EXPERIENCES ON THE IMPLEMENTATION OF THE "ENERGY BALANCE" METHODOLOGY AS A DATA QUALITY CONTROL TOOL: APPLICATION TO THE BUILDING ENERGY CONSUMPTION OF A LARGE UNIVERSITY CAMPUS

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ABSTRACT

As the energy costs have been increasing and more energy efficient measures have been promoted in the buildings sector, the reliability of energy consumption data has been attracting significant attention. For example, the reliability of the determination of energy savings depends on that of the energy consumption data, which has to be verified before and after any efficiency measure is applied. From other perspective, verifying energy use data on a regular basis would allow the engineers to identify and assess commissioning opportunities confidently.

This paper presents the application of an innovative data screening methodology as a data quality control tool for energy consumption data. The methodology has been applied to a large university campus where the monthly energy consumption, of approximately 100 buildings, must be verified. One of the main responsibilities of the Energy Management Office of the university is to provide monthly utility consumption and cost information to accounting for utility billing of individual buildings.

The methodology, which is based on the first law of thermodynamics, or energy conservation, has proved to be an effective data quality screening method for verification of metering sensors when heating, cooling and electricity consumption are separately metered in a building. The methodology is anticipated to be suitable for automated application. In some cases, the methodology could also help to rehabilitate energy use data.

BACKGROUND

The challenge of data reliability has recently attracted significant attention, particularity related to the need to accurately determine energy use savings (ASHRAE 2005). ASHRAE Guideline 14-2002, which has defined acceptable approaches for the accurate determination of energy savings, bases its criteria on the amount and quality of the data available (ASHRAE 2002).

Of all the measured energy use data, the least reliable is that related to the Btu metering. The measurement errors here are often compounded by scale factor errors or other software miscalculations. These errors are not easy to detect because the energy use depends on many factors, such as the ambient conditions and occupancy, and the determination of their influence in a suitable and quick way is not readily available. Therefore, the opportunity to find mechanisms to automatically detect and correct these errors could be very valuable. An innovative technique based on the first law of energy in conjunction with the concepts of analytical redundancy, has been proposed, tested and suggested as a data screening tool that eventually could lead to the automatic detection and correction of measured data (Shao and Claridge, 2006). This technique is applicable when heating, cooling and electricity consumption are separately metered in a building.

This paper illustrates the application of the new data screening technique to identify specific types of data faults, and presents the first interpretation to the analysis of energy consumption data of approximately 100 buildings on the Texas A&M University main campus. This analysis of the results from the application of the "Energy Balance" methodology will serve to help determine the rules required to automate the process.

'ENERGY BALANCE' PARAMETER: GENERAL FORMULATION

The general derivation of the "Energy Balance" screening methodology comes from the first law of thermodynamics. The process is modeled as a semi-empirical methodology based on analytic redundancy (Shao and Claridge, 2006) applied to the whole building energy consumption data. For a whole-building thermodynamic model, the heat flow rates and the rates of enthalpy flow across the boundary of its control volume and the rates of work performed on the building may be broken into its major components. The energy balance equation for a building in a lumped form can be expressed as:

$$\frac{d}{dt}\overline{E} = \overline{Q}vent + \overline{Q}solar + \overline{Q}cond + \overline{Q}occ + \overline{W}bheat - \overline{W}bcool + f\overline{W}bele \qquad (1)$$

Where *E*, is the thermal energy storage in the building; *Wbele* is the whole building electricity use for lighting and equipment (non HVAC electric use); *Wbcool* is the whole building Chilled Water consumed to remove heat from the building; and Heating Hot Water required to provide heat in the building is represented by the term *Wbheat*; *Qsolar* is the solar radiation through the envelope; *Qvent* is the ventilation air and infiltration via doors, windows, or air-handling units; *Qcond* is the heat transmission through the building structure; and *Qocc* is the heat gain from occupants. The factor *f* is the portion of electricity that is converted to heat and appears as load within the building, e.g., by lighting –electricity →light →heat– and by plug loads –electricity → offices-classrooms-laboratories equipment →heat–, there may be a time delay in this term relative to the actual time when the electricity is used. This equation is intended to capture the salient features of the building energy consumption without the complexity of the details such as the spatial variations of the temperatures inside and outside the building. Therefore, if the analysis is made on the basis of a period greater than a day the equation can be considered quasi-steady. If it is arranged in a practical way, with the parameters that are typically metered and monitored in buildings, the equation could be represented as

$$EB_L = \overline{W}bheat - \overline{W}bcool + f\overline{W}bele = -(\overline{Q}vent + \overline{Q}solar + \overline{Q}cond + \overline{Q}occ) \qquad (2)$$

In this equation, the denominated "Energy Balance" (EB_L) term, represents a relationship between the metered parameters in the energy analysis. Shao and Claridge (2006) have proved that the EB_L parameter is independent of the type of air handling unit that is used in the building HVAC system. A typical parametric representation of the EB_L parameter as a function of the outside temperature follows a predominant line behavior, as shown in Figure 1. A more detailed parametric study of this parameter can be found in Shao (2004). The values of the EB_L parameter are influenced by uncertainties of the instruments used for measurement of the energy consumption and the incomplete model used for its formulation.

