

THE BENEFITS OF 8760 HOUR-BY-HOUR BUILDING ENERGY ANALYSIS



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Introduction

As energy costs rise, building owners are becoming increasingly interested in operating costs and energy efficiency. As a result, building energy analysis (BEA) is becoming an important tool in the HVAC design field. Currently many BEA tools are available to engineers. Most are in the form of computer programs and employ a variety of methods with different benefits. Among these, BEA tools such as Carrier's HAP program that use the 8760 hour-by-hour method can offer the greatest benefits because they yield highly accurate, sophisticated system comparisons. This article will discuss the benefits of 8760 hour building energy analysis by first explaining the basics of building energy analysis and the requirements for high quality BEA system comparisons. Then, major BEA methods will be evaluated with special emphasis on the benefits of 8760 hour-by-hour versus reduced hour-by-hour methods.

What Is Building Energy Analysis?

Building energy analysis is the technique of estimating energy use and operating costs for a building and its energy consuming systems. In our industry, particular emphasis is placed on the energy use of a building's HVAC systems. The purpose of BEA is to compare the energy use and operating costs of alternate system designs in order to choose the optimal design. The analysis mathematically simulates the thermal performance of the building to determine cooling and heating loads. It then mathematically simulates the performance of HVAC equipment in response to these loads to determine energy use over the course of a year. Finally, energy data is used to calculate operating costs.

Requirements For High Quality Results.

Successful building energy analysis relies on considering as many of the physical factors influencing building loads and equipment performance as possible. The ultimate result of the analysis is a predicted operating cost. An accurate cost prediction relies on energy use data, which in turn relies on equipment simulations, which must be based on building load predictions, all of which must be accurate.

Concisely stated, high quality results can be obtained when the analysis considers:

1. **The Range and Timing of Weather Conditions.** Varying levels of temperature, humidity and solar radiation during the year influence building loads and equipment performance. In each geographical location conditions range from hot to cold, wet to dry and sunny to cloudy in different ways. Considering the actual ranges of these conditions and when they occur on a daily, monthly and yearly basis is crucial to producing accurate energy use results.
2. **The Hourly and Daily Variation in Internal Loads.** Patterns of building use involving occupancy, lighting and equipment operation can change significantly from one day to the next. Considering these use patterns in their correct day-to-day sequence is important in generating accurate load data.
3. **The Dynamic Nature of Building Heat Transfer.** The process of converting heat gains and losses to cooling and heating loads is a transient rather than a steady-state process. Heat gains occurring during one hour often affect loads over a number of succeeding hours. Consequently, it is important to consider accurate sequences of heat gains occurring during the day. In addition, because weather conditions and building use profiles vary from day to day, sequences of heat gains can affect loads from one day to the next.
4. **The Response and Performance of HVAC Equipment.** How controls, systems and equipment respond to demands for cooling and heating in a building, and the factors that affect part-load performance of the equipment must be considered to yield accurate equipment energy use data.
5. **The Details Of How Utilities Charge For Energy Use.** Often prices for energy vary by season and time of day. Further, charges are often made for peak energy usage. As a result, the analysis must not only be able to produce accurate estimates of how much energy is used, but must also accurately determine when during the day energy is used.

Evaluation of BEA Methods

A wide variety of building energy analysis methods are currently available to HVAC engineers and range from simple to sophisticated. The simplest methods involve the largest number of simplifying assumptions and therefore tend to be the least accurate. The most sophisticated methods involve the fewest assumptions and thus can provide the most accurate results. Generally, BEA methods are divided into three categories:

- a) Single Measure Methods (example: Equivalent Full Load Hours)
- b) Simplified Multiple Measure Methods (example: Bin Method)
- c) Detailed Multiple Measure Method (example: Hour by Hour)

While methods in the first two categories serve a useful role in providing quick, preliminary energy estimates, the simplifications they involve impair their accuracy. Each will be briefly discussed below. The main focus of the following discussions, however, will be the different hour by hour methods contained in the third category.

Single Measure Methods

These methods involve one calculation of annual or seasonal energy use. The Degree-Day Method, for example, computes energy use by combining one degree-day weather value with a load value and an efficiency value to obtain seasonal or annual energy use. Similarly, the Equivalent Full Load Hour Method combines full load capacity, full load efficiency and equivalent full load hours to obtain annual energy use. In both cases, this level of simplicity is achieved by using such sweeping assumptions that the accuracy and reliability of these methods are very limited.

Simplified Multiple Measure Methods

These methods involve calculations of energy use at several different conditions. With the Bin Method, for example, energy use is computed at a series of outdoor air dry-bulb conditions. Results are then weighted according to the number of hours each dry-bulb condition is

expected to occur to determine annual energy use.

