The Research of Taiwan’s Green Building Energy-Saving Techniques

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***Abstract*—This research is based on Taiwan’s first zero-carbon green building-Magic School of Green Technology in National Cheng Kung University. Actual energy consumption will be measured to explore benefits of energy-saving. The design origin for this building encompasses 13 green energy-saving techniques. United States Department of Energy dynamic building energy analytical software, eQUEST, is used to execute the strictest energy consumption analytical assessment. It is forecasted to reach an energy-saving efficiency of 65% with energy use intensity (EUI) of 43 kWh/m².yr for the whole building, far below that of 169 kWh/m².yr found in Taiwan low/mid-rise office buildings. This building has begun operation in 2011, through actual readings from Building Energy Management System (BEMS) during January to September, first-half-year accumulated EUI of 33.5 kWh/m².yr against eQUEST analytical assessment of 38.2 kWh/m². yr for the same period. Demonstrating that eQUEST analytical assessed value is very consistent with building’s actual energy consumption readings. The energy consumption standard in the experimental research behind the Magic School of Green Technology stands at world class.**

Keywords- green building; LEE; EUI; eQUEST; BEMS

I. PREFACE

The rapid development of global economy created a surge in use of energy. Depletion of fossil fuels has significantly risen sharply. Exploitation of land resources and mass deforestation further brought about an accelerated increase in atmospheric concentration of carbon dioxide. The consequential effect on global climate is a phenomenon evidenced by recent global warming. Not only is it an ecological catastrophe, likewise, a substantial loss to our socio-economy. Taiwan is situated inside the subtropical climate zone, countermeasure to overcome humidity and high temperature poses great technological challenges. Frequent use of air conditioning without doubt prompts increases in energy consumption, highlighting importance of energy-saving countermeasures in a subtropical climate. This research examines Taiwan’s first zero-carbon green building, the Magic School of Green Technology in National Cheng Kung University. 13 energy-saving techniques are specifically applied during the initial building design phase. Dynamic building energy analytical software, eQUEST, funded by United States Department of Energy will be used to analyze and assess benefits of each energy-saving technique. Building Energy Management System (BEMS) was used to measure results of energy-saving since completion of the building in 2011. The building received diamond-grade tribute of Taiwan’s first zero-carbon green building. The energy consumption standard in the experimental research behind the Magic School of Green Technology stands at world class, turning itself an educational and R&D base for Taiwan green building.

II. RESEARCH METHODOLOGY AND CONTENT

Factors influencing the building’s energy consumption include outer-shell design such as orientation, window opening, sunshade, insulation, etc. Air conditioning, lighting, and the devices alike are also inputs in the energy-saving design. These combined factors surrounding energy consumption is very complex, and must first be rectified through continuous simulation to reach pre-determined energy-saving target.

This research encompasses two stages with the first one focusing on 13 energy-saving techniques that include window opening, sunshade, rooftop garden, fan-forced ventilation, buoyancy ventilation, air conditioning reduction, lighting reduction, air conditioning efficiency, lighting control, air exchange, power equipment, high-efficiency transformer, and renewable energy. BEMS is then used to explore actual energy-saving efficiencies in the second stage following building’s completion.

A. eQUEST Model Building Energy Consumption

Standard model building is established as an assessment method by setting similar simulated conditions such as climate, shape of building, operating duration, through eQUEST simulation analysis of energy consumption baseline for the whole year. eQUEST corresponds to constructing energy-saving techniques of the model building and the simulation analysis of energy consumption, benchmarking each of them against such baseline.

B. Energy Consumption Parameter of Standard Model Building

Weather data must first be defined in evaluating analysis of buildings’ energy consumption. The weather data of this research is based on typical meteorological year (TMY2) with 8760 hourly records in Taiwan. The energy consumption factors of the standard model building shown in Figure 1 employs 40% window opening rate; no sunshade; respective U value of 0.794 w/m²k and 0.99 w/m²k for exterior wall and rooftop; efficiency reference of air conditioner benchmarked by Bureau of Energy; light density at office space of 15 w/m², conference room of 20 w/m², and parking lot of 5.4 w/m². eQUEST is utilized for analyzing energy consumption of standard model building.

