being neglected, equation 8 becomes:

$$f_j(\vec{x}) = f_j(\vec{x}_0) + \Delta\vec{x}^T \frac{\partial f_j(\vec{x}_0)}{\partial \vec{x}} + \frac{1}{2} \Delta\vec{x}^T \frac{\partial^2 f_j(\vec{x}_0)}{\partial \vec{x}^2} \Delta\vec{x} + \mathrm{O}\left(\left| \Delta\vec{x} \right|^3 \right) \quad (9)$$

Or:

$$f_j(\vec{x}) \cong f_j(\vec{x}_0) + \Delta\vec{x}^T \frac{\partial y(j, \vec{x}_0)}{\partial \vec{x}} + \frac{1}{2} \Delta\vec{x}^T \frac{\partial^2 y(j, \vec{x}_0)}{\partial \vec{x}^2} \Delta\vec{x} \quad (10)$$

The previous equation is used to estimate $\vec{f}$ in equation 3. The jacobian is approximated in order to speed up the calculation:

$$\frac{\partial f_j(\vec{x})}{\partial x_i} \cong \frac{\partial y(j,\vec{x}_0)}{\partial x_i} + \frac{\partial^2 y(j,\vec{x}_0)}{\partial x_i^{\,2}} x_i \qquad (11)$$

Equation 3 is then solved using Choleski decomposition. The calculation is stopped whenever convergence is obtained or the maximum number of iterations is reached. It should be noted that Marquardt-Levenberg's method is a rather robust algorithm but is sensible to local minima. Since the optimisation problem that needs to be solved does not have a unique solution, it is imperative to wisely select the parameters to calibrate. Otherwise, one could end up with a solution that has no physical meaning. This is where the pre-calibration can be found handy for less experienced users.

SIMULATION

This section presents two real case studies that have been simulated and calibrated using the algorithm described previously.

Description of building #1:

This building is one of the service centers of the principal electricity utility in Quebec, Canada. Electricity is the only energy source used. The two-level building was built in 1986, its area is 14 693m² and its annual specific consumption is about 254 kWh/m². There are approximately 250 occupants. The center has office spaces, cafeteria and kitchen, computer rooms, garages and workshops. There are over 10 different HVAC systems including variable-volume fan systems (VAVS), packaged mu1tizone fan systems (PVAVS), single-zone fan systems with and without 100% outside air flow, packaged single zone air conditioner (PSZ) and packaged terminal air conditioner (PTAC).

An on-site survey has been done to gather building and HVAC data. Certain entries were unknown and recommended values have been applied.

The monthly electrical energy consumption and power peak demands obtained by simulation are compared to the measured results on figures 2 and 3. Table 2 shows the relative error on the monthly electrical energy (kWh) and power peak demand (kW) as well as the resulting error on the electrical utility bills. The maximum error on the monthly bills is 142.6 %. However, annually, is 55.1% since monthly bills are over and under estimated depending on the months.