QUALITY CONTROL METHODOLOGY

Knowing the pattern followed of the Energy Balance parameter as a function of the outside air temperature, it is possible to assemble a procedure to verify if the energy use data in a building is correct, provided that the electricity, chilled water and heating hot water are measured.

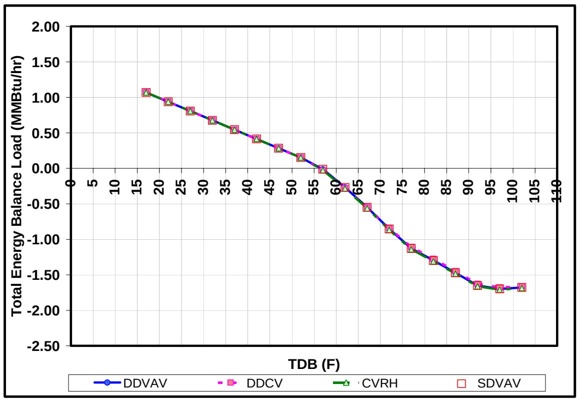

Figure 1 Energy Balance (EB_L) parameter as a function of the outside air temperature for different types of HVAC systems.

The general steps for this quality control can be enumerated as follows (See Figure 3).

1) Gather all the metered energy data, Non-HVAC electricity, chilled water, and heating hot water for the period of time that the data will be analyzed. In general, for a comprehensive analysis the typical period should be a year, but the analysis can be performed for monthly periods with the respective limitation of range in the ambient temperature and specific operational control conditions. The data can be analyzed as it is collected, depending on the interval over which the data is recorded, typically on an hourly basis. However, because of the simplified modeling used in the EB_L formulation, and to avoid any problems due to the delayed thermal response of the loads distribution, the most useful interval for analyzing the data is on daily basis.

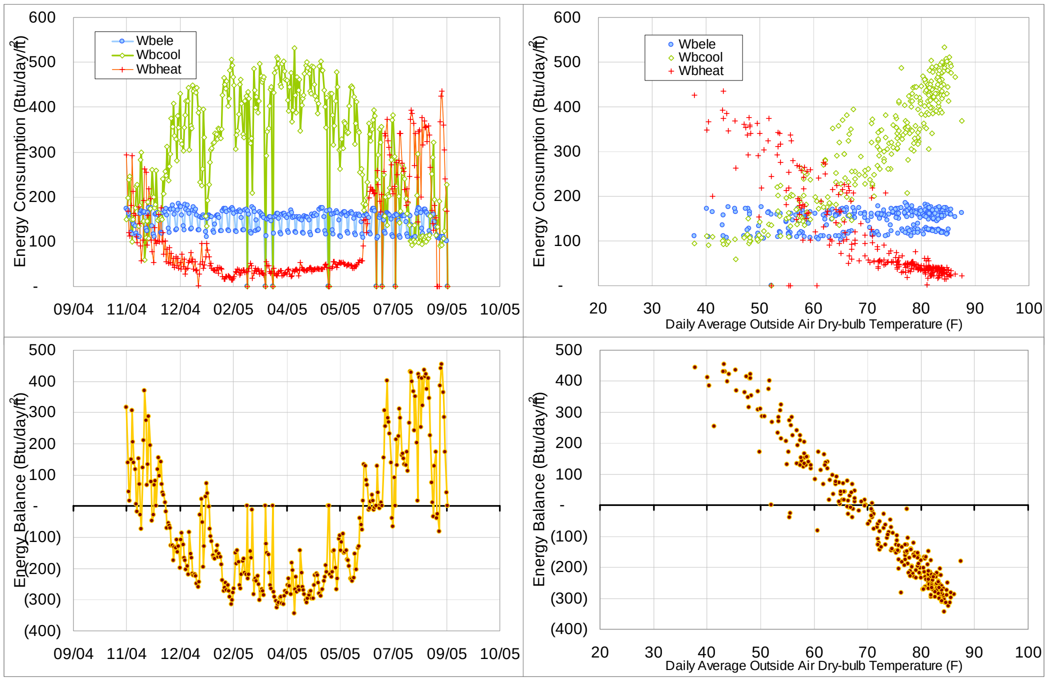

Figure 2 Typical 'Energy Balance' carpet plot for data screening

2) The Energy Balance (EB_L) parameter is evaluated and plotted as a function of the ambient temperature. The Figure 2 shows a data screening carpet plot, which includes a typical EB_L plot as a function of ambient temperature, the corresponding time series plot of each of the three series of energy use data, and a plot with their respective patterns as a function of the outside temperature. This carpet plot has been found to be a better data screening tool for visual analysis than if the contained plots are analyzed individually. The units for this plot are normalized to the total conditioned area to simplify cross comparisons among the same type buildings and presented in thermal units (Btu/day/ft^2).