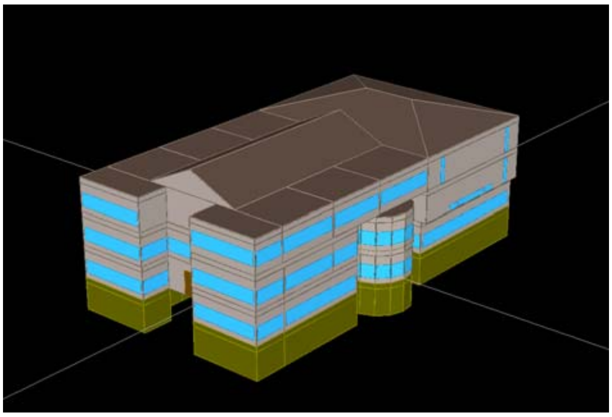

FIGURE I. STANDARD MODEL OF MAGIC SCHOOL OF GREEN TECHNOLOGY

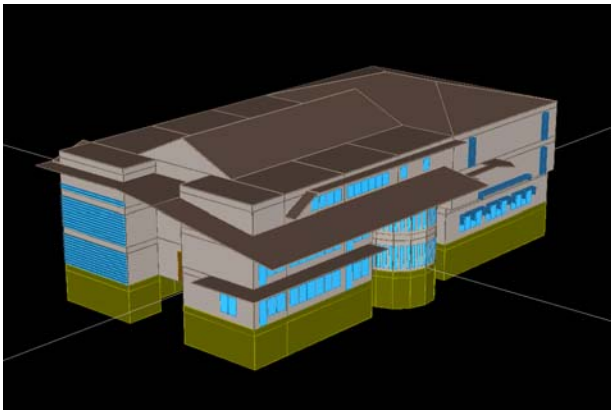

FIGURE II. OPENING REDUCTION AND SUNSHADE DESIGN

C. Energy Consumption Parameter of 13 Energy-Saving Techniques Model Building

1) Consumption Parameter of Energy-Saving Window Opening Design: Window opening design is the foremost important building block in energy-saving exterior plan. In the research cited from below reference footnote, it is found that rate of window opening directly affect air conditioning consumption under subtropical climate. The larger the opening the greater energy consumed with an estimate of 40%-50%. Figuring out how to restrain excessive opening should be the first step in energy-saving design. This research hence set the rate of opening at about 25% as shown in Figure 2.

2) Consumption Parameter of Energy-Saving Sunshade Design: Window opening is directly influenced by solar radiation; main cause of high air conditioning consumption. Sunshade design is then another important undertaking in reducing energy consumption used by air conditioning. Footnote research documented that sunshade can effectively block 68% of solar radiation annually while positioned on south-facing 45 degree angle under a subtropical setting. Through changes in air conditioning consumption used by office buildings, Sunshade can bring energy-saving benefits within tropical/subtropical countries such as Singapore, Hong Kong, Taipei, Tokyo, and Shanghai, by respective 15.8%, 15%, 12.9%, 15.6%, and 3.5%. It reveals the importance of energy-saving sunshade design under tropical/subtropical climate. The exterior building design in this research also employs sunshade as shown in Figure 2.

3) Consumption Parameter of Energy-Saving Rooftop Garden Thermal Insulation Design: Energy-saving characteristics of a building's insulation generally relate to conductivity or U value derived from its exterior wall and rooftop usage materials. Given an enhanced performance in thermal insulation as well as reduced solar radiation, operating expense can be lowered on lessening air conditioning load. This research uses insulation design by means of a rooftop garden. Through heat flow analysis, we discovered that regardless of its plantation, during hot summer days when outdoor temperature fluctuates between 7-10℃, such rooftop garden could maintain a surface temperature within 3℃ range. Demonstrating there is superior energy-saving benefits by reducing conductivity U value and solar radiation. The energy-saving rooftop garden design applied in this research is based on U value of 0.567 w/m^2k.

4) Consumption Parameter of Energy-Saving Fan-forced Ventilation Design: The purpose behind window opening design is principally drawing on vast amount of natural ventilation to effectively decrease air conditioning usage time. We make use of fan-forced ventilation in the office at temperature between 27-31℃. Only allow air conditioning when outdoor temperature exceeds 31℃ in order to reduce energy consumption. This research exploits the use of fan-forced ventilation design.

5) Consumption Parameter of Energy-Saving Buoyancy Ventilation Design: Indoor ventilation schemes can be divided into wind-induced and buoyancy ventilation. Tropical and subtropical climate zones possess good ventilation utilization rates due to prolonged monsoon and warmer season. Utilization rates for buoyancy ventilation tend to be low as cooler climate is not long enough. How to strengthen buoyancy ventilation utilization rate is a major breakthrough in this research on energy-saving technology. The research adopts passive solar chimney design along a large transparent glass window positioned southward at the ventilating roof. With the inner aluminum plate and surface body painted in black, they absorb heat via solar radiation, causing temperature differences among chimney and indoor to produce large channeling ventilation airflow. Further lengthening the usage time of buoyancy ventilation while shortens air conditioning annual operating duration. This research thereby introduces energy-saving buoyancy ventilation design.