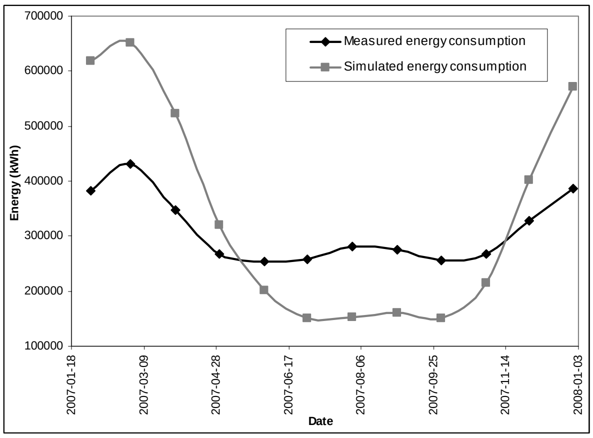

Figure 2- Measured and simulated monthly energy consumption for building #1

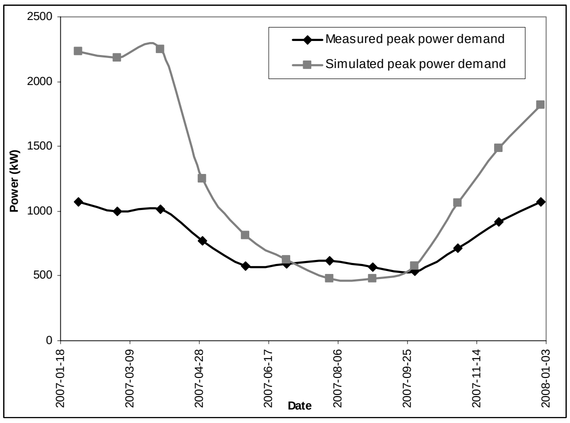

Figure 3-Measured and simulated monthly peak power demand for building #1

Table 2
Simulated (DOE2.1E) and measured energy consumptions, power peak demands and billing error for building #1

DATE	KWH ERROR	KW ERROR	BILLINGS ERROR
2007-01-31	61.4%	108.6%	135.8%
2007-02-28	50.9%	119.2%	130.9%
2007-03-31	50.1%	122.0%	142.6%
2007-04-30	19.7%	62.5%	49.2%
2007-05-31	-20.9%	40.6%	7.8%
2007-06-30	-41.2%	5.5%	-19.1%
2007-07-31	-45.7%	-23.0%	-33.1%
2007-08-31	-42.2%	-16.8%	-28.8%
2007-09-30	-41.2%	6.8%	-19.6%
2007-10-31	-19.9%	49.2%	15.2%
2007-11-30	22.3%	62.5%	62.6%
2007-12-30	47.9%	69.6%	90.4%

Building #2:

The second building is an office building located near Quebec City. Electricity is the only energy source for this building built in 1990. Its total area is approximately 8000m² and its annual specific consumption is 224kWh/m². The building has seven HVAC systems: four variable-volume fan systems (VAVS), one packaged mu1tizone fan system (PVAVS), one packaged single zone air conditioner (PSZ) and one packaged single zone air conditioner with 100% outside air (PSZ).

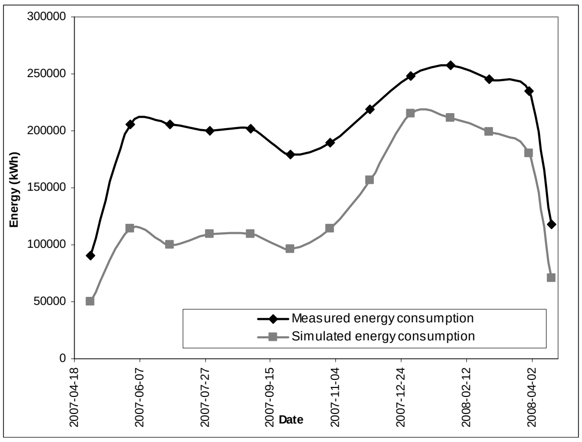

Figure 4- Measured and simulated energy consumption for building #2

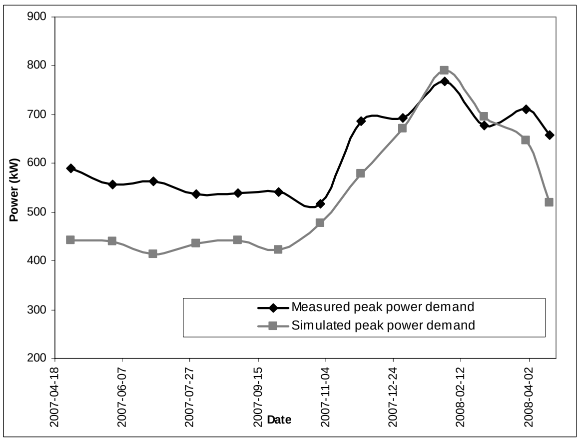

Figure 5-Measured and simulated peak power for building #2

Many DOE2.1E entries were not known and recommended values have been entered. The monthly electrical energy consumption and power peak demand obtained by simulation are compared with the measured ones and shown graphically on figures 4 and 5. Table 3 shows the relative error on the energy (kWh) and the power peak demand (kW) as well as the resulting error on the electical utility bills. The maximum error on the monthly bills is 40% and the annual bill is underestimated by 22%. Although the term “month” is used, it should be noted that the first and the last periods considered (dates 2007-04-30 and 2008-04-17) do not represent complete months. The first period counts 13 days, and the last, 17.