For example, the temperature 47 F would be used to represent the range of conditions between 45 F and 50 F, referred to as a "bin". Building loads and equipment energy use would first be calculated for the 47 F bin. Next, energy results would be multiplied the number of hours per year temperatures are expected to occur between 45 F and 50 F to determine annual energy use for that bin. Similar calculations would then be repeated for all other temperature bins for the local climate and would be summed to determine overall annual energy use.

While the Bin Method provides a vast improvement in sophistication over single measure methods, it has a fatal flaw. This flaw is that it must decouple weather conditions, loads and system operation from time. For example, hours in the 47 F bin, when the outdoor dry-bulb is between 45 F and 50 F, occur at a variety of times of day and night, days of the week and months of the year. Because a single calculation is performed to represent energy use for all these different times it is difficult or even impossible to accurately:

- a) Link solar radiation and humidity conditions to the bin.
- b) Consider hourly and daily variations in internal loads.
- c) Consider the transient hour to hour and day to day thermal performance of the building.
- d) Predict time-of-day energy use and peak demands.

Inevitably averaging assumptions must be made to shoehorn all these considerations into the framework of the bin analysis. And these assumptions impair accuracy. While the Bin Method is useful for simple, preliminary estimates of energy use and operating cost, it cannot provide the level of accuracy and sophistication offered by the detailed multiple measure methods.

Detailed Multiple Measure Methods

These methods perform energy calculations on an hour-by-hour basis. As a result, they have the potential to satisfy all the requirements listed earlier for high quality energy analysis results. There is, however, a certain amount of variation

among different detailed multiple measure methods, leading some methods to meet the accuracy requirements better than others. Within the detailed multiple measure category are two major sub-categories worth discussing:

- a) The Reduced Hour-By-Hour Method
- b) The 8760 Hour-By-Hour Method.

Reduced Hour-By-Hour Method: How & Why?

This method typically uses one 24-hour profile of average weather conditions per month. Energy simulations are performed for this average profile and results are then multiplied by the number of days in the month to obtain monthly energy totals. Upon this basic foundation, different reduced hour-by-hour methods make various improvements to enhance the accuracy of results:

- a) Some methods analyze building operation for a typical Weekday, Saturday and Sunday each month since building use profiles differ significantly between these days. One average weather profile is still used for all three typical day simulations each month.
- b) Some methods also analyze equipment operation for a hot and cold day each month in an attempt to improve estimates of peak electrical demand.
- c) Some methods simulate building operation for one 7-day week each month to try to account for day-to-day building dynamics. However, a one average weather profile is still used for all 7 days of the simulation.

The fundamental principle of this method is that building and equipment performance on hotter and colder than normal days each month averages out so that monthly energy use can be accurately predicted by simulating a small group of days using average weather conditions. The method offers the benefits of reduced calculation time and more moderate demands on computer memory and hard disk storage space.

8760 Hour-By-Hour Method: How and Why?

This method simulates building and equipment performance for all 8,760 hours in the year using

the proper sequence of days and actual weather data. No weighting of results or simplifications are necessary.

The fundamental principle is that the way to produce the most accurate energy and operating cost estimates is to mimic the real-time operating experience of a building over the course of a year. All the requirements listed earlier for high quality energy analysis results can be met with this approach. The actual weather data accounts for the range and timing of weather conditions in great detail. Further, the hourly and daily variation of building occupancy, lighting and equipment use can be easily accounted for. In addition, the full year simulation tracks the dynamic hour-to-hour and day-to-day thermal behavior of the building, and the response of HVAC equipment to this behavior. The ultimate result is high-quality data that can be utilized to produce accurate, detailed data about the quantity and timing of energy use. Both are requirements for accurate operating cost estimates.

Comparison of Reduced and 8760 Hour-By-Hour Methods

While the Reduced Hour-By-Hour method often provides accurate results, the 8760 Hour-By-Hour method can consistently provide superior accuracy and reliability. Among the reasons why, five stand out:

1. Better Estimates of Monthly Energy Use.

One of the flaws in the fundamental principle of the reduced hour-by-hour method is that it relies on building and HVAC system behavior being "continuous" and "linear" during the month. Often these requirements are not met and this adversely affects accuracy

"Continuous" is a mathematical term that in this context refers to a consistent mode of operation (it does not refer to constant 24-hour operation of equipment). For example, during a summer month HVAC system operation is continuous when cooling is consistently done on all days whether hot, cool or average weather conditions prevail. In this situation simulation of system performance for one 24-hour average weather profile has the best chance of approximating the total energy use for a month.