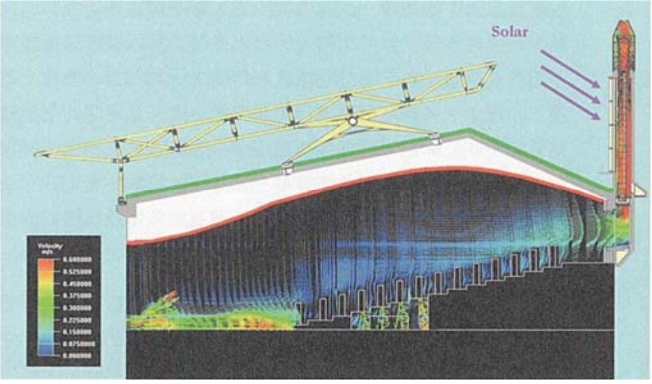

FIGURE III. BUOYANCY VENTILATION DESIGN CFD SIMULATION, INTERNATIONAL CONFERENCE, MAGIC SCHOOL OF GREEN TECHNOLOGY [2]

6) Consumption Parameter of Energy-Saving Air Conditioning Reduction Design: High air conditioning consumption is the primary cause of energy consumption. What makes such high energy consumption include poor divisional design, excessive host air conditioner load, and so on. In order to prevent excess loading, strict requirement for air conditioner heat load must be calculated. We prepared proper air conditioning division in this research to analyze dynamic heat load.

7) Consumption Parameter of Energy-Saving Lighting Reduction and Ambiance Control Design: Lighting design is one aspect often been neglected. Aside from excessive lighting generated by poor design, low luminous efficacy lights have also mistakenly used. Selecting the right high-efficiency light source shall for that reason be the first step of energy-saving lighting. This building uses Germany's lighting design software, DIALux, to simulate analysis of lighting. High-efficiency light sources such as T5 fluorescent, cold cathode fluorescent lamp (CCFL), and ceramic mental halide lamp are used with dimming control system installed to lower density of light. Lowering the density of light not only is beneficial in reducing energy consumed, but as well reducing the heat produced from indoor lighting. The light density in this research sets respective value of office space, conference room, and parking lot respectively at 9 w/m², 10.4 w/m², and 3.2 w/m².

III. Benefit Assessment And Verification of Energy-Saving Techniques

A. Benefit Assessment of Energy-Saving Techniques

eQUEST is used in performing different energy consumption of the model building's 13 energy-saving techniques. They are categorized into five major energy consumption items, including air conditioning, lighting, equipment, air exchange, and power equipment. Together make up the annual energy consumption of the building. This value then can be divided by the floor area to obtain EUI value. Poor sunshade design, improper ventilation, excessive air conditioning and lighting load, and inefficient facilities all result in rises in EUI. EUI is best in measuring the level of building's energy-saving indicator. Benefits of these 13 energy-saving techniques are shown below in Table 1 and Figure 4.

B. System Performance Verification and Actual Energy Consumption Analysis

Commissioning is a systematic process of ensuring that operational requirement of the new building such as air conditioning, lighting, power, and BEMS control system, are met with stated design intent. This building has begun operation in 2011, through actual readings from Building Energy Management System (BEMS) during January to September, shown in Table 2, accumulated EUI of 33.5 kWh/m².yr against eQUEST analytical assessment of 38.2 kWh/m².yr for the same period, shown in Table 3, Figure 5. Demonstrating that eQUEST analytical assessed value is very consistent with building's actual energy consumption readings. The energy consumption standard in the experimental research behind the Magic School of Green Technology stands at world class.

- Though this building was completed and begun operation in January 2011, however, the actual use of the office building commenced in around March to April. January to March was used as an adjustment phase for the operation of air conditioning. So eQUEST's estimated energy consumption is 18.8%, 22.8%, and 17.7% less for January, February, and March than actual consumption.
- There is a mutual relationship between actual energy consumed and daily scheduled operating time. Each occupied storey in this building consists of office, meeting room, a 300-person capacity international conference room space. During air conditioning operation in summer, eQUEST forecasts are based on a monthly usage of 24 days for office and meeting room space, and 16 days for the conference room. BEMS actual usage time for office space uses only 4, 23, and 21days for April, May, and June, respectively. Usage time for the meeting room space is far lower than the estimated days by 20% below. The actual usage for international conference room uses 5, 10, and 5 days for April, May, and June, far below eQUEST estimated days. So eQUEST's estimated energy consumption during the summer is 15%,12.3%,15.4%,16.2%,1.1%, and 1.5% less for April, May, June, July, August, and September than actual consumption.

