STUDY OF THE OUTSIDE AIR ENTHALPY EFFECTS IN THE SCREENING OF METERED BUILDING ENERGY DATA

Jing Ji, Ph.D.
Research Associate

Juan Carlos Baltazar, Ph.D.
Associate Research Engineer

David E. Claridge, Ph.D., P.E.
Professor / Director

Energy Systems Laboratory, Texas Engineering Experiment Station
Texas A&M University, College Station, TX

ABSTRCT

The energy consumption in a building is affected by many parameters including the occupancy, equipment, schedule time, HVAC systems and outside environment conditions. Currently, the outside air dry-bulb temperature (T_{OA}) is the primary variable used in the data driven analysis for building energy use, including development of energy consumption models and measurement of savings. The measured building energy data analysis based on the variable of T_{OA} has the drawback of overlooking several effects such as humidity, wind and solar.

The application of outside air enthalpy (h_{OA}) on a methodology name as "Energy Balance" for screening building energy data to study the influence of outside air humidity on building energy analysis has been presented in this paper. The variable of h_{OA} has been implemented in a developed screening tool, which is the application of first law energy balance, to analyze the building energy use. The energy balance load (E_{BL}) for a whole building, which is the difference between the heating requirements plus the electric gain and the cooling load, has been presented by the two variables of h_{OA} and T_{OA}, respectively. A design of experiment process is conducted to study the linear relations for the E_{BL} as the function of h_{OA} and as the function of T_{OA}. The comparison results lead the conclusion that the E_{BL} in the high temperature range could be better presented with the application of h_{OA} instead of T_{OA}. The energy analysis for buildings located in hot and humid climate would be better performed by using h_{OA}. Study cases are also presented to illustrate the difference between application of h_{OA} and T_{OA} in energy use data analysis for buildings with different functions. The statistics study shows that the energy use analysis for buildings classified as laboratory would be improved in the application of h_{OA} as the variable instead of T_{OA}.

INTRODUCTION

The methodology of energy balance load has been proposed as a tool for screening building energy data which are separately recorded according to individual heating, cooling and electricity consumptions (Shao and Claridge, 2006). Although different air handle units (AHU) have different energy use patterns on individual heating and cooling, the air side simplified simulation shows that the defined E_{BL} has the similar pattern for four basic AHUs. (CVRH: single duct constant air volume with terminal reheat; DDCV: dual duct constant air volume; DDVAV: dual duct variable air volume; and SVAV: single duct variable air volume) (Shao, 2005). The methodology of energy balance load provides the prospect application in the analysis of energy use for buildings having various AHUs. This methodology has been implemented into energy use analysis for quality assurance of the energy use data for buildings on the Texas A&M University campus (Baltazar *et al.*, 2007).

It was found the slope and intercept of the defined E_{BL} is changed with buildings. It is necessary to further study the effects of parameters and building functions on the E_{BL} behaviors. Generally, the outside air temperature has been used to study the E_{BL} behaviors. However, the pattern for E_{BL} in the high temperature range has less linearity with the T_{OA}.

This paper presents the analytical study of the behaviors for E_{BL} as function of T_{OA} and h_{OA}. The slope and cross point of the E_{BL} have been investigated through simplified air side model simulation, the analytical model, and validation by actual energy use data. The parameters effects have also been demonstrated using the method of design of experiments (DOE) to characterize the various effects of parameters. In order to improve the analysis of building consumption in high temperature, the enthalpy of outside air is used in study the behaviors of E_{BL}. Additionally, the paper illustrates the application of h_{OA} to analyze the energy data in summer.

ANALYTICAL STUDY OF E_{BL}

The energy balance load (E_{BL}) is defined from the whole building thermodynamic model based on the analytical redundancy (Shao and Claridge, 2006). The equation to represent the E_{BL} is expressed as:

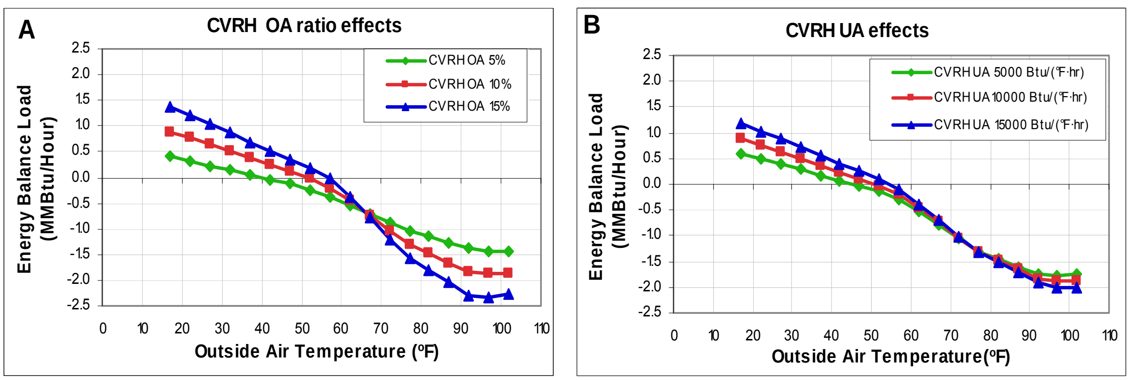
$$\begin{aligned} E_{BL} &= Wbele + Wbheat - Wbcool \\ &= -(Q_{Sol} + Q_{Air} + Q_{Con} + Q_{Occ}) \end{aligned} \quad (1)$$

Where *Wbele* is the whole building electricity use for lighting and equipment in the building, *Wbheat* is the input heating to maintain the conditions in a building, and *Wbcool* is the input cooling to maintain the conditions in a building. Q_{Sol} is the solar heating gain, Q_{Air} is the ventilation and infiltration air via doors, windows and air handling units, Q_{Con} is the heat transmission through the building structure, and Q_{Occ} is the heating gain from occupants.

