A Case Study of Weather Impact on Energy Conservation Measures in Building

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Abstract

Buildings consume more than 40% of the world's primary energy, of which heating, ventilation, and air-conditioning (HVAC) is the largest end use. Nowadays, more energy conservation measures (ECMs) are developed to improve the building performance and reduce energy use. Furthermore, the variations of thermal loads and energy use of HVAC in buildings are directly influenced by weather. The energy use in buildings calculated using the typical metrological year (TMY) weather data aims to represent the average or typical values but not necessarily so because different types of buildings with different energy service systems and operations have different responses to weather. This paper presents a case study to investigate the impact of weather on energy savings of various ECMs for an actual office building using EnergyPlus simulations with 32-year (1980 to 2011) Actual Meteorological Year (AMY) weather data. The building model is calibrated with actual monthly electricity bills. Then different building performance levels are simulated by varying the ECMs. A comprehensive analysis is conducted to assess the benefit of each ECM and their integrated design effect. Finally, the simulated results are compared with the measured data to evaluate the annual energy use and energy-saving.

Keywords: Building Simulation, Energy Conservation Measure, Building Energy Performance, EnergyPlus

1 Introduction

Buildings consume more than 40% of the world's primary energy, of which heating, ventilation, and air-conditioning (HVAC) is the largest end use. In the United States, buildings consume a significant portion of energy in the country for heating, cooling, and power, and it is estimated that nearly 30% of this consumption could be saved by energy conservation and/or sustainable building design and operations. In the United Kingdom, more than 60% of energy is used to condition the indoor environment [1]. Therefore, energy retrofits and the implementation of conservation measures can be cost-effective means of reducing energy consumption in buildings. Nowadays, more high efficiency equipment and energy conservation measures (ECMs) are developed and applied to buildings in order to improve the building performance and reduce energy use. However, efforts to improve energy efficiency should therefore not only concentrate on the design of the air conditioning system but also include the building itself. While more focus is on developing new building materials and improving the efficiencies of building equipment as well as the research of occupant behavior in buildings. The comprehensive analysis is needed to evaluate the benefit of each ECM and their integrated design effect.

The impacts of alternative energy conservation measures on building energy requirements were conducted. The energy conservation strategies and their impact on the thermal environment were explored [2]. Parametric variations in envelope design and HVAC operation on energy performance and thermal comfort of a typical commercial office building in Singapore are investigated. By ranking their effectiveness in reducing energy consumption, strategies for energy conservation are derived. Utilization of daylighting and the use of high efficiency lighting systems produced the greatest saving of the order of 25% and 13% respectively. The impact of alternative energy conservation measures on energy requirements in office buildings in hot and humid climates was investigated [3]. Different types of HVAC systems were selected and different feasible and practical operational energy conservation measures were evaluated using the energy simulation tool. Based on the results of this research work, several recommendations are made for the existing office building. The specific energy consumption of the buildings for heating, cooling and lighting purposes, as well as the consumption of the office equipment is reported [4]. The potential and the limitations of various energy conservation systems and alternative techniques were assessed. The possible reduction of the load for heating, cooling, and lighting purposes is found to be between 22-37%. The various energy conservation measures on heating, ventilating and air conditioning and lighting systems for a four floors institutional building in subtropical climate are evaluated [5]. The results of the simulation were verified with measured energy consumption profile for base model. Then, the simulation was conducted for different ECMs and their results were analyzed. Thermal performance of these ECMs strategies were also evaluated and verified by thermal comfort index. It was found that the building can save up to 41.87% energy without compromising occupancies thermal comfort by implementing the ECMs into the existing system. The conservation measures including window glazing, occupancy sensors, cold deck temperature set point and reduced ventilation air were evaluated [6]. The use of occupancy sensors in the office spaces to reduce lighting and air handling energy was attractive. Reducing ventilation air in the morning hours was promising from an energy savings perspective but may need more research on indoor air quality and air diffusion and recirculation.