If a whole year of Energy Balance values are positive for a building in a hot climate, the building heating data that has been recorded is too high or the cooling data is too low. Inversely, if the entire data-pattern for the EBL plot is negative, the building cooling values are too high or the heating and/or non-HVAC electric consumption values are too low. These observations can be used to detect systematic problems in the energy consumption data that is being collected.

3) An essential part of any screening process is the detection and quantification of missing data. Depending on quantity of missing data, a specific procedure for filling data can be followed (Baltazar and Claridge, 2002).

Although the quality control procedure has been explained only to detect problems in an energy consumption data set, the same procedure may be used to rehabilitate some of the energy use data sets for specific conditions.

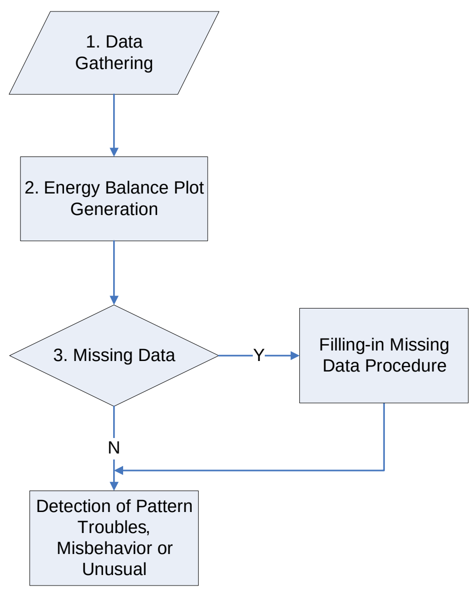

Figure 3 Block Diagram of the Quality Control Process.

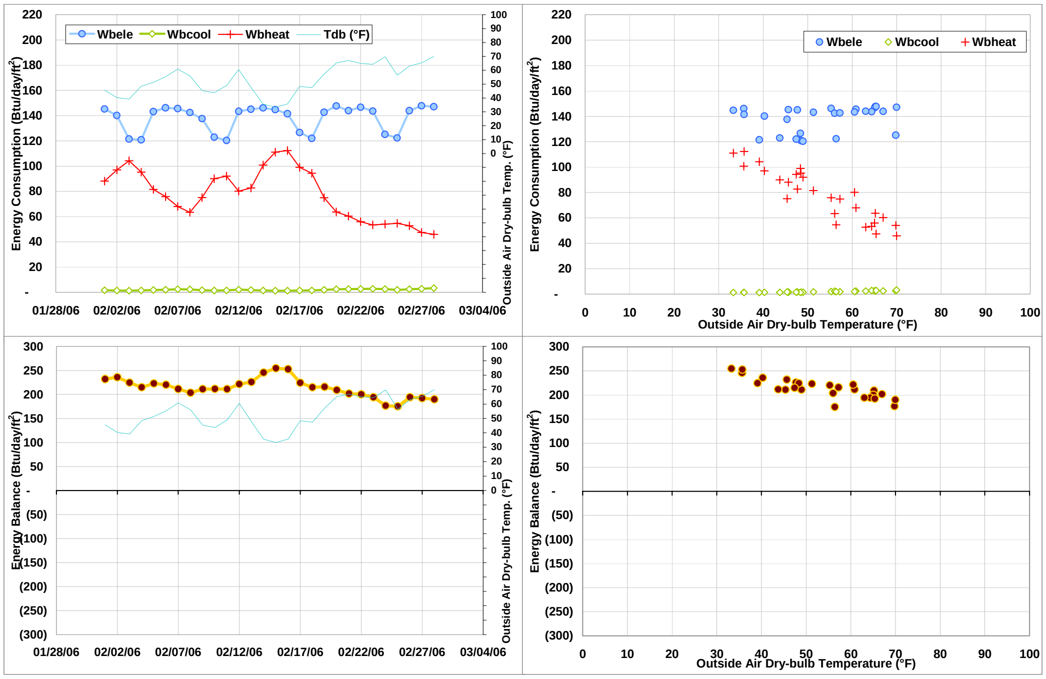

Figure 4 The ‘Energy Balance’ carpet plot for February 2006 for the Zachry Engineering Center on the Texas A&M University Campus illustrates the impact of improperly scaled chilled water consumption data.

RESULTS: TYPICAL CASES

Application of this quality control methodology to the recorded energy consumption data of approximately 100 buildings on the Texas A&M University main campus has shown several different error types.