Table 3
Simulated (DOE2.1E) and measured energy consumptions, power peak demands and billing error for building #2

DATE	KWH ERROR	KW ERROR	BILLINGS ERROR
2007-04-30	-44.6%	-44.6%	-31.7%
2007-05-31	-44.4%	-44.4%	-33.8%
2007-06-30	-51.3%	-51.3%	-40.2%
2007-07-31	-45.2%	-45.2%	-33.5%
2007-08-31	-45.8%	-45.8%	-33.4%
2007-09-30	-46.2%	-46.2%	-34.7%
2007-10-31	-39.8%	-39.8%	-25.3%
2007-11-30	-28.4%	-28.4%	-21.8%
2007-12-31	-13.3%	-13.3%	-6.3%
2008-01-31	-17.7%	-17.7%	-3.4%
2008-02-29	-18.8%	-18.8%	-6.6%
2008-03-31	-23.4%	-23.4%	-20.6%
2008-04-17	-40.0%	-40.0%	-28.0%

RESULTS AND ANALYSIS

This section presents the results obtained by calibrating the two simulated building described in the previous section.

Building #1

For the simulation of building one, pre-calibration suggested the adjustment of the following parameters:

- Total air flow rate and maximum heating temperature for PSZ units
- Total air flow rate for the VAVS units
- Floor insulation
- Plug loads
- Lighting density
- Outside air flow rate/pers

Among that list, using the on-site survey, it was possible to establish that the principal unknowns were floor insulation, outside air flow rate/pers (OA flow rate), plug loads and total air flow rate of the PSZ units. Therefore, those four parameters were adjusted through calibration. Table 4 shows the range of values selected for each calibration iteration as well as the variation that was applied to the parameters.

For the first iteration, all four parameters were selected. The ranges were adjusted according to the degree of uncertainty associated with each of the parameters. It turned out that the floor insulation and the flow rate were ignored by the calibration process. Therefore, for the other calibration runs, only the plug loads and the outside air flow rate/pers were selected. For the last calibration, since the measured and simulated profiles were much closer, the ranges were reduced. Calibration was stopped after three iterations for the following reasons: errors were considerably reduced, the variation of the plug loads was no longer at the top of the range selected and a fourth calibration could not improve the results. Figures 6 and 7 show the results of the calibrated monthly results compared with the initial simulation and the measured data.

Table 4
Parameters' range /variation for each calibration

	PARAMETER	RANGE	VARIATION APPLIED
1	Floor insulation OA flow rate/pers Plug loads PSZ air flow rate	-30% to +30% -60% to +60% -80% to +160% -30% to +30%	0% 0% +160% 0%
2	Floor insulation OA flow rate/pers Plug loads PSZ air flow rate	0% -60% to +10% -80% to +160% 0%	0% -53.7% +160% 0%
3	Floor insulation OA flow rate/pers Plug loads PSZ air flow rate	0% -20% to +20% -20% to +20% 0%	0% -13.0% -5.2% 0%

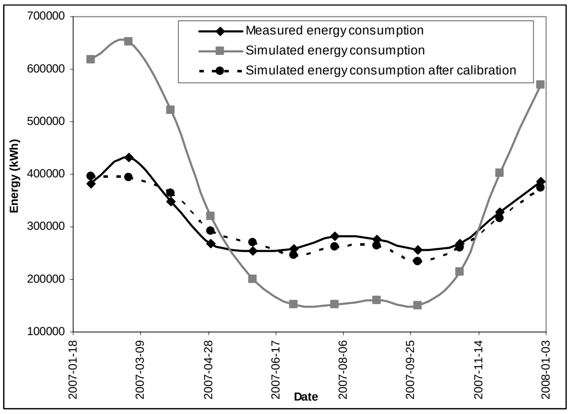

Figure 6- Measured and simulated and calibrated energy consumption for building #1

