MULTI-YEAR (MY) BUILDING SIMULATION: IS IT USEFUL AND PRACTICAL?

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ABSTRACT

This paper discusses a multi-year (MY) approach to building energy simulation and presents a pilot study in Hong Kong that investigates long-term building energy performance using MY weather data. Building energy simulations in the pilot study were carried out using the DOE-2.1E program. A set of 17 years hourly weather data (1979-95) was taken as the weather input to drive the simulation. It is found that the MY approach can provide more information for the analysis of long-term building energy performance and climatic properties. It can also remove the ambiguity of typical years and design weather in the present-day simulation approach. Although the MY approach has many advantages, its implementation does require great efforts since a lot more data and computations are involved. The availability of MY weather data is a critical limiting factor at present. To carry out MY simulation effectively, it is important to develop an efficient simulation process and new ways of interpreting simulation results. It is hoped that more thoughts can be stimulated to develop this approach for improving the accuracy and capability of building energy simulation.

INTRODUCTION

Weather data is important for driving building energy simulation and designing energy efficient buildings. The type of weather data being used in a simulation analysis determines the accuracy and characteristics of the results (Crawley and Huang, 1997). To fully represent the long-term climatic conditions, it is desirable to have a long period of weather data for driving the simulation. However, because of the complexity of the weather data and associated computations, it is often formidable in the past to employ a full set of multi-year (MY) weather data in building energy simulation.

In most cases, weather data of a single year, known as a ‘typical year’, is used as the weather input for building energy simulation (Chow and Fong, 1997; Lam, Hui and Yuen, 1992). A typical year may be a whole calendar year, such as a Test Reference Year (TRY) (NCC, 1976); it may also consist of linked monthly segments of weather data selected from the meteorological records, such as a Typical Meteorological Year (TMY) (Marion and Urban, 1995; NCC, 1981). The ability of a typical year to represent the parent MY weather data depends on the selection method and the characteristics of the simulation system (Lam, Hui and Chan, 1996). Although typical years can simplify the work on weather data, there is no guarantee that they will exhibit the long-term characteristics of the climate (Boland, 1995).

It is generally believed that MY weather data is ideal for assessing the overall performance and sensitivities of simulation models (Keeble, 1990). With the rapid increase of computing power in the past decade, the difficulty of using MY weather data in building energy simulation is becoming less critical. Nowadays, it is possible to carry out MY simulation to study the energy and thermal performance of buildings, if the weather database exists. By using MY simulation, the problems associated with typical years can be avoided and a wider spectrum of energy and climatic behaviour can be studied.

Nevertheless, implementing the MY approach does require great efforts since a lot more data and computations are involved. Particular care is needed to establish the weather data, perform the MY simulation and evaluate the simulation results. Many studies have been carried out on the development and analysis of typical years (Hitchin, et al., 1983; Crow, 1984; Lund, 1985; Pissimanis, et al., 1988; Said and Kadry, 1994; Lam, Hui and Chan, 1996;). But very few studies looked at the use of MY weather data in building energy simulation.

This paper discusses the MY approach to building energy simulation and presents a pilot study in Hong Kong that investigates long-term building energy performance using MY weather data. It is hoped that more thoughts can be stimulated to develop this approach for improving the accuracy and capability of building energy simulation.

WHY MULTI-YEAR?

Although the weather methodology of different building energy simulation programs may not be the same, a common approach is to employ two sets of weather data for design load calculation and energy calculation, respectively. These two sets of data are known as ‘design weather’ and ‘typical weather’.

Design weather represents the severe climatic conditions for sizing plant and equipment; typical weather (expressed as typical years) represents the average long-term weather conditions for estimating year-round energy consumption. Figure 1 shows the relationship between design and typical weather.