Two of the more common problems that have been detected are errors in the scale of the recorded data, and errors due to the apparent malfunction of the sensors. The errors related to scale factors are typically due to errors in the database processing or in the factors that are set in the data loggers. On the other hand, sensor malfunctioning is a more difficult error to detect. In this case, the Energy Balance method shows more of its potential for quality control. As noted previously, the Energy Balance methodology may also be use to rehabilitate some erroneous data, or at least to some extent ensure that any corrected or filled gaps in data sets are within an expected range.

Case I: Scale Factor Correction.

Figure 4**Error! Reference source not found.** shows the energy balance plot for the Zachry Engineering Center building for February 2006. In this plot, it is observed that the chilled water consumption data has a problem –the ‘Energy Balance’ parameter data is all highly positive, indicating that the chilled water data values are too small. In addition, it is evident that the chilled water pattern has a problem. The ‘Energy Balance’ methodology can help to rehabilitate the chilled water consumption data, as the EB_L data pattern is well defined and is quite linear as expected. Further examination shows that the chilled water data needs to be scaled. A simple trial-and-error procedure leads to a factor of 60. The ‘Energy Balance’ plot after applying a scaling factor of 60 to the chilled water shows that the energy balance typical pattern (see Figure 5) now presents typical behavior. A subsequent investigation of the chilled water metering found that the hardware was working perfectly and that the error in the recorded consumption came from a missing conversion factor of 60 in the database processing software.

Case II: Meter Incorrectly Labeled

Figure 7 shows the energy balance carpet plot for the Texas Veterinary Medical Diagnostic Laboratory building. The building has six meters: two for Wbele, two for Wbcool, and two more for Wbheat. The meters are separated in two sets; one for the upper part of the building and other for the lower part of the building. From the plot, it is observed that the time series plots show some abrupt changes and the temperature dependent plots show a lot of scatter with the hot water data possibly showing multiple patterns, so there is a problem in one of the data streams. Analyzing the upper-right hand plot, in

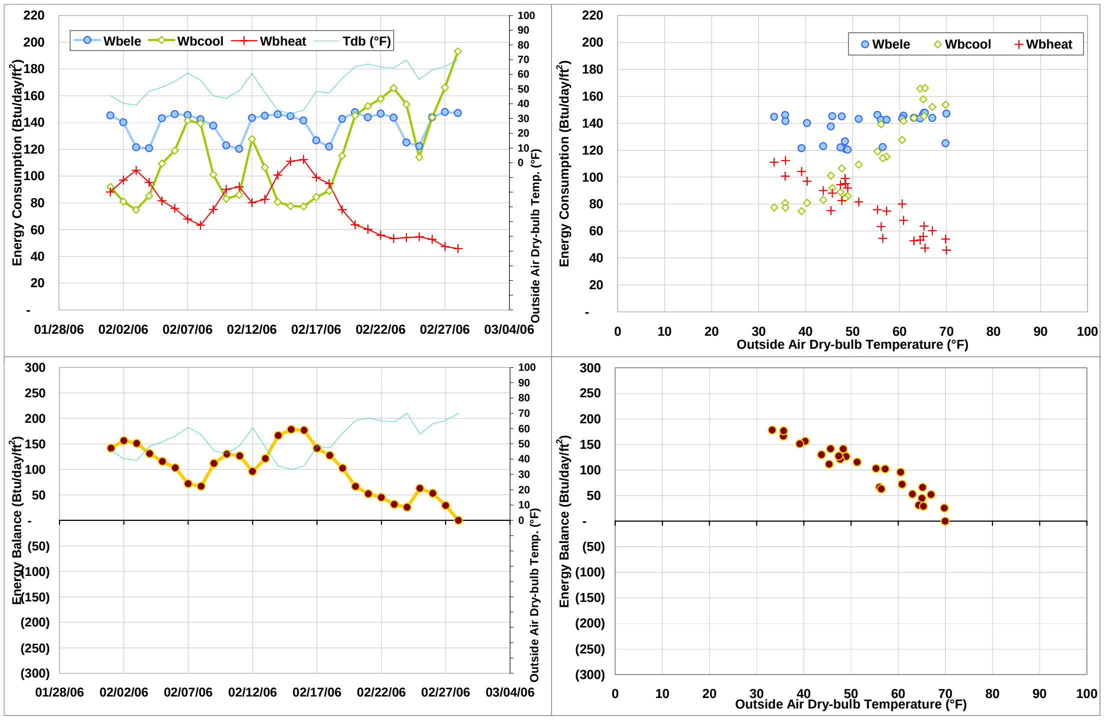

Figure 5 'Energy Balance' carpet plot with the chilled water consumption for the Zachry Engineering Center multiplied by 60.