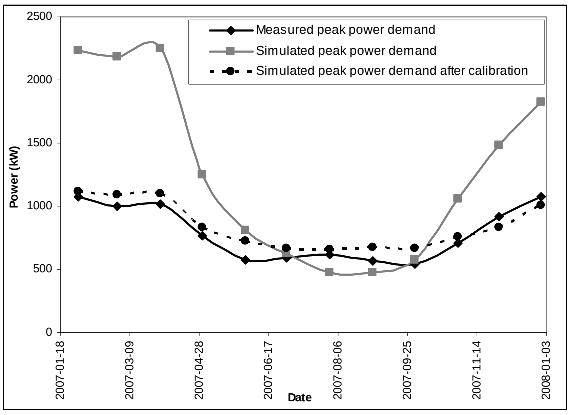

Figure 7-Measured, simulated and calibrated peak power demand for building #1

Table 5 shows the relative errors on the monthly electrical consumption (kWh), peak power demand (kW) and utility bill for the calibrated simulation. The maximum error on the monthly bills is 13.5% and the annual bill is overestimated by 3%.

Table 5
Simulated (DOE2.1E) and measured energy consumptions, power peak demands and billing error for building #1

DATE	KWH ERROR	KW ERROR	BILLINGS ERROR
2007-04-30	3.3%	4.1%	3.4%
2007-05-31	-8.6%	9.9%	0.8%
2007-06-30	4.4%	8.7%	6.0%
2007-07-31	9.1%	8.3%	7.3%
2007-08-31	6.7%	25.8%	13.5%
2007-09-30	-4.2%	12.5%	3.7%
2007-10-31	-7.0%	6.8%	-0.1%
2007-11-30	-4.2%	17.9%	5.5%
2007-12-31	-7.9%	24.4%	6.5%
2008-01-31	-2.9%	6.2%	1.8%
2008-02-29	-3.7%	-9.1%	-5.8%
2008-03-31	-3.3%	-6.4%	-4.5%
2008-04-16	3.3%	4.1%	3.4%

Building #2

For the simulation of building two, pre-calibration suggested the adjustment of the following parameters:

- Wall, roof and windows insulation
- Plug loads
- Lighting density
- Outside air flow rate/pers
- Maximum heating temperature of a PSZ unit
- Total air flow rate of the PSZ
- Total air flow rate of the PVAVS
- Total air flow rate of the VAVS

The pre-calibration suggestion was used. However, people sensible and latent heat gains were added to the list of parameters to calibrate. The simulation file for this case came from an older version of the building simulation software where people heat gains could not be modified via the interface. Therefore, the corresponding parameters were added to ensure that the default value was reasonable. Two calibration iterations were made.

Table 6 shows the range of values imposed for each parameter as well as the variation applied for each iteration of calibration. On the second iteration, the ranges were reduced since the measured and calibrated simulation profiles were closer.

Calibration was stopped after two iterations for the following reasons: errors were considerably reduced, the variation of the PVAVS air flow rate was no longer at the top of the range selected and a third calibration could not improve the results. For the last calibration, since the measured and simulated profiles were much closer, the ranges were reduced.