The building energy use is affected by many influencing factors, among which weather plays a unique and important role. The variations of thermal loads and energy use of HVAC in buildings are directly and significantly influenced by weather. The energy use in buildings calculated using the typical metrological year (TMY) weather data aims to represent the average or typical values but not necessarily so because different types of buildings with different energy service systems and operations have different responses to weather. Furthermore, a single set of energy use results from the TMY simulation does not provide the range of variations due to the change of weather from year to year. The use of inappropriate weather data can result in large discrepancies between predicted and measured performance of buildings. The influence of the various weather data sets on simulated annual energy use and cost are compared [7]. The variations of the annual energy consumption and costs can be significant from the simulation results using different weather data sets. The results show that the TMY and the WYEC data sets represent the closest typical weather patterns. Simulated results using the TMY weather data provides the average/typical energy use for buildings, but the peak electric demand predictions and uncertainty analyses based on TMY are often not reliable because a single year cannot capture the full variability of the long-term climate change [8]. In view of the long-term climate change, the year period assigned for TMY selection should include the most recent meteorological data and should be reasonably long to reflect the weather variations [9].

This paper presents a case study to investigate the impact of weather on energy savings of various ECMs for an actual office building using EnergyPlus simulations with 32-year (1980 to 2011) Actual Meteorological Year (AMY) weather data. The office building is located in Hsinchu, Taiwan. The EnergyPlus model of the building is calibrated with actual monthly electricity bills. Then different building performance levels are simulated by varying the efficiencies of building envelope, HVAC, and lighting. A comprehensive analysis is conducted to assess the benefit and potential of each ECM. Finally, the simulated results are compared with the measured data to evaluate the annual energy use and energy-saving. The research findings from this study can improve understanding and estimating the impact of energy-saving measures considering the weather variation in the long term, thus to support technology assessment and policy making. Additionally, considering the weather impact year-over-year can improve the evaluation of ECMs investment risks for new and existing buildings by taking into account their life-cycle energy and cost savings.

2 Methods

The energy models are simulated using EnergyPlus 7.2. There is a total of 264 simulation runs: 1 Office Building Type X 8 Energy Conservation Measures including base case X 1 Climate X 33 Weather Files including 32 AMYs and 1 TMY. The performance metrics of each AMY run are compared with those of the corresponding TMY3 run to calculate the percentage changes. Furthermore, the simulated results of each energy conservation measure are compared with base case to assess the energy saving potentials.

The analysis in this case study follows these procedures:

1. The base case model is first created according to the as-built building design drawings and specifications.
2. The base case model is then calibrated to match the monthly billed electricity use kWh.
3. Compare the percentage changes between the results from AMYs and TMY to assess the weather impact on building energy performance.

4. Alternatives are created based on the base case model to evaluate energy efficiency measures.

To investigate the weather impact on energy savings and demand reduction of building technologies, the building energy models with different ECMs are simulated using the TMY3 and 32-year AMY weather files. The weather data used for this case study include 32 AMY weather files of Hsinchu city in Taiwan from 1980 to 2011 and 1 TMY weather file. Each weather file contains 8760 hourly values of 14 weather parameters including dry-bulb and wet-bulb temperatures, solar radiations, etc. Hsinchu has a hot-humid climate corresponding to the 2A climate zone defined by the US Department of Energy. The energy savings and demand reductions of the every ECM models over the base case model using the same TMY3 or AMY weather files are calculated to determine their variation ranges. The source energy is used in this study because it considers the energy loss during energy generation, transmission, and distribution.

The type of building simulated in this study is an office building. This building was built between 1983 and 1985 in Hsinchu, Taiwan. The building has a total floor area of 7300 m² with one basement floor of 900 m² and four above-grade floors of 1600 m² each. The footprint of the basement floor is 11.25 m by 80 m. The above-grade 4 floors have the same footprint of 20 m by 80 m. Except the basement floor, each floor has a corridor in the center of the floor plan. The basement spaces are mostly unconditioned except the conference room. The common areas on the East and West sides of the building are unconditioned. Each floor has a floor-to-floor height of 4 m with a plenum height of 1.3 m. The building structure is concrete. Double pane windows are used with exterior shading from overhangs and side fins. Window-wall-ratio is about 18%. The long axis is along the East-West direction. The front façade faces the North with 15 degrees toward the East. The building has a maximum occupancy of about 360 occupants. The building has an entrance shading on both the South and North facades and no adjacent buildings or tree shading are considered. The 3D configuration of building is shown in figure 1.

EnergyPlus version 7.2 is used to perform the building simulations. EnergyPlus has innovative simulation capabilities including sub-hourly time steps, an integrated solver for system models with a zone heat balance model, and user definable and configurable HVAC systems and components. It calculates space temperature, occupant thermal comfort, cooling and heating loads, HVAC equipment sizes, energy consumption, utility cost, air emissions, water usage, renewable energy, etc.