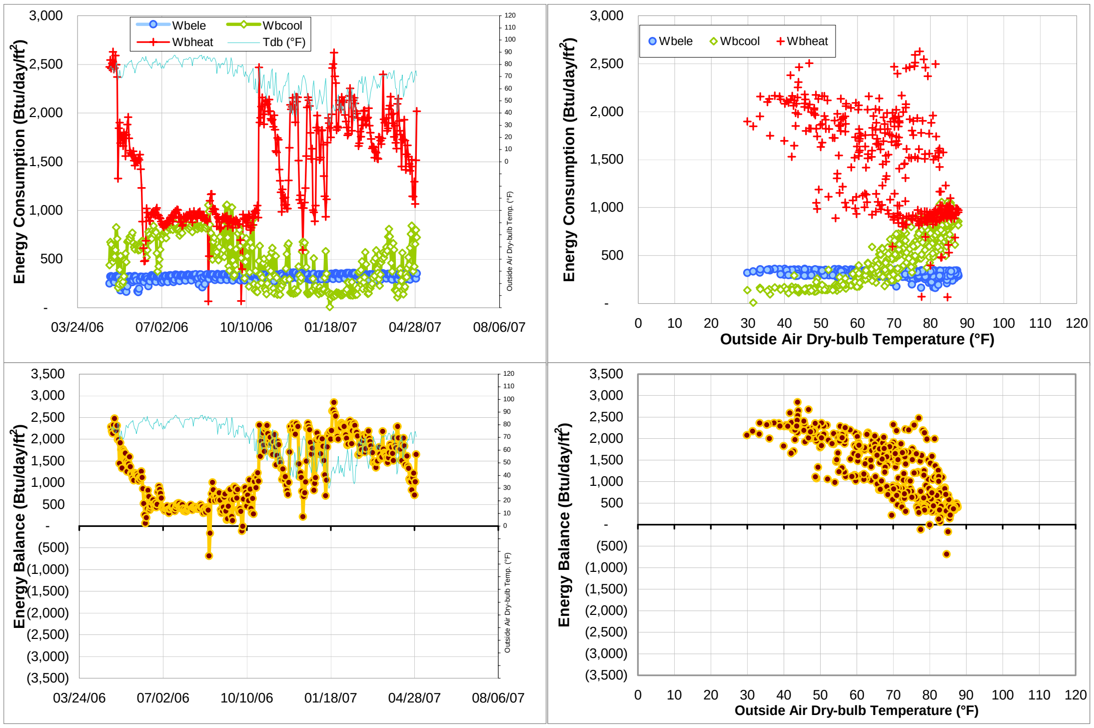

Figure 6 'Energy Balance" carpet plot for the Texas Veterinary Medical Diagnostic Laboratory from 5/1/2006-4/30/2007.

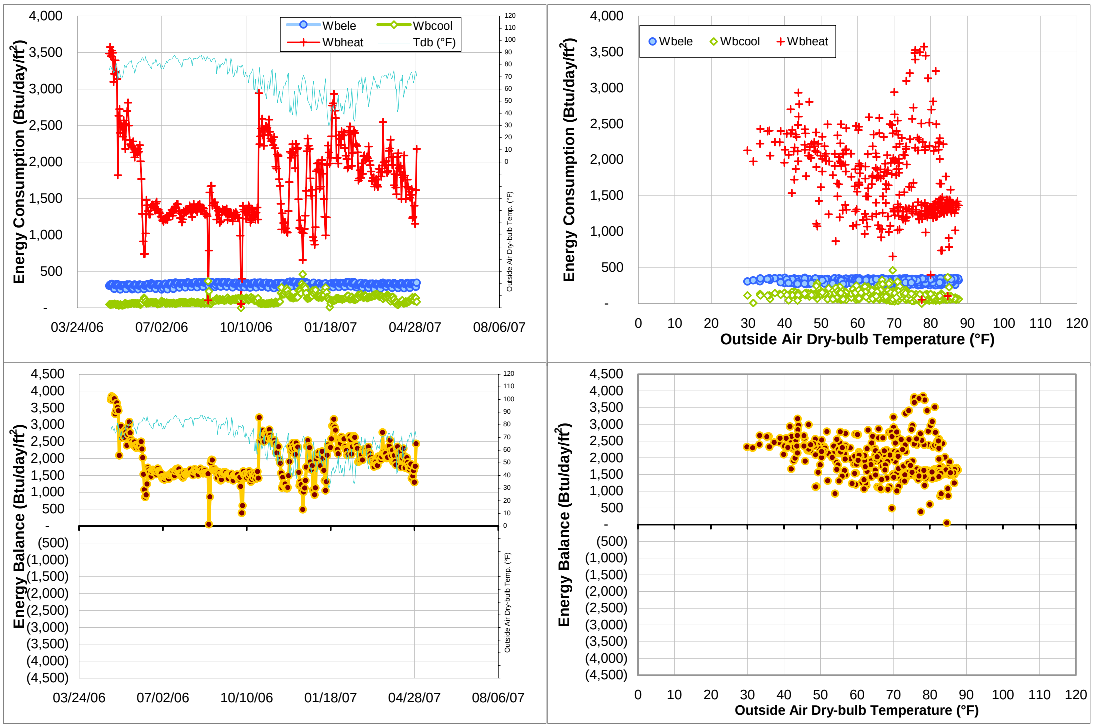

Figure 7 ‘Energy Balance” carpet plot for the first set of meters (Set 1) of the Texas Veterinary Medical Diagnostic Laboratory from 5/1/2006-4/30/2007.