Slope of the E_{BL} as the function of T_{OA}

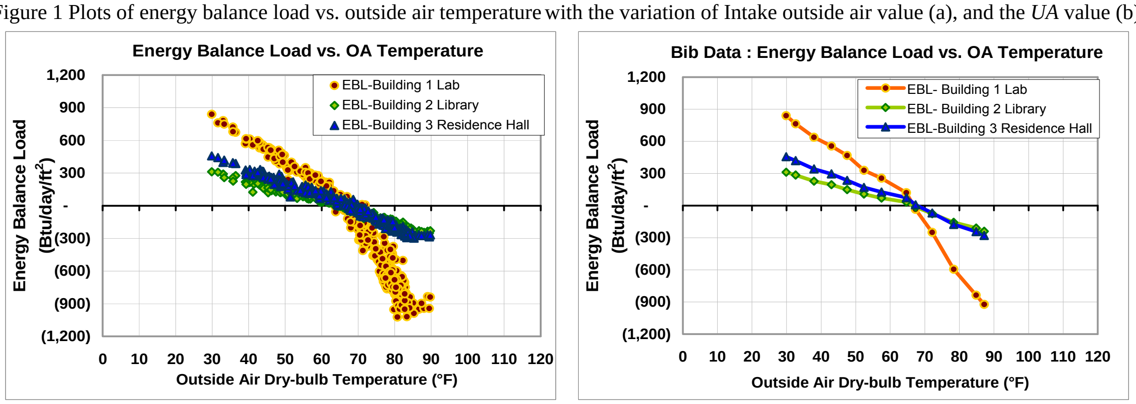
Eqn. 2 indicates that the slope of E_{BL} as a function of T_{OA} depends on the amount of intake outside air and the *UA* values.

$$\begin{aligned} E_{BL} &= Wbele + Wbheat - Wbcool \\ &= -(Q_{Sol} + Q_{Air} + Q_{Con} + Q_{Occ}) \\ &= -(Q_{sol} + V_{OA}\rho C_P(T_{OA} - T_z) + [\rho h_{fg}(\frac{V_{OA}}{X_{OA}}(w_R - w_{CL}) \\ &\quad + V_{OA}(w_{OA} - w_R))]^+ + UA(T_{OA} - T_z) + Q_{OCC}) \\ &= -(V_{OA}\rho C_P + UA)(T_{OA} - T_z) - (Q_{sol} + Q_{occ} \\ &\quad + [\rho h_{fg} V_{OA}(\frac{(w_R - w_{CL})}{X_{OA}} + (w_{OA} - w_R))]^+) \end{aligned} \quad (2)$$



(a) (b)

Figure 1 Plots of energy balance load vs. outside air temperature with the variation of Intake outside air value (a), and the *UA* value (b)



(a) (b)

Figure 2 Plots of energy balance load vs. outside air temperature for three different buildings using the daily data(A) and bin data (B)

Figure 1 shows simulation results of the slope change with the change of the value of intake outside air and the *UA* value in the CVRH system ((a). change of the value of intake outside air; (b). change of the *UA* value). The same results have been achieved in the other three systems (DDCV, DDVAV, and SDVAV). Figure 2 shows the plot of energy balance load vs. outside air temperature (E_{BL} vs. T_{OA}) using the actual data for three buildings with difference functions ((a) using the daily data; (b) using the bin data). The value of E_{BL} in Figure 2 is normalized with the area of a building with the unit of Btu/ft^2/day. The slope of E_{BL} in building with the function of laboratory is steeper than other two buildings which are library and residence hall, respectively.

Cross point temperature in the E_{BL}

The cross point temperature is defined as the temperature at the E_{BL} equal to zero. Eqn. 3 shows the explanation of the items of Q_{Air}, and Q_{Con}.

$$\begin{aligned} Q_{Air} &= Q_{Air,sen} + Q_{Air,Lat} \\ &= V_{OA}\rho C_P (T_{OA} - T_Z) + \\ &[\rho h_{fg}(\frac{V_{OA}}{X_{OA}} w_R(1-X_{OA}) + V_{OA}w_{OA} - \frac{V_{OA}}{X_{OA}} w_{CL})]^+ \\ Q_{Con} &= UA(T_{OA} - T_Z) \end{aligned} \tag{3}$$

Substitute Eqn. 3 into Eqn. 1, Eqn. 4 has been achieved:

$$\begin{aligned} E_{BL} &= Wbele + Wbheat - Wbcool \\ &= -(Q_{Sol} + Q_{Air} + Q_{Con} + Q_{Occ}) \\ &= -(Q_{sol} + V_{OA}\rho C_P (T_{OA} - T_z) \\ &\quad + Q_{Air,Lat} + UA(T_{OA} - T_z) + Q_{Occ}) \end{aligned} \tag{4}$$

The boundary condition of E_{BL}=0 occurred at the cross point temperature,

$$\begin{aligned} E_{BL} &= -(Q_{sol} + V_{OA}\rho C_P (T_{OA} - T_z) + Q_{Air,Lat} \\ &\quad + UA(T_{OA} - T_z) + Q_{Occ}) = 0 \end{aligned} \tag{5}$$

Rearrange the Eqn.5:

$$T_{OA} = T_Z - \frac{Q_{Sal} + Q_{Air,Lat} + Q_{Occ}}{V_{OA}\rho C_P + UA} \tag{6}$$

From the Eqn. 6, it could be drawn the conclusion that the cross point temperature is always lower than the zone temperature.