Table 6
Parameters' range /variation for each calibration

	PARAMETER	RANGE	VARIATION APPLIED
1	Wall insulation	-30% to +30%	0%
	Roof insulation	-30% to +30%	-13%
	Window insulation	-30% to +30%	0%
	Sensible heat	-40% to +40%	-15%
	Latent heat	-40% to +40%	0%
	Plug loads	-80% to +160%	+84%
	Lighting density	-50% to +50%	+50%
	OA flow rate/pers	-50% to +50%	0%
	Air flow rate (PVAVS)	-40% to +40%	+40%
	PSZ Max supply T	-20% to +20%	0%
	Air flow rate (VAVS)	-40% to +40%	+35%
2	Wall insulation	-20% to +20%	0%
	Roof insulation	-20% to +20%	0%
	Window insulation	-20% to +20%	0%
	Sensible heat	-20% to +30%	0%
	Latent heat	-30% to +30%	0%
	Plug loads	-80% to +80%	+27%
	Lighting density	-50% to + 2%	0%
	OA flow rate/pers	-40% to +40%	0%
	Air flow rate (PVAVS)	-20% to +20%	+ 2%
	PSZ Max supply T	-20% to +20%	0%
	Air flow rate (VAVS))	-20% to +20%	+0%

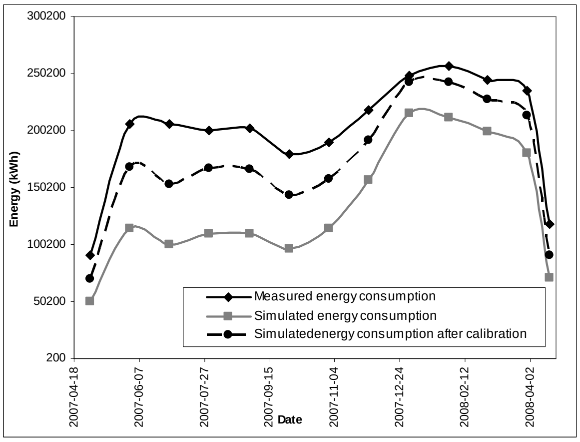

Figure 9- Measured and simulated and calibrated energy consumption for building #2

Figures 9 and 10 show the calibrated profiles with the initial simulation and the measured data. Table 7 shows the relative errors on the monthly electrical energy consumption, power peak demand and bills for the calibrated simulation. It can be noted that the maximum error on the monthly bill is now 10.9%. However, the annual difference is -1.1%.

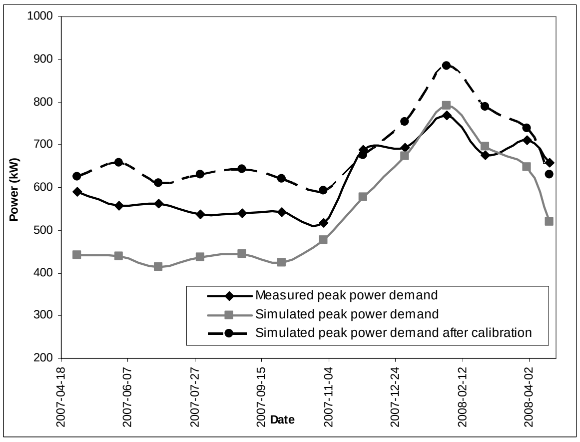

Figure 10-Measured, simulated and calibrated peak power demand for building #2

Table 7
Simulated (DOE2.1E) and measured energy consumptions, power peak demands and billing error for building #2

DATE	KWH ERROR	KW ERROR	BILLINGS ERROR
2007-04-30	-23.0%	5.8%	-4.0%
2007-05-31	-18.1%	18.2%	-1.8%
2007-06-30	-25.7%	8.4%	-10.3%
2007-07-31	-16.7%	17.6%	-1.4%
2007-08-31	-17.4%	19.1%	-1.2%
2007-09-30	-19.9%	14.6%	-3.5%
2007-10-31	-16.9%	14.8%	-2.6%
2007-11-30	-12.3%	-1.6%	-6.4%
2007-12-31	-2.2%	8.8%	3.3%
2008-01-31	-5.5%	15.1%	9.7%
2008-02-29	-7.2%	16.4%	5.0%
2008-03-31	-9.1%	4.0%	-1.3%
2008-04-17	-22.5%	-4.0%	-10.9%

Since, for this building, hourly consumption was available, a verification of the hourly profiles was made. Figures 11 and 12 show the "median profiles" of winter week days and Saturdays. It can be noted on figure 12 that the calibrated profile ignores activity on Saturdays. Working hours during week days also seem different (see figure 11). Schedules in the initial simulation were modified to correct some differences and the simulation was recalibrated. The results are presented in thin black lines in figures 11 and 12.