Figure 6, it may be observed that the heating hot water plot has an unusual pattern. Separating the corresponding meters for the upper and lower parts of the building and creating an EB_L plot for each one (see Figure 7 and Figure 8) shows that the “Set 1” meters have a problem. In Figure 7, the EB_L plot is always positive and relatively flat – or with low dependence on outside temperature– which is an indication of errors in the data, It may be observed that the chilled water consumption is always lower than the electric consumption and the heating hot water consumption over a wide range of temperatures. Clearly there is a problem in the chilled water values. The hot water pattern is both very high and rather scattered with multiple patterns within the overall pattern suggesting that these values are in error as well. The EB_L pattern in Figure 8 for the Set 2 meters presents a much more typical pattern, although the heating hot water pattern is a little spread.

A further check on the flow rates for CHW and HHW, in Figure 9, shows that the HHW flow is almost constant for the whole year while the difference between the CHW supply and return temperatures is largest during the winter. Therefore, it is clearly that the CHW and HHW flow rates have been mislabeled and incorrectly interchanged. After this detailed review, the maintenance department checked, and confirmed that the flow channel for chilled water had been switched with the hot water flow channel. Figure 10 presents the EB_L carpet plot for the Set 1 meters after correction and Figure 11 is the integrated whole building EB_L carpet plot after correction was made. The EB_L plot shows a typical behavior and corroborates that the changes made were suitable.

Both of the previous explained cases presented in this paper show that the Energy Balance methodology can be a very helpful tool in diagnosis of faulty metering, and illustrates its use for data analysis and data rehabilitation. More specific cases will be presented in a subsequent paper where the potential of the methodology will be expanded.

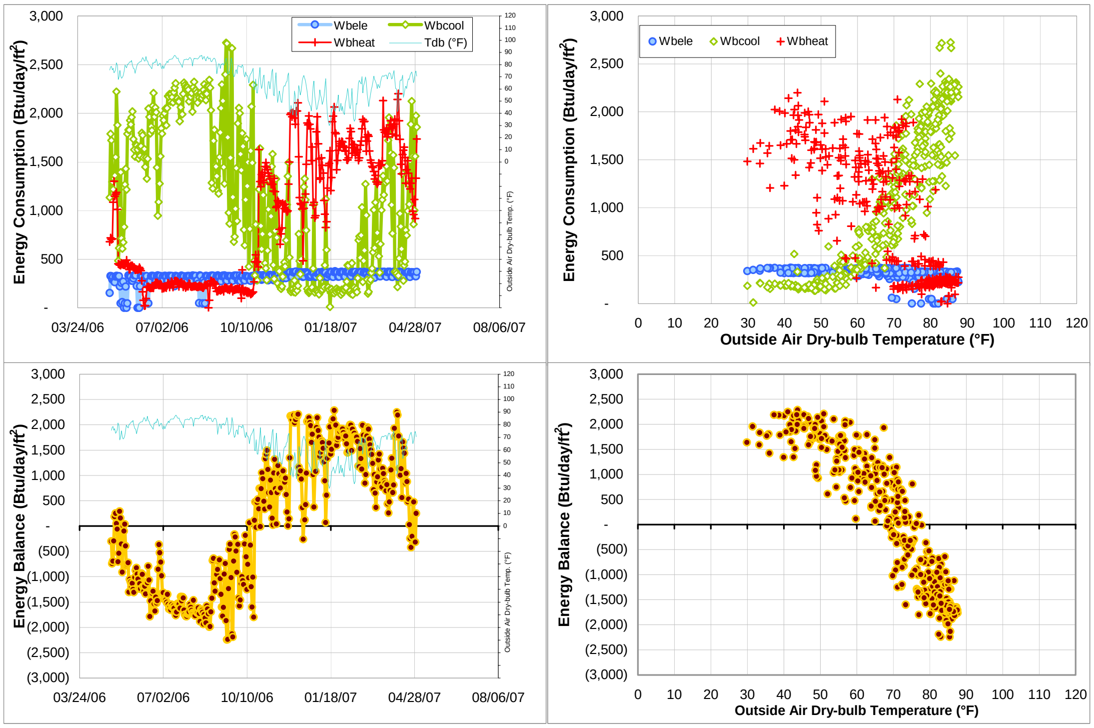

Figure 8 'Energy Balance" carpet plot for the second set of meters (Set 2) of Texas Veterinary Medical Diagnostic Laboratory from 5/1/2006-4/30/2007.