This section proposes several energy conservation measures (ECMs) in order to reduce the energy use of the base case building if it is retrofitted. There are 7 ECMs studied including efficient lighting systems, high performance windows, wall insulation, efficient chillers, efficient cooling towers, variable speed drives for pumps, daylighting and controls. Based on the calibrated base case model, the following energy efficiency measures are evaluated to explore their energy savings potential. Each ECM alternative is based on the base case and modifications are made to incorporate the energy efficiency measure described in the table 1.

Table 1 Measure Description

Alternatives	Description
Base Case: As-Built Calibrated	The calibrated model for the as-built building.
ECM1 - More Efficient Lighting	Average LPD of 9.8 W/m², office spaces LPD of 12.6 W/m². (Base Case – average LPD of 14.0 W/m², office spaces LPD of 18 W/m²)
ECM2 - Double Tinted Low-e Windows	Ufactor = 1.364 W/ m²·K, SHGC = 0.27, VT=0.64 (Base Case – Ufactor = 2.61, SHGC = 0.62 , DOE-2 Code 2202)
ECM3 - Add Wall Insulation	Mass wall, Ufactor = 2.83 W/ m²·K (Base Case – Mass wall, Ufactor = 0.44)
ECM4 - Efficient Chillers	Chiller's COP = 6.395 (Base Case – 4.396)
ECM5 - VSD Pumps	Variable Speed Drive for chilled water pumps (Base Case – Constant speed pumps)
ECM6 - Daylight Controls	Daylight sensors on the South and North side spaces to control 1/3 of the spaces lighting power. (Base Case – No daylighting control)
ECM7 – Combination of ECMs	Combination of ECM1 to ECM6

3 Results

Model calibration is to match the predicted energy use with history billing data of the same building in year 2010 by reasonably adjusting model inputs. Figures 1 shows simulation results. The annual electricity use is within the 3.4% error range, while the monthly electricity use has a wider error range. The model predicted a higher 11.2% of kWh is probably due to the operating schedules assumed the same for each month. In this figure, it can be found that an obvious drop occurred in February, this is because that more people took vacation in February because of Chinese New Year and therefore that resulted in the building was unoccupied during this period. In summary, if measured occupant schedule and monthly electric demand kW is available for calibrating the model, it is excepted that the error range can be reduced.

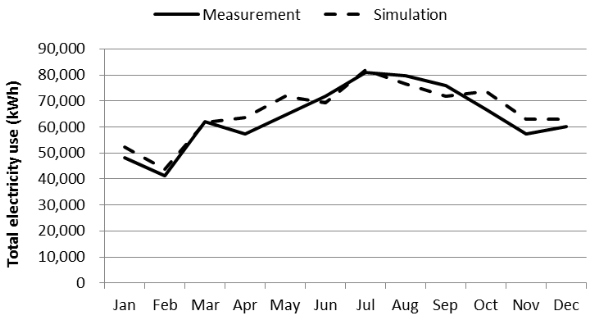

Figure 1 Predicted and billed monthly electricity use (kWh) of the base case

The percentages of predicted annual electric end use of the base case for chiller, lighting, equipment, fans, and pumps are indicated in figure 2. The most electricity uses are contributed by chiller and lighting and their electricity use percentages are 25% and 30%, respectively. They share over 50% of annual total electricity use. On the other hand, it is expected that the energy saving potentials of chiller and lighting are greater than others if suitable energy conservation measures are applied.