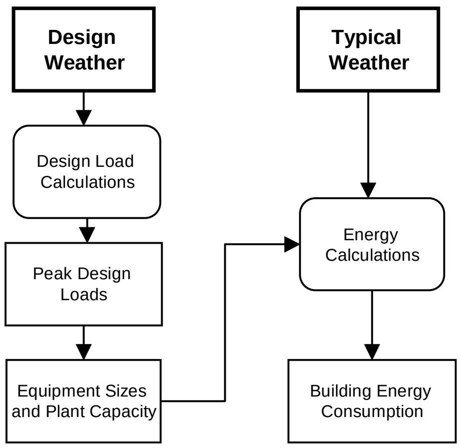

Figure 1 Relationship between design weather and typical weather

The concept of design weather arises from traditional heating, ventilating and air-conditioning (HVAC) design calculation which estimates peak design loads based on selected indoor and outdoor design conditions. When the design weather is defined and formulated in building energy simulation, the establishment of hourly design data becomes ambiguous as it is difficult to determine which set of extreme values of the weather parameters, such as temperature, humidity and solar radiation, is correct and adequate (Mason and Kingston, 1993). Inappropriate design data may lead to overdesign and inefficient building operation (Mason, 1993).

For long-term energy estimation, a typical year is considered not very satisfactory because it is difficult to select a year which is 'typical' for all circumstances. Crawley and Huang (1997) found that none of the methods for selecting typical years is consistently better than the others. Pre-selected typical years are not able to fulfill the requirements in all situations. This problem, together with the lack of weather data in some locations, has led some researchers to develop synthetic years which are mathematical representation of the weather data series (Degelman, 1991; Knight, Klein and Duffie, 1991; Yik and Kot, 1989). However, the behaviour of the climatic parameters is so complicated that a good representation of the weather is very hard to achieve.

Simulation using MY weather data may seem cumbersome in the first instance, but it is an effective way to avoid the previous problems. Table 1 shows a comparison of typical year and MY weather data. A major advantage of the MY approach is the ability to represent the long term and to provide detailed information for the analysis of long-term climatic properties and building energy performance. If a specific year is required for a simulation task (such as for an energy audit of existing buildings), the MY method can offer the data easily since the MY data set contains every year of the weather database.

Table 1 Comparison of typical year and multi-year weather data

	Typical Year	Multi-year
Amount of weather data	One single year	Multiple years
Ability to represent the long term	Depends on selection method and system	Very good
Ability to represent a specific year	No (generally)	Yes
Amount of simulation	One round	Multiple rounds

A MY climate series is the ideal resource for analysing all likely weather scenarios that may affect the performance of a design (CIBSE, 1996). Design optimization can be achieved by examining the simulation results over the multiple years. If properly designed, it is possible to establish HVAC plant capacities using iterative simulation (Mason and Kingston, 1993).

Past experience shows that the need of building energy design and simulation is changing constantly. For example, full hourly data which is 'expensive' in the past is now commonplace in HVAC design and simulation programs. It is reasonable to predict that future simulation tasks will require MY weather data for a thorough climate and energy assessment. The question will become: Why not multi-year?

HOW TO CARRY OUT MULTI-YEAR SIMULATION

It is important to consider carefully the simulation process when using MY weather data. Figure 2 shows the conventional and MY simulation approaches. The weather data preparation is straight-forward in the MY approach since no selection process is needed. But the simulation procedure is more complicated as the usual simulation task is run over the multiple years. All in all, the following factors are critical when planning MY simulation:

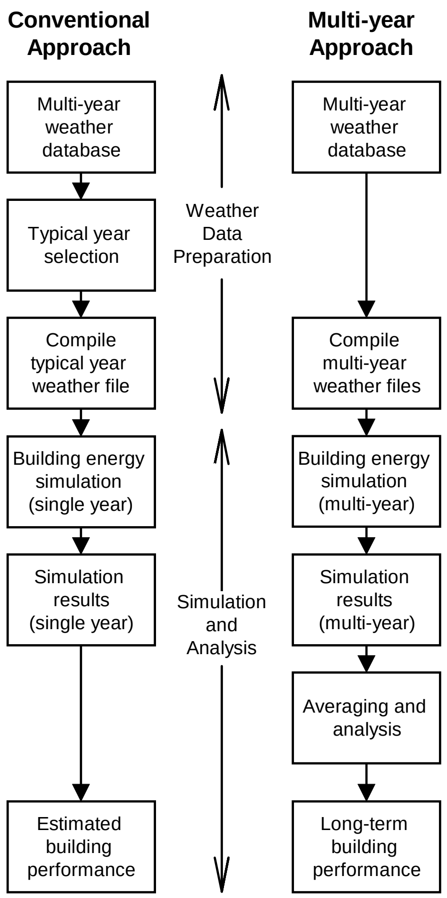

Figure 2 Conventional and multi-year simulation approaches

(a) Availability of MY weather data.