Application of enthalpy (h_{OA}) in the E_{BL} methodology

Figure 3 shows the energy balance sensible load and latent load as the function of T_{OA} using the simplified air side model simulation. The figure shows that the energy balance sensible load has the linear relationship with T_{OA}, but the energy balance latent load doesn't have the linear relationship with T_{OA}. Because of this phenomena, the energy balance pattern didn't have the clear linearly relationship with T_{OA} when the latent load existed in high temperature, as shown in Figure 4 (a), but Figure 4 (b) shows a better linear behaviors when the enthalpy of outside air is applied to present the pattern of E_{BL}.

Following derived equations confirmed that the E_{BL} has more linear behaviors as the function of enthalpy.

$$h = c_{pa} T_d + w(h_{g,ref} + c_{pw} T_d) \tag{7}$$

C_{pa}: Specific heat of dry air
T_d: Dry bulb temperature
C_{pw}: Specific heat of superheated water vapor
$h_{g,ref}$: Enthalpy of water vapor at appropriate reference temperature
w: Humidity ratio

$$\begin{aligned} E_{BL} &= -(V_{OA}\rho C_P + UA)T_{OA} + (V_{OA}\rho C_P + UA)T_Z - (Q_{sol} + Q_{occ} + \\ &[\rho h_{fg} V_{OA} w_{OA} + \rho h_{fg} V_{OA} \frac{X_R}{X_{OA}} w_R - \rho h_{fg} V_{Tot} w_{CL})]^+) \\ &= -[(V_{OA}\rho C_P T_{OA} + \rho h_{fg} V_{OA} w_{OA}) + UAT_{OA}] + \\ &[(V_{OA}\rho C_P + UA)T_Z - \rho h_{fg} V_{OA} \frac{X_R}{X_{OA}} w_R] \\ &-(Q_{sol} + Q_{occ} - \rho h_{fg} V_{Tot} w_{CL}) \end{aligned} \tag{8}$$

Compare the left of Eqn. 7 with the item of ($V_{OA}\rho C_p T_{OA} + \rho h_{fg} V_{OA} w_{OA}$), the Eqn. 8 can be expressed with similar Eqn. 9.

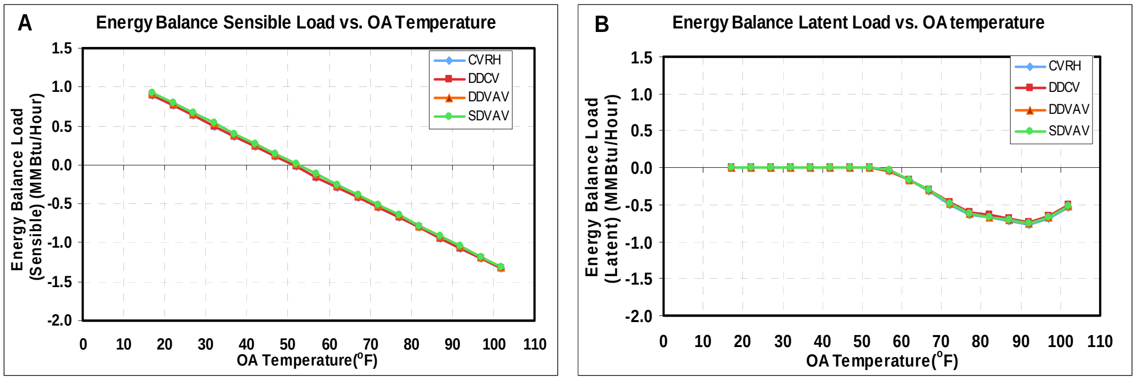
$$\begin{aligned} E_{BL} &\approx -[V_{OA}\rho h_{OA} + UA\frac{h_{OA} - w_{OA}h_{g,ref}}{c_{pa} + w_{OA}c_{pw}}] \\ &+[(V_{OA}\rho C_P + UA)T_Z + \rho h_{fg} V_{OA} w_R - \rho h_{fg} V_{Tot} w_R] \\ &-(Q_{sol} + Q_{occ} - \rho h_{fg} V_{Tot} w_{CL}) \\ &\approx -(V_{OA}\rho + \frac{UA}{c_{pa} + w_{OA}c_{pw}})h_{OA} + (V_{OA}\rho + \frac{UA}{c_{pa} + w_R c_{pw}})h_Z \\ &+UA(\frac{w_{OA}h_{g,ref}}{c_{pa} + w_{OA}c_{pw}} + \frac{w_R h_{g,ref}}{c_{pa} + w_R c_{pw}}) \\ &-\rho h_{fg} V_{Tot} w_R - (Q_{sol} + Q_{occ} - \rho h_{fg} V_{Tot} w_{CL}) \end{aligned} \tag{9}$$