As can be seen from this example, the calibration procedure has some limitations. There is no schedule adjustment possible with the module; only maximal value of a parameter can be adjusted. For several parameters (plug loads, lighting density, ventilation, outside air), DOE2.1E requires both a nominal value and a schedule. For example, lighting density could have a maximum value of 22W/m² but has also a schedule modulating that value (0%-100%) for each hour of the day. Especially since it has been designed for monthly data, the calibration module will calibrate only the nominal value. It has no way of verifying if the schedule is erroneous. This could lead to false adjustments. Another problem is that the calibration module cannot detect if the user has made a wrong choice of system type or has forgotten equipments such as economizer. Again, the calibration module will adjust the selected parameters to its best, but the results won't necessarily make sense.

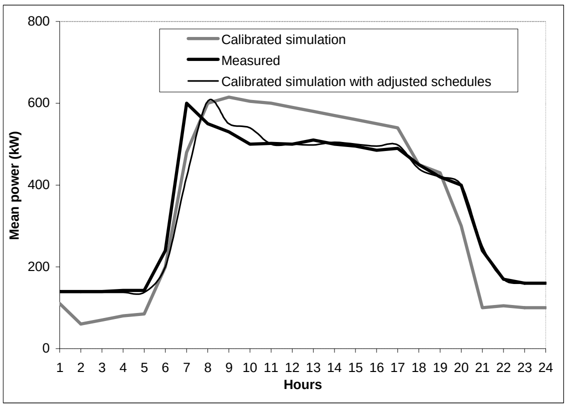

Figure 11-Winter week-days median hourly profiles

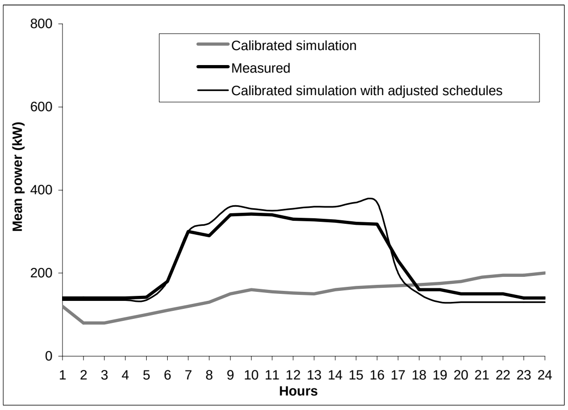

Figure 12–Winter Saturdays median hourly profiles

CONCLUSION

The calibration method proposed in this article combines intuitive method and mathematical algorithm to assist the user into fitting the simulation to the measured monthly electrical consumption and power peak demand. According to the differences observed between the measured profile and the simulation results as well as certain simulation input data, a set of parameters to calibrate is proposed to the user. Selection of those parameters is not necessarily a guarantee of perfect fitting between measured and simulated profiles. The user must still be critical about the choice of parameters and their possible range of values. The calibration algorithm then conducts more simulations to evaluate the impact of each parameter on the electrical consumption and peak power demand. From this information, a mathematical procedure predicts the variation that must be applied to each parameter in order to minimize the differences between the simulated and measured profiles. The two case studies show that more than one calibration runs are usually required. Nervertheless, even if the error on monthly data is considerably reduced, it is possible, as was found with building #2, that the hourly profile is erroneous. Therefore, schedule adjustments should be made prior to calibration. If the user does not have specific information on schedules but has the hourly consumption data, as was done with building #2, daily profiles could be studied to deduce the different schedules.

Future work will include statistical verification of the software entries, enhanced pre-calibration and multisource calibration. A statistical verification will be put into place to ensure that the different parameters do not show extreme values or omissions due to errors from the user. Moreover, some retrofitted buildings will be investigated in order to validate the calibration method for energy saving predictions.

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