(b) Complexity of the simulation process.

(c) Benefits of using MY simulation.

The availability and quality of hourly weather data will determine the feasibility of MY simulation. This is critical at present since a full set of MY weather data is often not available to program users. Examples of weather database now exist for building design include: USA (NREL, 1992), UK (CIBSE, 1996; Page, Gibbons, and Lowe, 1985; Hitchin, et al., 1983) and Hong Kong (Lam, Hui and Chan, 1996). These weather databases contain 10 to 30 years of weather data and are often used to derive typical years through statistical analysis of the climatic elements. If the weather database is not available for a location, raw weather data from the respective local weather station will be needed for establishing the simulation weather files.

The complexity of MY simulation arises not only from the increased amount of simulation but also from the need to prepare the weather data files. Like other climatological research, establishing weather data files to fulfill the simulation needs is not simple (Donn and Amor, 1993). Care should be taken to the management of missing data, spikes and data formatting. Knowledge of climatology and computing techniques, and reasonable amount of engineering judgements are required. Solar radiation data is usually the most problematic and has often limited the scope of long-term weather data for building energy analysis (Stoffel, 1995).

A sore point to note is that the benefits of using MY simulation should be weighed against the required efforts. Not all circumstance can justify this if the weather data are not readily available. Even if the weather files are available, an efficient simulation process is required to carry out the MY simulation. A mechanism for automating the simulation process will certainly help simplify the task; a systematic way of interpretation is essential for examining a large amount of time-series simulation results. The cost benefits of a MY approach have to be assessed in each case since they may vary quite a lot.

PILOT STUDY IN HONG KONG

To investigate the MY approach, a pilot study has been performed in Hong Kong. Weather data files of Hong Kong for the years 1979 to 1995 have been developed and used as the weather input to drive the simulation. This 17-years hourly weather database is the best available one in Hong Kong and is established from the raw climatic data measured by the Royal Observatory Hong Kong (ROHK, 1995). The weather files are compiled in TMY format (NCC, 1981) and have been processed into binary files for use by the simulation program.

The simulation tool used in this study is the personal computer (PC) version of the DOE-2.1E building energy simulation program developed by the Lawrence Berkeley National Laboratory (Acrosoft International, Inc., 1994). To facilitate the analysis, a supporting utility program developed by the author was used to perform the simulations (Hui and Lam, 1995). This program automates the simulation process with multiple weather files, extracts key results and handles simulation input and output.

The building model being studied is a 40-storey square office building (35 m by 35 m) with curtain-wall construction and a central HVAC system. Further details of the building model can be found in Lam and Hui (1993). This model has been used for studying the energy performance of office buildings in a previous research study (Lam and Hui, 1996).

One thing often overlooked by users of simulation tools is the holiday schedule. The holiday list has significant influence on the simulation results as the internal loads (occupancy, lighting and equipment) and system operation are affected by it (Hui, 1995). This is particularly important when MY weather data is used since every year may have different holiday schedules. The use of typical year data may not be able to consider this if the typical year is constructed from linked monthly segments. To cater for the actual holidays in Hong Kong, the holiday schedules of DOE-2 have been adjusted before the simulation.

ANALYSIS OF SIMULATION RESULTS

To illustrate how the MY simulation results can be used to study the long-term building energy performance, let us look at three major end results of the simulation:

(a) Chiller plant sizes in kW.

(b) Annual electricity consumption in MWh.

(c) Monthly electricity consumption in MWh.