The Eqn. 9 indicates that E_{BL} as a function of h_{OA} with the slope of

$$k = -(V_{OA}\rho + \frac{UA}{c_{pa} + w_{OA}c_{pw}})$$

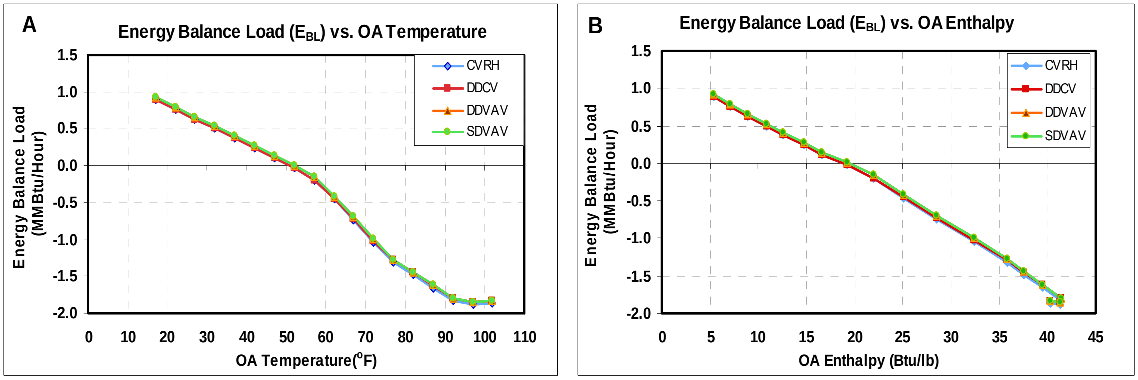
and the interception of

$$\begin{aligned} b &= (V_{OA}\rho + \frac{UA}{c_{pa} + w_R c_{pw}})h_Z \\ &+ UA(\frac{w_{OA}h_{g,ref}}{c_{pa} + w_{OA}c_{pw}} + \frac{w_R h_{g,ref}}{c_{pa} + w_R c_{pw}}) \\ &- \rho h_{fg} V_{Tot} w_R - (Q_{sol} + Q_{occ} - \rho h_{fg} V_{Tot} w_{CL}) \end{aligned}$$



(a) (b)

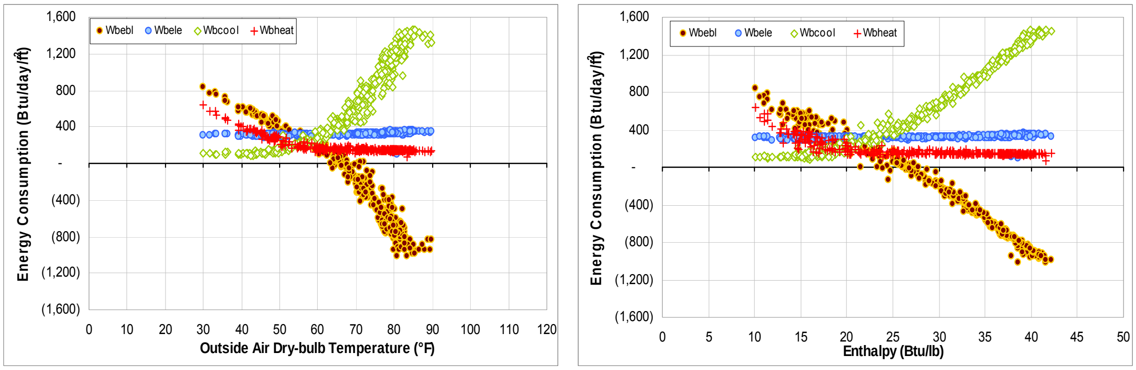
Figure 3 The simplified air side model simulation results of (a) Energy balance sensible load vs. Outside air temperature and (b) Energy balance latent load vs. Outside air temperature for the four basic AHUs



(a) (b)

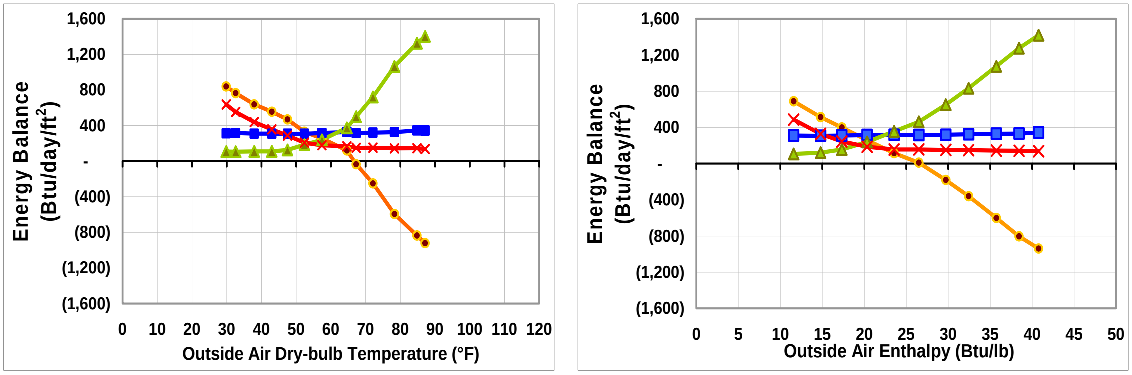
Figure 4 The simplified air side model simulation results of (a) Energy balance load vs. Outside air temperature and (b) Energy balance load vs. Outside air enthalpy for the four basic AHUs

Figure 5 (a) shows the plot E_{BL} and energy use of electricity (ELE), chilled water (CHW) and heating hot water (HHW) as the function of T_{OA} and Figure 5 (b) shows the plot E_{BL} and energy use of electricity (ELE), chilled water (CHW) and heating hot water (HHW) as the function of h_{OA} using the daily consumption data. Figure 6 show the similar plots to Figure 5 with the bin data.