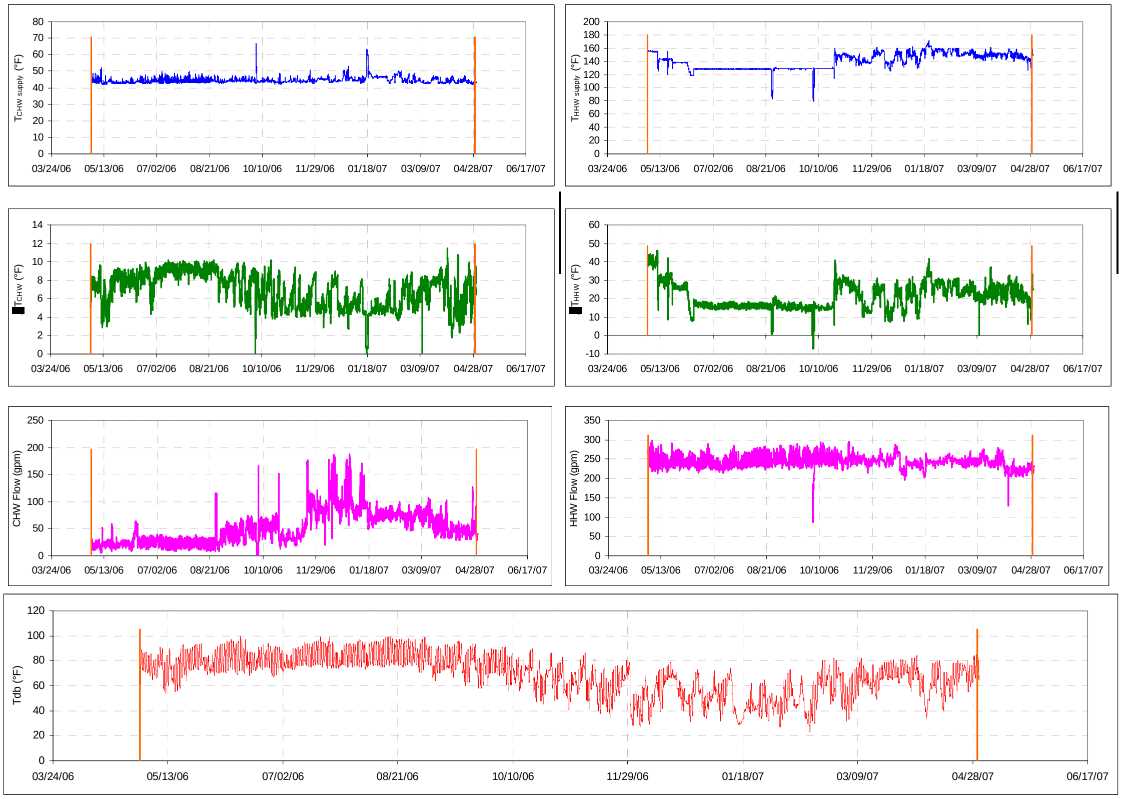

Figure 9 Time series plot for supply temperature, supply and return temperature difference and flow rate of CHW and HHW of the Set 1 meters at the Texas Veterinary Medical Diagnostic Laboratory from 5/1/2006-4/30/2007.