Chiller Plant Sizes

The capacity of the chiller or refrigeration plant can be determined by automatic sizing from the peak cooling load calculated from the weather file. It can also be determined by setting up a 'design day' in the building input. Table 2 gives the input parameters of a 'cooling design day' set up in our study. A constant temperature cycle was used to estimate the required cooling capacity for the design day weather.

Table 2 Cooling design day input parameters

Dry-bulb temperature	33 ℃
Dewpoint temperature	26.4 ℃
Wind speed	2 m/s
Wind direction	East
Cloud amount	0
Clearness	1
Daily temperature cycle	Constant

Figure 3 shows the chiller plant sizes calculated from the weather files and the design day, respectively (the peak cooling loads usually occur in July, August or September). The range of variation over this 17-years period is 2,172 kW, or 23% of the mean value for all the years in this period. The difference between the chiller size calculated from the design day and from the yearly maximum which occurs in 1987 is 852 kW, or 8% of the yearly maximum. This indicates that better design optimization and saving in first costs of the chiller plant can be achieved using MY simulation.

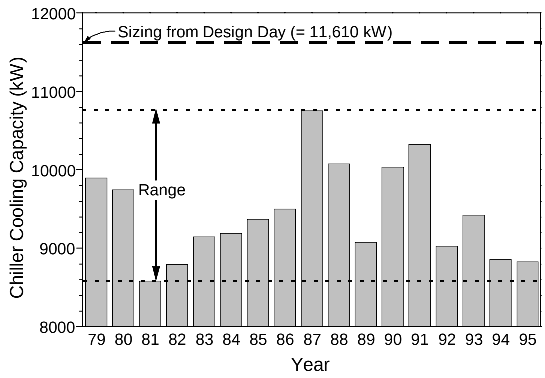

Figure 3 Chiller plant sizes

The information about the long-term cooling demands is also useful for plant operation and demand-side management. Demand profiles over multiple years can help building engineers evaluate their operation strategies and achieve better resource planning that minimizes the cost of energy supply while meeting reliability needs and other objectives.

Annual Electricity Consumption

The building electricity consumption (in MWh) is the total building energy consumption of the model building since electricity is the only energy source in this building. Figure 4 shows a comparison of the annual electricity MWh calculated for the years 1979-95. Values for the long-term mean and two typical years are also drawn on the graph. The Test Reference Year (TRY) is the year 1989 selected from a previous study (Hui and Lam, 1992); the Typical Meteorological Year (TMY) was selected using TMY method from FS statistics of daily indices (Lam, Hui and Chan, 1996). The Typical Meteorological Months (TMMs) composing the TMY are Jan. (1980), Feb. (1990), Mar. (1993), Apr. (1980), May. (1989), Jun. (1986), Jul. (1986), Aug. (1986), Sep. (1982), Oct. (1984), Nov. (1989) and Dec. (1993).

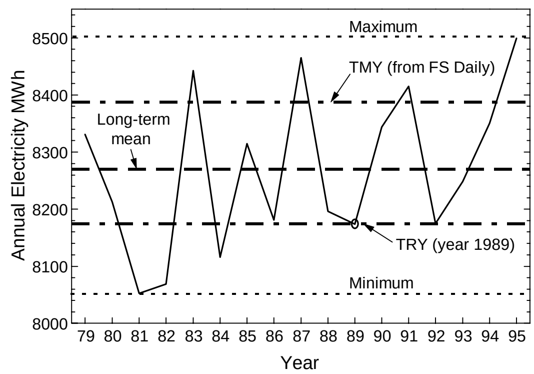

Figure 4 Comparison of Annual electricity MWh

The range of variation over this 17-year is 447 MWh, or 5.4% of the long-term average MWh. This range