(a) (b)

Figure 5 (a) Plot of the E_{BL}, energy use of ELE, CHW and HHW vs. OA temperature (b) Plot of the E_{BL}, energy use of ELE, CHW and HHW vs. OA Enthalpy in a building using daily data



(a) (b)

Figure 6 (a) Plot of the E_{BL}, energy use of ELE, CHW and HHW vs. OA temperature (b) Plot of the E_{BL}, energy use of ELE, CHW and HHW vs. OA Enthalpy in a building using daily bin data

FACTORS EFFECTS INVESTIGATION FOR THE E_{BL}

The method of full factorial design was used to study the effects of input parameters on E_{BL} behaviors. A factorial design is widely used when there are several factors of interest in the experiments. In such designs factors are varied together. Specifically, with a factorial experiment, all possible combinations of the levels of the factors are investigated in each complete trial or replicate of the experiment. The effect of a factor is defined as the change in response produced by a change in the level of the factor. Five parameters are intake OA ratio, cold deck temperature, zone temperature, *UA* value, and occupant density. In this factorial design, all five factors have two levels, denoted by "-1" and "+1". Table 1 shows the set point for the parameters

Table 1 Parameter level for factor design

	-1	+1
OA Ratio	5%	15%
T_{CL}	45°F	65°F
Tz	68°F	82°F
UA	5000 Btu/(hr*F)	15000 Btu/(hr*F)
Occupant density	300 ft²/person	500 ft²/person

The corresponding effects of factors are analyzed by the normal probability plot of the effect and the Pareto charts. The normal probability plot of the effect estimates is a very helpful method in judging the significance of factors in a 2^k experiment, especially when many effects are to be estimated. If none of the effects are significant, then the estimates will behave like a random sample drawn from a normal distribution with zero mean, and the plotted effects will lie approximately along a straight line. Those effects that do not plot on the line are significant factors. (Montgomery and Runger, 2004) In the normal probability plot of the effect, the x-axis represents the effects, and the y-axis represents the cumulative probabilities. The scale of y-axis is constructed in such a way that if the data points follow a normal distribution, the cumulative probabilities will plot as a straight line. For effects that are from a normal distribution with mean zero, the plot of the effects should approximate a straight line with the line passing through the point ($x=0,y=0.5$). Significant effects much different from 0 will fall away from this line. Effects that are unusually small or large and fail to follow the straight line pattern are judged to be significant. (Ledolter and Swersey, 2007)

For the 2^5 design in the operation, the number of estimated effects is $31\times(2^5-1)$. The procedure for plotting normal probability of the effect is the following. First, the 31 effects have been ordered from small to large. The smallest among the 31 effects represents a cumulative probability between 0 and 1/31 and is assigned a cumulative probability (y-value) at the midpoint of that interval. The second smallest among the 31 effects represents a cumulative probability between 1/31 between 2/31 and is assigned a y-value at the midpoint of that interval. The third smallest effect is assigned a cumulative probability at the midpoint of the interval 2/31 to 3/31, and so forth. In general, with *m* effects, the *i*th smallest effect is plotted at a cumulative probability of (*i*-0.5)/*m*. (Ledolter and Swersey, 2007)

The software Minitab was used to analyze the parameter effects on the slope and intercept of the simulation results. The scale on the cumulative probability (y-axis) in the normal probability of the effect, such as Figure 7, Figure 8, Figure 9 and Figure 10, is not linear. This is where the normal distribution comes into play.
In the normal probability plot of the effect, the insignificant effects and significant effects have been distinguished by fitting a straight line to the middle portion of the graph. The value of Lenth's pseudo standard error (*PSE*) (Lenth, 1989) is also added in normal probability plot in Minitab. The pseudo standard error (*PSE*) is defined as:

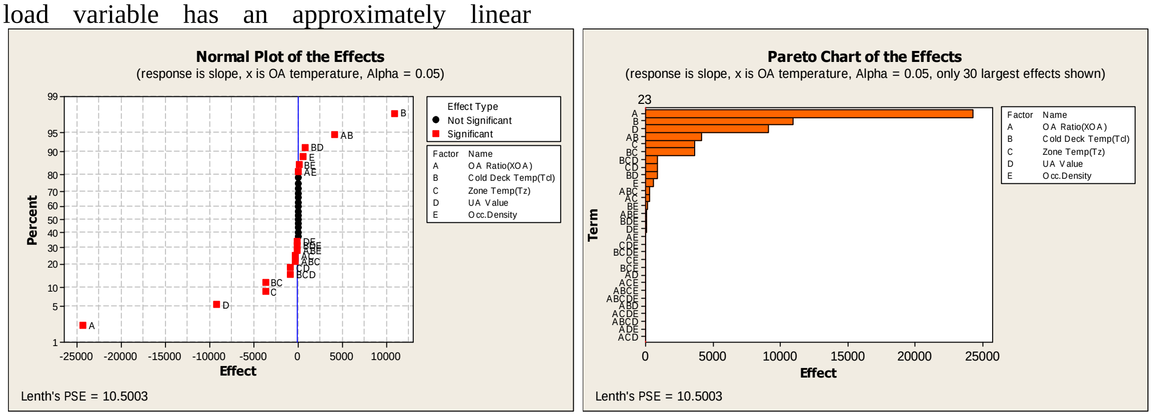
$$PSE = 1.5 \times median\ |m_i|$$

The Pareto chart is a special type of bar chart where the values being plotted are arranged in descending order. In Minitab, the line is drawn at the margin of error (*ME*) on the Pareto chart. The margin of error is defined as:

$$ME = t_{(\alpha/2,n)} \times PSE$$

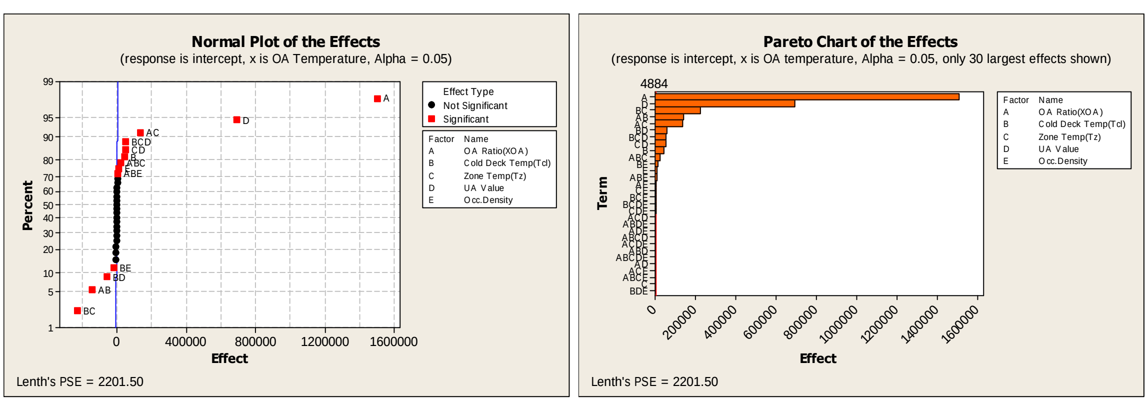
To analyze the parameter's effect on energy balance load, it is assumed the energy balance load variable has an approximately linear relationship either T_{OA} or h_{OA} according to the simplified air side model simulation results. Generally, the relationship can be expressed as: $y = k_1 x + k_2$

Figure 7and Figure 8 show the parameter effects on the E_{BL} when the T_{OA} is used in presenting the function. Figure 7 show the plot of the parameter effects on the slope (variable: k_1, (a): the normal probability plot; (b): the Pareto plot.) Those plots show that the outside air ratio and the UA values have the significant negative effect on the slope while the cold deck temperature has the significant positive effect on the slope. Other factors (zone temperature and occupant density) have fewer effects on the slope of the energy balance load. Figure 8 shows the plot of the parameter effects on the intercept (variable: k_2, (a): the normal probability plot; (b): the Pareto plot). The effects of factor A (OA ratio) and D (*UA* value) are far away from the normalized line. The plots indicate the OA ratio and UA value have the highest influences on the intercept of the assumed regression line.



(a) (b)

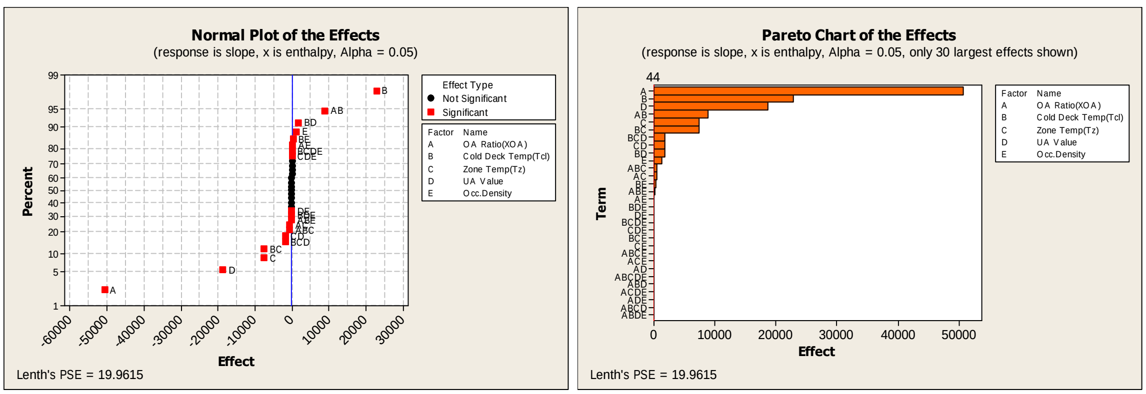
Figure 7 (a) Parameters effects on the slope (x-T_{OA}, Y-E_{BL}) and (b) Pareto chart of parameters effects on the slope (x-T_{OA}, y-E_{BL})



(a) (b)

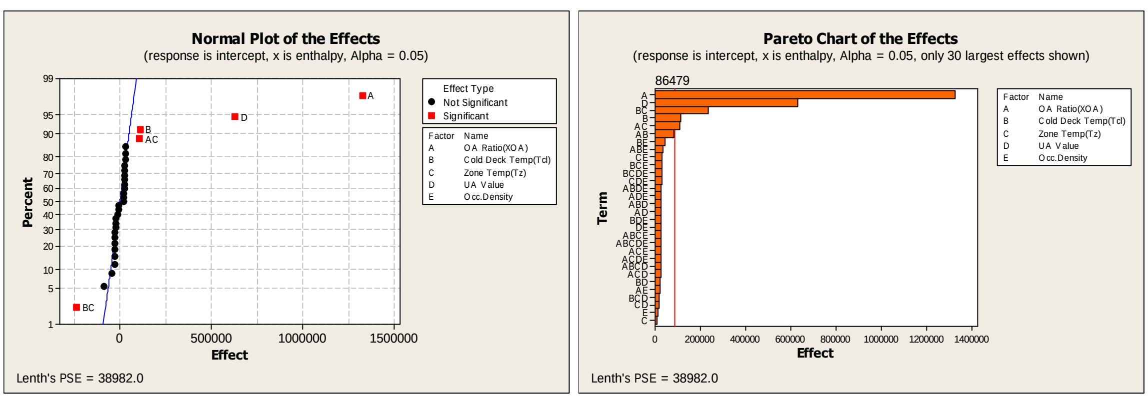
Figure 8(a) Parameters effects on the intercept (x-T_{OA}, y-E_{BL}) (b) Pareto chart of parameters effects on the intercept (x-T_{OA}, y-E_{BL})