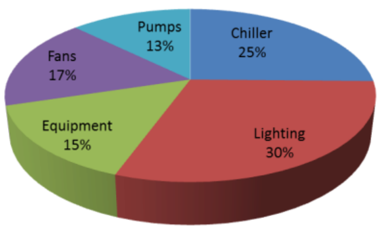

Figure 2 Percentages of predicted annual electric end use of the base case

According to the applications of different energy conservation measures, the variations of electricity use of chiller and lighting as well as the total electricity use are showed in figure 3. As for the electricity use variations of chiller by applying different energy conservation measures, it can be seen that the electricity use droped significantly if the ECM 4, high effieient chiller, is applied. Compared with the electricity use of chiller of base case, the reduction of electricity use is about 31%. Additionally, the electricity use is decreased slightly if ECM 2, ECM 3, and ECM 4 are applied. This is because the high effiecient lighting and envolop systems can help the building to reduce the internal and external thermal loads and therefore the loading of HVAC system can be decreased. However, the high efficient lighting and envolop system seem not very useful for reducing the electricity use of chiller in this study. As for the electricity use variations of lighting by applying different energy conservation measures, it can be found that the adoptions of high efficient lighting and daylight control, such as ECM 1 and ECM 6, can reduce the electricity use significantly. Compared with the electricity use of lighting of base case, the electricity use reductions of ECM1 and ECM 6 are about 30% and 49%, respectively. From the simulation results, it indicates that the daylight control can decrease the electricity use significantly. However, in general, it is more difficult to apply this measure in the existing building due to the building construction and cost issues. Finally, as for the variations of total electricity use by applying different energy conservation measures, the electricity use reductions of ECM 1 to ECM 6 compared with base case are 9.7%, 1%, 0.6%, 8.4%, 5.9%, and 16%, respectively. As for the ECM 7, it represents the combination of ECM 1 to ECM 6, the electricity use reduction can be as high as 35.5%.

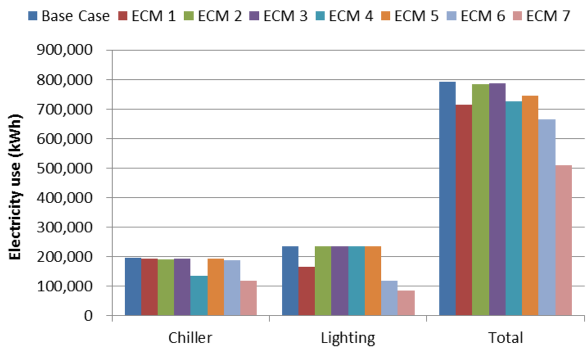

Figure 3 Comparison of energy saving potential of different energy conservation measures

The variations of monthly electricity use including base case and each energy conservation measures are displayed in figure 4. In general, the variation trends of each ECM are correspondent with base case. It is expected that the electricity use is increased during summer due to the energy consumption of HVAC system for cooling. Furthermore, the obvious drop of electricity use in February can be seen in the figure. The building is occupied fewer days because the people take long vacation during Chinese New Year, as discussed above.

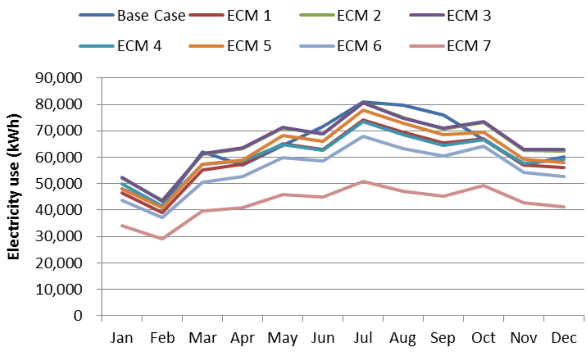

Figure 4 Variations of monthly electricity use for base case and different energy conservation measures.

The variations of annual HVAC energy use for the base case and 7 different energy conservation measures by using TMY3 and AMY weather data are shown in figure 5. The HVAC energy use includes the energy consumptions of chillers, pumps, fans, and cooling towers. HVAC energy use is directly affected by weather, because the cooling and heating loads of buildings are dependent upon weather conditions such as outdoor air temperature and humidity, wind speed, and solar radiation. The simulation results from using the TMY3 weather data are used as the baseline in this figure. In general, the AMY results show large differences when compared to results using the TMY3 weather data. As for the base case, the TMY3 results can over-estimate AMY results as much as 4% and under-predict as much as 9%. For the ECM 4 and ECM 5, these two measures affect the HVAC energy use more directly, as showed in the figure. The TMY3 results can over-estimate AMY results as much as 3% and under-predict as much as 7% for the case of ECM 4. The TMY3 results can over-estimate AMY results as much as 3% and under-predict as much as 10% for the case of ECM 5. In general, the precentage of under-predict is usually greater than that of over-estimate for each case.