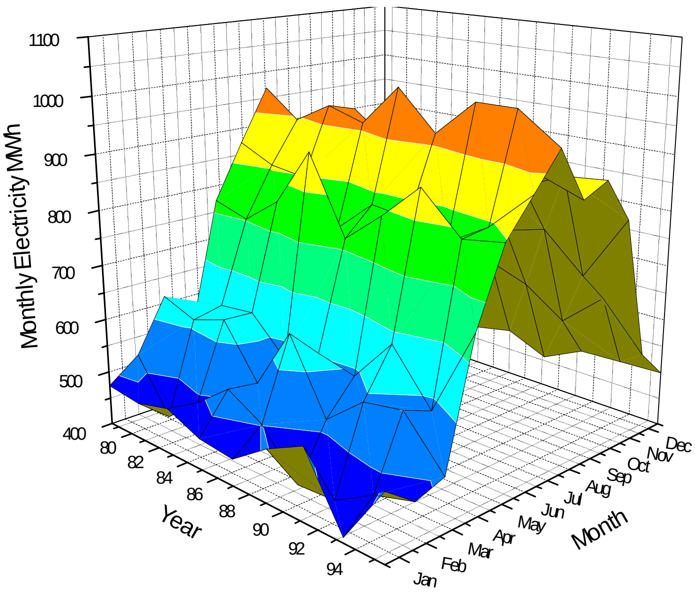

Figure 5 Monthly electricity MWh

Table 4 Statistical analysis of electricity MWh for the years 1979-95

	Maximum (MWh)	Minimum (MWh)	Mean (MWh)	Range (MWh)	Range (% of mean)	Std.Dev. (MWh)	Std. Dev. (% of mean)
Jan	529.6	(S) 402.7	474.1	126.9	26.8	33.2	7.0
Feb	525.7	411.3	(S) 452.0	114.4	25.3	37.8	8.4
Mar	631.4	472.4	559.6	159.0	28.4	44.8	8.0
Apr	707.7	486.6	575.8	(L) 221.1	(L) 38.4	(L) 62.7	(L) 10.9
May	904.7	752.4	815.4	152.3	18.7	48.9	6.0
Jun	896.9	757.8	829.2	139.1	16.8	36.3	4.4
Jul	(L) 1012.4	(L) 893.7	(L) 961.5	118.7	12.3	32.9	3.4
Aug	953.2	858.3	899.6	(S) 94.9	(S) 10.5	(S) 26.4	(S) 2.9
Sep	925.2	796.7	857.8	128.5	15.0	33.5	3.9
Oct	820.8	690.6	754.4	130.2	17.3	37.5	5.0
Nov	679.8	539.9	606.2	139.9	23.1	45.1	7.4
Dec	(S) 524.4	457.5	483.9	66.9	13.8	18.8	3.9
Year	8499.2	8052.6	8269.7	446.6	5.4	138.3	1.7

Note: Std. Dev. = standard deviation (sample); (L), (S) = largest and smallest in monthly values

is smaller than that of the chiller cooling capacity and this implies that the annual MWh is less sensitive to the change of weather file than the peak cooling load. Irregularity of the climatic patterns tends to level off when the annual energy consumption is calculated. Findings from a research study in USA (Crawley and Huang, 1997) show similar results and they have further suggested that the total energy costs vary less overall than energy consumption.

Monthly Electricity Consumption

Figure 5 shows the monthly electricity MWh calculated for the years 1979-95. The different levels of energy consumption can be seen easily from the profile of the 3D surface. Vertical cross-sections along the x-axis and y-axis show respectively the monthly and yearly profiles of the MWh data.

Variations of the monthly MWh can also be studied by examining the statistics of the data. Table 4 gives the results of statistical analysis of the monthly and annual electricity MWh data. The maximum, minimum, mean, range and standard deviation of the

MWh data are provided. It can be seen that the monthly MWh has larger variations than the annual MWh. The largest variation occurs in April and the smallest one occurs in August. In general, the variation in the summer period (June to September) is smaller than the rest of the year. This suggests that the simulation results for the summer months will not differ very much in each of these years, but for the winter months (January to April), the energy consumption may vary a lot if different years are being used.