Alternative analysis is using the h_{OA} instead of T_{OA} for analysis of parameters effects on energy balance load. Figure 9 shows the plot of the parameter effects on the slope (variable: k_1, (a): the normal probability plot; (b): the Pareto plot). Similar to the plots of parameter effects using T_{OA}, it is shows that the outside air ratio and UA value have the significant negative effect on the slope while the cold deck temperature has the significant positive effect on the slope. Other factors (zone temperature and occupant density) have fewer effects on the slope of the energy balance load. Additionally, the correlative items are distributed along the normalized line. It implies that the effects of the correlative items could be neglected in the engineering application. Figure 10 shows the plot of the parameter effects on the intercept (variable: k_2, (a): the normal probability plot; (b): the Pareto plot). It is obvious that the outside air ratio and the *UA* value have the significant positive effect on the intercept. It presents that more conclusive results of parameter effects would be drawn by using the enthalpy in analysis instead of T_{OA} based on the Figure 10, which shows that fewer items are marked having significant effects on the intercept of the energy balance load.



(a) (b)

Figure 9 (a) Parameters effects on the slope (x-h_{OA}, y-E_{BL}); (b) Pareto chart of parameters effects on the slope (x-h_{OA}, y-E_{BL})



(a) (b)

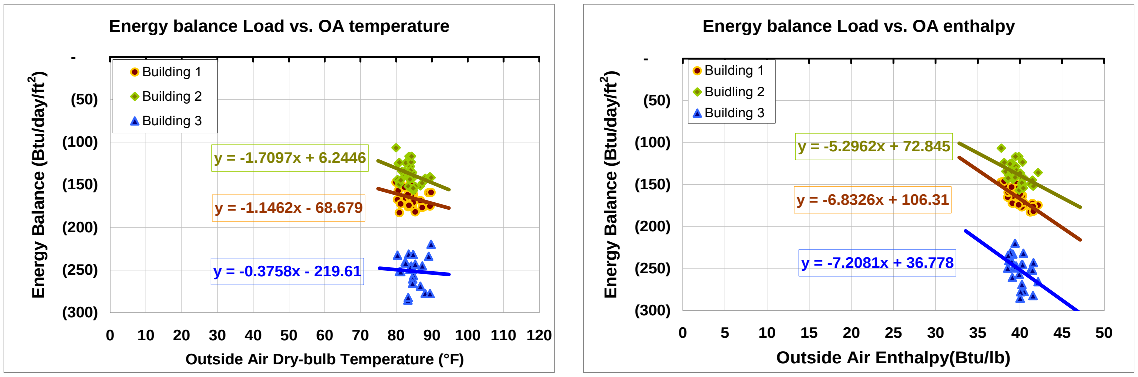
Figure 10 (a) Parameters effects on the intercept (x-h_{OA}, y-E_{BL}); (b) Pareto chart of parameters effects on the intercept (x-h_{OA}, y-E_{BL})

APPLICATION OF E_{BL} IN THE ENERGY DATA QUALITY ASSURANCE

The methodology of the E_{BL} have been applied to analyze the energy data to fulfill the quality assurance of utility bills (Baltazar *et al* , 2007). It is has been approved to be an effective data quality screening method for buildings having metering data for electricity, heating and cooling consumption. The methodology of the E_{BL} as a function of T_{OA} has the limitation in analysis of the summer data because of the high temperature and limited data range. Since the latent load in summer is larger than that in other seasons, and the latent load also varied with the buildings, it is difficult to analyze the energy data in one month in summer. Application of h_{OA} in presenting E_{BL}

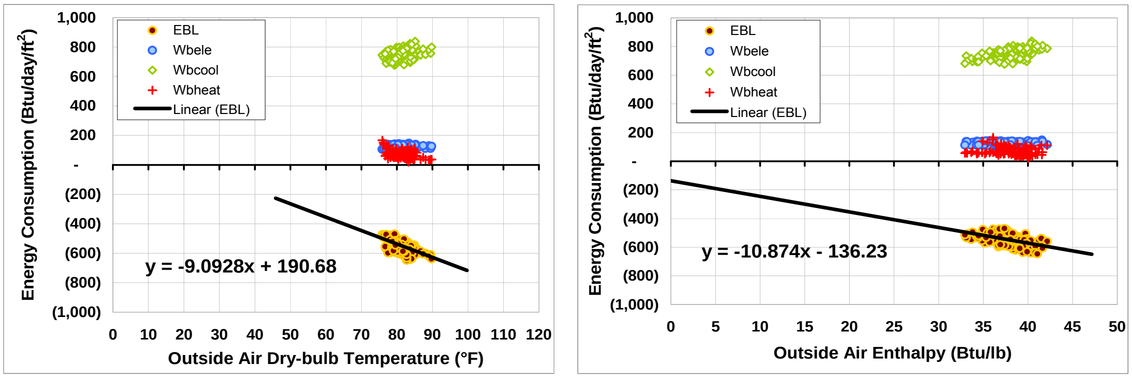
for summer data has the advantage in better representative patterns of building energy use than using the T_{OA}. Figure 11 shows the plot of E_{BL} for three buildings on campus during August 2007 (a: E_{BL} as a function of T_{OA} ; b E_{BL} as a function of h_{OA}). The cross point temperature in E_{BL} as function of T_{OA} has the large range from negative to positive value. It is very hard to use the slope and intercept to apply the methodology of the energy balance in the data quality assurance. With the application the h_{OA} in analysis of E_{BL}, the ranges of slope and intercept have been narrowed down. The equations to present the E_{BL} pattern have been generated in Figure 11 (a) and (b). It shows that the linearity of E_{BL} could be expressed better through h_{OA} in stead of T_{OA} in summer.