However, system operation is often not "continuous" during a month, especially during intermediate seasons. For example, during an autumn month, cooling may be done on warmer than average days, economizer operation may occur on average days, and heating may occur on cooler than normal days. A simulation of one average day for such a month may indicate little or no cooling and heating because it does not consider the warmer and colder than average conditions.

In moderate climates this problem can become severe when the only time heating occurs is on colder than average winter days. Because only average winter weather is considered, most or all of the heating duty for the year may be missed by an average-day simulation approach.

Finally, "linear" behavior is a requirement for averaging to be accurate. For example, if cooling loads are 20% larger when the temperature is 15 F warmer than average, and 20% smaller when the temperature is 15 F cooler than average, cooling loads are linearly proportional to outdoor temperature. Averaging of the warm day and cool day loads will result in loads similar to those produced by simulating only the average weather day. However, loads depend on more than just outdoor temperature. Solar radiation, internal loads and hour-to-hour and day-to-day dynamic behavior also affect loads and often result in non-linear behavior.

Another example involves cooling equipment. If equipment input kW decreases 8% for every 10% drop in part-load ratio, input kW and load are linearly proportional. If this relationship holds true, simulation of equipment performance for one average day per month has the best chance of accurately approximating equipment performance on the collection of hot, average and cool days during the month. Unfortunately, the performance of equipment is often non-linear due to part-load, entering condenser temperature and other performance factors. Consequently, the accuracy of the average day approach can be degraded when equipment behavior is non-linear.

The 8760-hour method avoids these problems by simulating building and equipment operation for the entire month. Actual weather data used by the simulation consists of a collection of days, all with different combinations of temperature, humidity and sunshine.

Figures 1 and 2 provide an example of this kind of data for the month of September in Chicago. Figure 1 demonstrates the way dry-bulb temperatures can vary during a month. The dotted lines in this figure are the upper and lower limits of the average temperature profile for the month that would be used by the reduced hour-by-hour method. Comparison of the average and actual data shows a significant number of hours outside the range of conditions considered by the average day simulation approach.

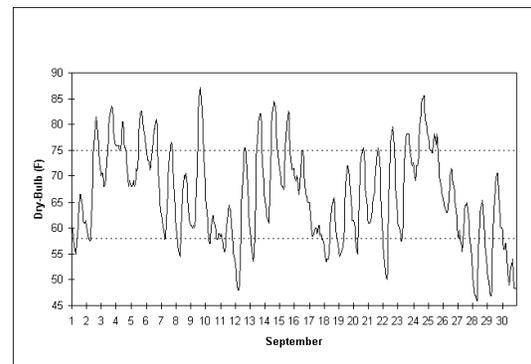


Figure 1. Chicago Weather / September Dry Bulbs

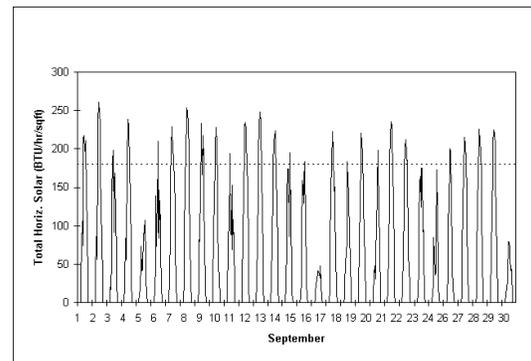


Figure 2. Chicago Weather / September Solar

Likewise, Figure 2 demonstrates the variation of solar radiation profiles during the month. The dotted line indicates the maximum solar flux in the average day profile used by the reduced hour-by-hour method. Once again, there are many conditions with greater sunshine and less sunshine than considered by the average day approach. More importantly, comparison of the peaks and valleys in Figures 1 and 2 shows that hot days are not always sunny, and cool days are not always cloudy. The diverse collection of hot, cold, sunny, cloudy and in between conditions shown in these figures illustrates the complex nature of actual weather data and provides evidence that building loads will not be a simple linear function of outdoor air temperature.

By considering a diverse collection of weather conditions each month, the 8760 hour method produces a diverse, realistic set of cooling and heating loads for the month. Further, because a full month of days are simulated, the appropriate factors influencing equipment performance are considered. There is no reliance on the assumption of "continuous" or "linear" behavior, and the estimates of monthly energy use can be highly accurate.

2. Higher Quality System Comparisons.

The issues discussed under item (1) affect not only the accuracy of monthly energy estimates, but also the quality of system comparisons. This is because many of the system design alternatives commonly considered exhibit behavior that is both discontinuous and non-linear.