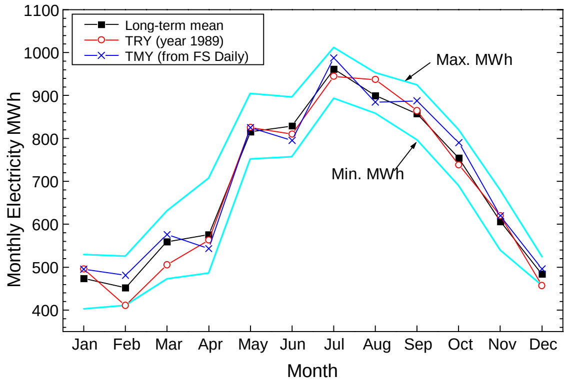

Figure 6 Comparison of monthly electricity MWh

Figure 6 shows a comparison of the monthly electricity MWh. The range of monthly variations, the long-term mean and the values for the two typical years (TRY and TMY) are given. With the MY simulation results, an indication of how well the typical years perform can be seen. But it is hard to say which typical year is better in representing the long-term mean since it varies from month to month.

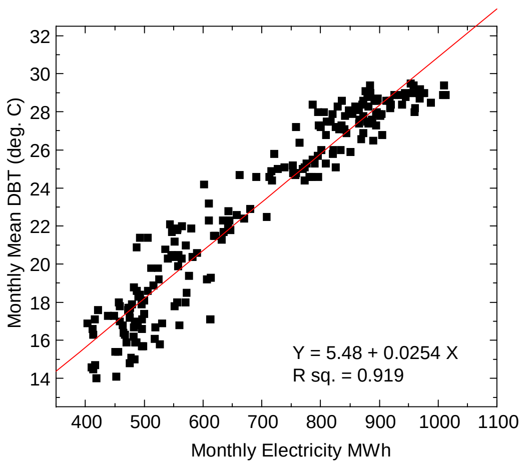

Figure 7 Correlation between monthly electricity MWh and monthly mean dry-bulb temperature

The monthly MWh data can also be used to investigate the correlation between building energy use and weather parameters. For example, the monthly mean dry-bulb temperature (DBT) is plotted against the monthly MWh in Figure 7. It can be seen that they have good correlation and a regression equation can be developed between them. The information about this relationship is useful for energy and demand-side management.

CONCLUSIONS

Accurate and reliable weather data are crucial for building energy simulation and analysis. In the past, MY weather data is very seldom used in building energy simulation because the costs and time of using them are substantial. With the increase of computing power and development of building energy simulation methods, the use of MY weather data becomes more feasible and is worth examining at this stage.

It is believed that a MY approach (as compared with a typical year approach) can provide a wider spectrum for studying climatic behaviour and building energy performance. Essential information developed from it can be used for optimizing building design and operation. Moreover, MY simulation has the potential to solve the problems of design and typical weather since one set of weather data can be used simultaneously for determining the design loads and long-term energy performance of buildings. Figure 8 shows the concept of a complete MY approach to building energy simulation which will avoid the separation of design and typical weather data (compared with Figure 1).

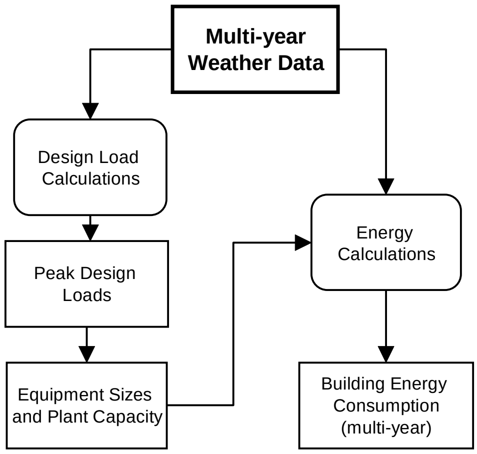

Figure 8 A complete multi-year approach to building energy simulation

Although the MY approach has many advantages, its implementation also requires great efforts. The availability of weather data is a critical limiting factor at present. An efficient simulation process and new ways of interpreting simulation results are needed to take full advantage of this option.

To conclude, the MY approach is useful for improving the accuracy and capability of building energy simulation. Its practicability is likely to increase with further development of building energy simulation techniques. It is time to rethink about the traditional approach to weather input and to adapt the simulation tool to the MY simulation tasks.

ACKNOWLEDGEMENT

The Royal Observatory Hong Kong is acknowledged for supply of weather data of Hong Kong.

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