Figure 12 shows the energy use (ELE, CHW and HHW) and energy balance load for a office building during summer in College Station, TX ((a): the E_{BL} and energy consumptions as a function of the $T_{OA;}$ (b): the plot of E_{BL}, energy consumptions as a function of the h_{OA}). From the plot of Figure 12 (a), it is very hard to detect the failure in the consumption for the building since the data is drawn on a scale that may make the slope difficult to notice. Energy consumption trends are also correct. The bin data then was grouped to analyze the energy use for the building as shown in Figure 13. The linear model equation for the E_{BL} shown in Figure 13 (b) has the negative x-intercept. That means that the building balance condition is at very low enthalpy. It indicates that there are some errors in the energy consumption. After further check, it was found that the CHW flow meter has wrong readings.



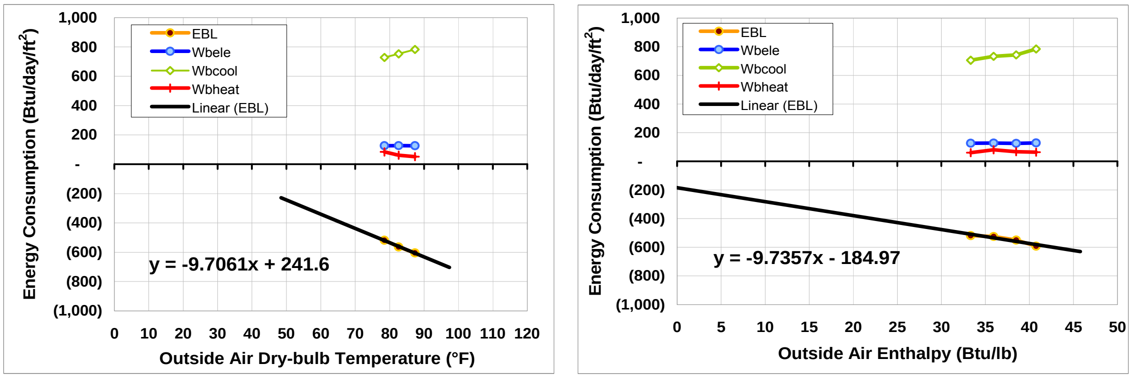
(a) (b)

Figure 11 (a) Plot of E_{BL} vs. T_{OA} and (b) Plot of E_{BL} vs. h_{OA} for three buildings during August 2007.



(a) (b)

Figure 12 (a) Plots of E_{BL}, energy use of ELE, CHW and HHW vs. OA temperature (b) Plots of E_{BL}, energy use of ELE, CHW and HHW vs. OA enthalpy for a building during summer using daily data



(a) (b)

Figure 13 (a) Plots of E_{BL}, energy use of ELE, CHW and HHW vs. OA temperature (b) Plots of E_{BL}, energy use of ELE, CHW and HHW vs. OA enthalpy for a building during summer using bin data

SUMMARY AND CONCLUSIONS

The further study for the methodology of the Energy balance load (E_{BL}) has been presented. The behaviors of the E_{BL} have been investigated by the analysis of the defined mathematical model of whole building energy balance. The simplified air side simulation has been conducted to study the patterns of E_{BL}. The actual measured energy use data has been applied to prove the conclusion of analytical study and simulation results. The factor effects analysis through the experimental design lead the conclusion of that the outside intake air volume and the *UA* value have the most negative effects on the slope of the E_{BL} pattern; while the cold deck temperature has the most significant positive effect on the slope of the E_{BL} pattern.

The behaviors E_{BL} have been studied using the variable of beside the T_{OA}. Analysis of E_{BL} as a function of h_{OA} have the advantage to present the energy data in high temperature since the latent load effect can be represented though the variable of enthalpy instead of the temperature. The E_{BL} has a better liner relationship to the h_{OA} than the T_{OA}. Using enthalpy in E_{BL} analysis for energy use data provided a beneficial approach to analyze the energy data in summer. The application of the E_{BL} as the function of h_{OA} to analyze the summer data for actual buildings has been presented. An example of the methodology of enthalpy for E_{BL} analysis applied to detect the failure of metering data of energy consumption has been also illustrated.

REFERECE

Baltazar, J. C., Sakurai,Y., Masuda, H., Feinauer, D., Liu, J., Ji, J., Claridge, D.E., Deng, S., & Bruner, H. (2007). Experiences on the Implementation of the "Energy Balance" Methodology as a Data Quality Control Tool: Application to the Building Energy Consumption of Large University Campus, *7th International Conference for Enhanced Building Operations*, Nov. 1-2, 2007 San Francisco, California

Ledolter, J., & Swersey, A.J. (2007). Test 1-2-3: Experimental Design with Applications in Marketing and Service Operations, *Stanford Business Books*, Stanford, California

Lenth, R.V., (1989), Quick and Easy Analysis of Unreplicated Factorials, *Technometrics*, Vol. 31 No.4, 469-473

Minitab Inc. (2007), Minitab 15 Manual. Retrieved November 28, 2007, from http://www.minitab.com/products/minitab/documentation.aspx

Montgomery, D.C. and George C.R (2004). Applied Statistics and probability for Engineers, 4th Edition, *John Wiley* & Sons, Inc.

Shao, X., (2005). First Law Energy Balance as a Data Screening Tool, *M.S. Thesis*, Mechanical Engineering Department, Texas A&M University, College Station, TX, May.

Shao, X. and Claridge, D.E., (2006). Use of First Law Energy Balance as a Screening Tool for Building Energy Data, Part I – Methodology, *ASHRAE Transactions - Research*, Vol. 112, Part 2, QC-06-068.