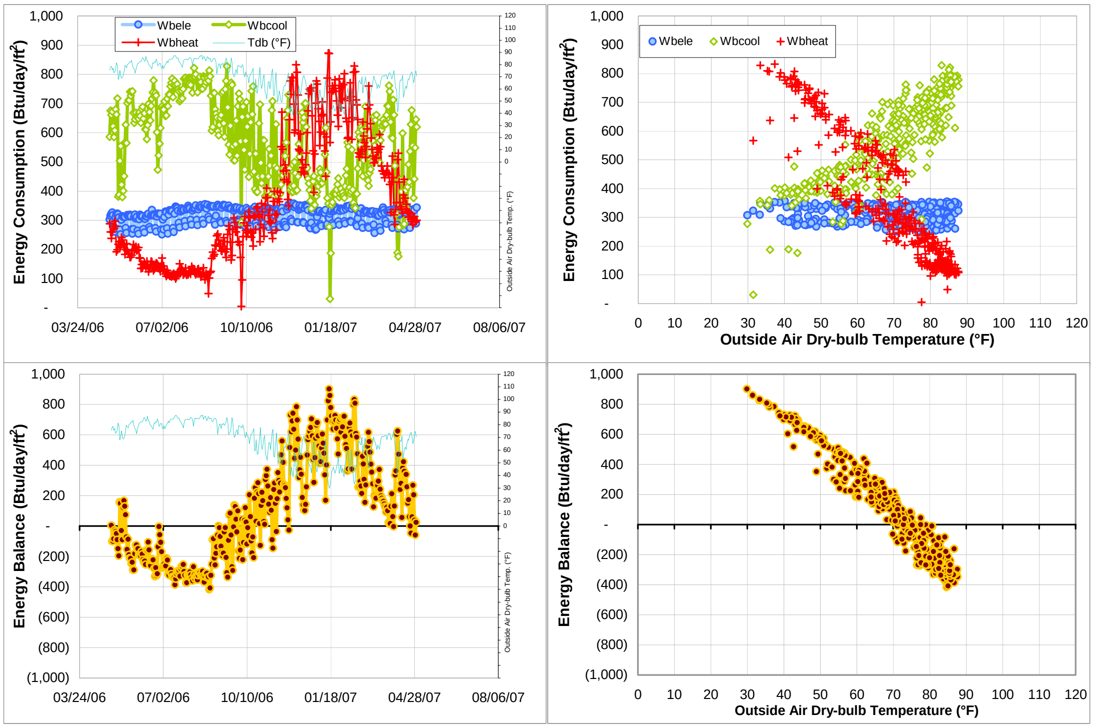

Figure 10 'Energy Balance" carpet plot for the first set of meters of Texas Veterinary Medical Diagnostic Laboratory from 5/1/2006-4/30/2007 with flow rate meter corrected.

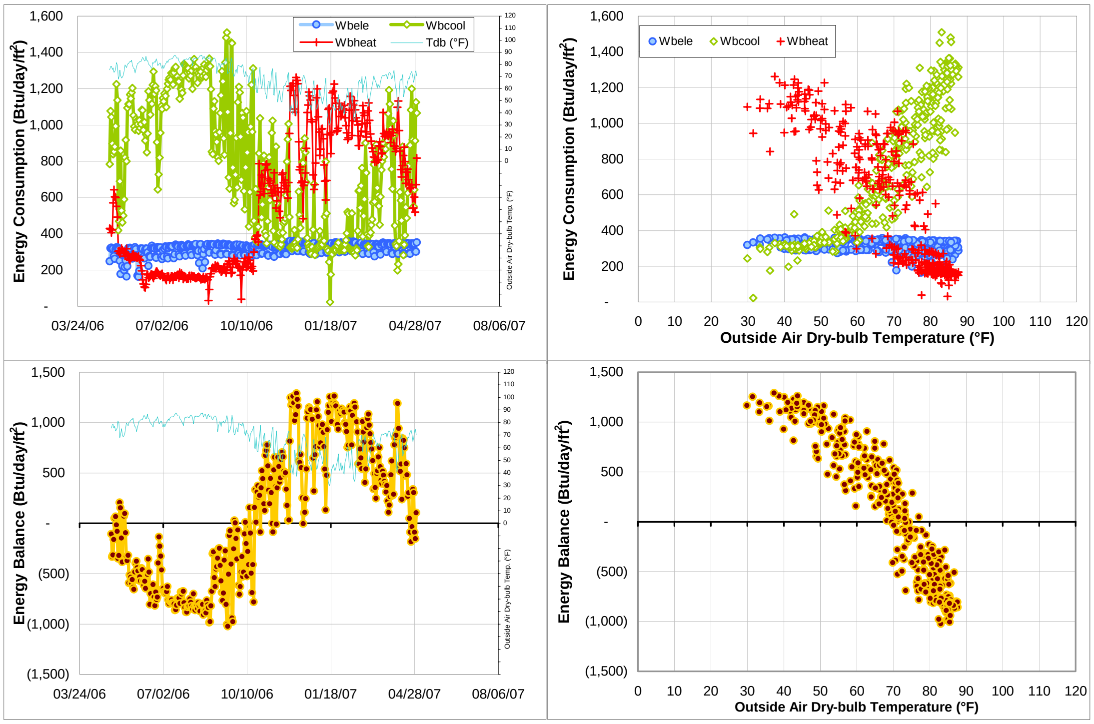

Figure 11 'Energy Balance" carpet plot for the second set of meters (Set 2) Texas Veterinary Medical Diagnostic Laboratory from 5/1/2006-4/30/2007 with flow values corrected.

CONCLUSIONS

The application of an innovative methodology for diagnosis and rehabilitation of energy use data has been presented. The methodology as implemented in this paper uses daily measured energy use – electricity, chilled water and hot water– and daily average ambient temperature. The quality control methodology using the 'Energy Balance' parameter has been used to verify monthly energy consumption and to detect anomalies in consumption patterns in energy consumption data for approximately 100 building on the Texas A&M University campus. The methodology has proved to be a versatile tool and it is planned to automate the process in the future

The most common errors found in the data consumption were those related to scale factors and malfunctioning of the hardware. Two cases have been shown to illustrate the ways to approach these problems through the "Energy Balance' methodology.

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