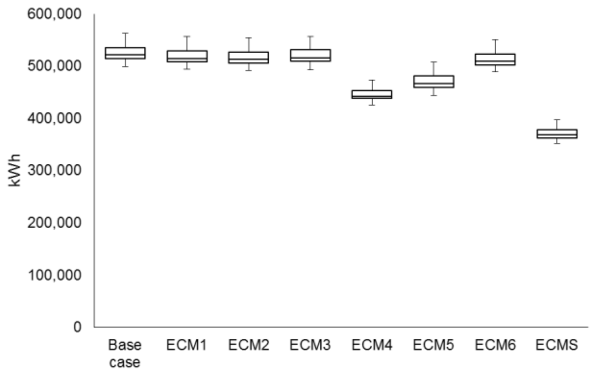

Figure 5 Variations of annual HVAC energy use of base case and different energy conservation measures by using TMY3 and AMY weather data

Similar results as shown in figure 5 are shown in figure 6, but for the building total energy use. The variations of annual building total energy use are about one-third of those of the HVAC energy use, because weather changes only affect the HVAC energy use. Similar but slightly different patterns are observed for the building total energy use. In general, the AMY results show noticeable differences from those from the TMY3. As for the base case, the TMY3 results can over-estimate AMY results as much as 2% and under-predict as much as 5%. In this figure, ECM 1, ECM 4, and ECM 6 influence the variations of annual building total energy use more effectively. The TMY3 results can over-estimate AMY results as much as 2% and under-predict as much as 5% for the case of ECM 1. The TMY3 results can over-estimate AMY results as much as 2% and under-predict as much as 4% for the case of ECM 4. The TMY3 results can over-estimate AMY results as much as 7% and under-predict as much as 11% for the case of ECM 6. In summary, the precentage of under-predict is usually greater than that of over-estimate for each case, the same trend as discussed in figure 6.

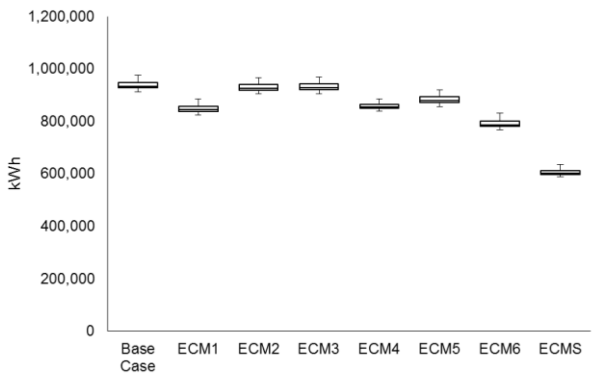

Figure 6 Variations of annual total energy use of base case and different energy conservation

measures by using TMY3 and AMY weather data

4 Conclusion

This paper presents a case study to investigate the impact of weather on energy savings of various ECMs for an actual office building using EnergyPlus simulations with 32-year AMY weather data. From the simulation results of this work, the applications of high efficient lighting system and chiller can improve the building energy performance and therefore reduce the electricity use. Furthermore, the simulation results from using TMY3 weather data are usually over-estimate or under-predict. Therefore, it is necessary to run simulations with AMY weather data to fully assess the impact of weather on the long-term performance of buildings and to evaluate the energy savings potential of energy conservation measures for new and existing buildings from a life cycle perspective. Future work will continue to investigate the weather impact and different energy conservation measures for other building types and various types of building efficiency.

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6 References

1. Clarke J. A. Assessing building performance by simulation. Building and Environment, 1993, 28(4), 419-427.
2. Tham K. W. Conserving energy without sacrificing thermal comfort. Building and Environment, 1993, 28(3), 287-299.
3. Iqbal I., Al-Homoud M. S. Parametric analysis of alternative energy conservation measures in an office building in hot and humid climate. Building and Environment, 2007, 42, 2166-2177.
4. Santamouris M., Argiriou A., Dascalaki E., Balaras C., Gaglia A. Energy characteristics and savings potential in office buildings. Solar Energy, 1994, 52(1), 59-66.
5. Rahman M. M., Rasul M. G., Khan M. M. K. Energy conservation measures in an institutional building in subtropical climate in Australia. Applied Energy, 2010, 87, 2994-3004.
6. Carriere M., Schoenau G. J., Besant R. W. Investigation of some large building energy conservation opportunities using the DOE-2 model. Energy Conservation & Management, 1999, 40, 861-872.
7. Crawley D.B. Which weather data should you use for energy simulations of commercial buildings? ASHRAE Transactions, 1998, 104(2), 498-515.
8. Barnaby C.S., Crawley D.B. Weather data for building performance simulation. Building Performance Simulation for Design and Operation, 2011, Spon Press, 37-55.
9. Chow T.T., Chan A.L.S., Fong K.F., Lin Z. Some perceptions on typical weather year-from the observations of Hong Kong and Macau. Solar Energy, 2006, 80, 459-467.