"Discontinuous" refers to inconsistent operation. That is, operation that starts and stops rather than continuing for all operating conditions during a month. "Non-linear" refers to the fact that there is often not a simple proportional relationship between load or outdoor temperature and equipment performance, as discussed in item (1).

A comparison of air handling systems with and without a non-integrated outdoor air economizer provides a good illustration of this problem. With this type of economizer control, economizer dampers open when outdoor air temperature drops below the supply air temperature. The system can then immediately use outdoor air for free cooling; mechanical cooling can be turned off. For this example, assume the supply air temperature is 57 F and that we are simulating system operation for the weather data shown in Figure 1. The dotted lines in this figure indicate the upper and lower limits of an average temperature profile for the month. Because this average profile ranges between 58 F and 75 F, a simulation using the reduced hour-by-hour approach would never find a condition when the economizer dampers opened during September; free cooling would never be available. However, with the 8760 hour method, the use of actual temperature profiles for the month result in 119 hours during 13 days when temperatures drop below 57 F. If cooling loads exist during these times, the economizer would operate to provide free cooling. Therefore, because an economizer exhibits discontinuous operation, turning on and off at specific conditions, the reduced hour-by-hour approach may not be able to successfully account for its

operation. In our example the reduced hour-by-hour method would underestimate the benefit of the economizer.

Similar situations can exist for other system components and controls that involve discontinuous, on/off behavior. Examples include ventilation heat reclaim, supply air reset, humidity control, cooling tower fan cycling, and loading and unloading of chiller networks as well as many others.

3. More Accurate Load Histories.

The fact that the 8760 hour method simulates building thermal performance day to day for the entire year means it can correctly account for day to day dynamic load behavior. This results in more accurate load profiles, which ultimately lead to more accurate energy use predictions.

For example, on a Monday morning in the summer, pulldown loads tend to be larger than on other days of the week due to the heat accumulated by the building mass during the weekend. In addition to resulting in larger cooling loads, these conditions can sometimes set the monthly electric demand.

In reduced hour-by-hour methods that do not simulate a full week of operation, each day is simulated separately from all other days. Consequently, day to day building dynamics cannot be considered, and the building load histories are more simplistic. In those reduced hour-by-hour methods that do simulate a 7-day sequence each month, results tend to be unrealistic since the same average weather profile is used for all 7 days.

4. Higher Quality Time Of Use Energy Data.

Because of the diverse weather conditions and operating conditions, and because of the dynamic nature of building heat transfer, 8760 hour methods can produce energy use data that not only accurately defines how much energy is used, but when during the day and week the energy is used. When energy prices vary with time of day, accuracy of the timing of energy use is critical for producing accurate operating cost data.

5. More Accurate Estimates of Peak Demand.

Finally, by considering the full range of weather and operating conditions experienced by a building during a month, the 8760 hour method

is able to produce more accurate estimates of peak energy demand. When utility rates include a demand charge component, a significant part of the energy cost can be due to the peak energy use rather than the quantity of energy used. Many reduced hour-by-hour methods must determine demands from average day simulations which tend to underestimate demand values. Those methods that add consideration of hot and cold day weather profiles can provide an improvement in demand estimates. However, it is important to recognize that demand will be dependant on more than just the outdoor air temperature. Solar radiation, internal loads, building use profiles and day to day building dynamics also play an important role. The 8760-hour method is the only method that can simultaneously consider all these factors.

Thus, while the Reduced Hour-By-Hour Method considers many of the factors required for high-quality energy estimates, certain aspects of the method are flawed and can limit the accuracy of the method. Because the 8760 hour method uses a more detailed, comprehensive approach to building simulation, it can consistently overcome these problems to provide accurate, reliable energy estimates.

Conclusion

This article has discussed the important benefits of the 8760 hour-by-hour building energy analysis method. This method is certainly not new. Computer programs using this method have been available for nearly three decades. However, because many of these programs were developed on mainframe computers as research tools, the programs, and by association, the 8760 hour method itself acquired a reputation of being complicated, difficult and impractical to use. It is important to note that these are problems with the implementation of the 8760 hour method, not with the method itself. If the 8760 hour method is implemented in a well-designed, well-documented microcomputer program, the 8760 hour method can be as easy to learn and use as reduced hour-by-hour methods. In developing Carrier's Hourly Analysis Program we have put two decades worth of experience in the HVAC software field to work to produce an 8760 hour energy analysis tool that is both powerful and easy to use. The resulting program maximizes the benefits of the 8760 hour method while minimizing or even eliminating costs traditionally associated with use of this method.



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