TABLE I. “MAGIC SCHOOL OF GREEN TECHNOLOGY” BENEFIT ANALYSIS OF ENERGY-SAVING TECHNIQUES

Model Building	Step 0	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8	Step 9	Step 10	Step 11	Step 12	Step 13
	Standard Value	Window Opening	Sunshade	Rooftop Garden	Fan-forced Ventilation	Buoyancy Ventilation	Air Conditioning Reduction	Lighting Reduction	Air Conditioning Efficiency	Lighting Efficiency and Control	Air Exchange	Power Equipment	High-efficiency Transformer	Renewable Energy
Annual Air Conditioning Consumption [kWh]	172856	136008	120216	117584	101792	83368	67576	62964	47172	44262	44262	44262	35506	
Annual Lighting Consumption [kWh]	107720	107720	107720	107720	107720	107720	107720	83380	83380	62600	62600	62600	59783	
Annual Equipment Consumption [kWh]	29390	29390	29390	29390	29390	29390	29390	29390	29390	29390	29390	29390	28067	Annual Total Estimate 16187[kWh]
Annual Ventilation Consumption [kWh]	3677	3677	3677	3677	3677	3677	3677	3677	3677	3677	1047	1047	1000	
Annual Power Equipment Consumption [kWh]	10093	10093	10093	10093	10093	10093	10093	10093	10093	10093	10093	4829	4612	
Annual Total Energy Consumption [kWh]	323736	286888	271096	268464	252672	234248	218456	189504	173712	150024	147392	142128	128968	112781
EUI [kWh/m2.yr]	123	109	103	102	96	89	83	72	66	57	56	54	49	43
Accumulation Energy-saving Efficiency[%]	0.0%	11.4%	16.3%	16.5%	22.0%	27.4%	32.3%	41.0%	46.2%	53.4%	54.6%	55.6%	60.1%	65.1%

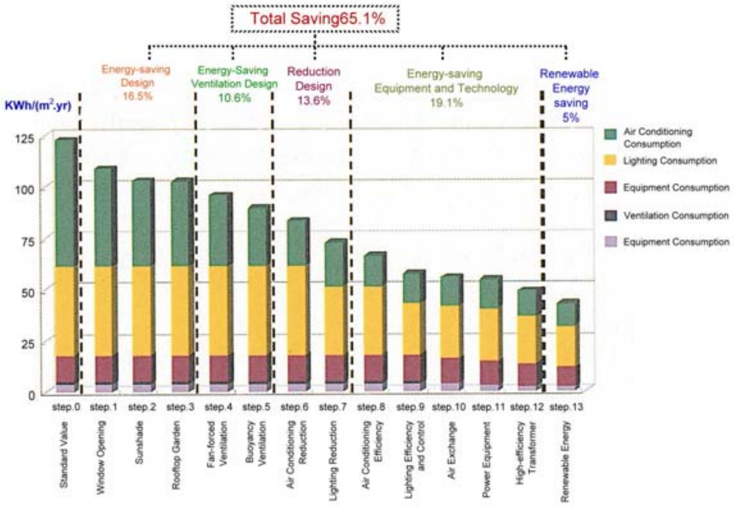

FIGURE IV. “MAGIC SCHOOL OF GREEN TECHNOLOGY” CUMULATIVE BENEFITS OF ENERGY-SAVING TECHNIQUES

TABLE II. 2011 JAN-SEP ACTUAL ENERGY CONSUMPTION

Month / Energy Consumption [kWh]	January	February	March	April	May	June	July	August	September
Air conditioning	0	0	1083	1408	3878	5088	5062	5016	4423
Lighting	1090	1308	1287	1323	1418	1352	1218	1298	1409
Power	2784	3112	3249	2123	3120	3019	2816	4143	4067
Outlet	1225	1325	1703	2050	2825	2722	2517	2829	2633
Total	5099	5745	7322	9318	11241	12181	11613	13286	12532

TABLE III. DIFFERENCES BETWEEN EQUEST SIMULATION ESTIMATE AND ACTUAL ENERGY CONSUMPTION

	January	February	March	April	May	June	July	August	September
eQUEST Simulation Estimate [kWh]	6280	7440	8900	10960	12820	14400	13860	13440	12730
Actual Energy Consumption [kWh]	5099	5745	7322	9318	11241	12181	11613	13286	12532
Differences [%]	-18.8%	-22.8%	-17.7%	-15%	-12.3%	-15.4%	-16.2%	-1.1%	-1.5%

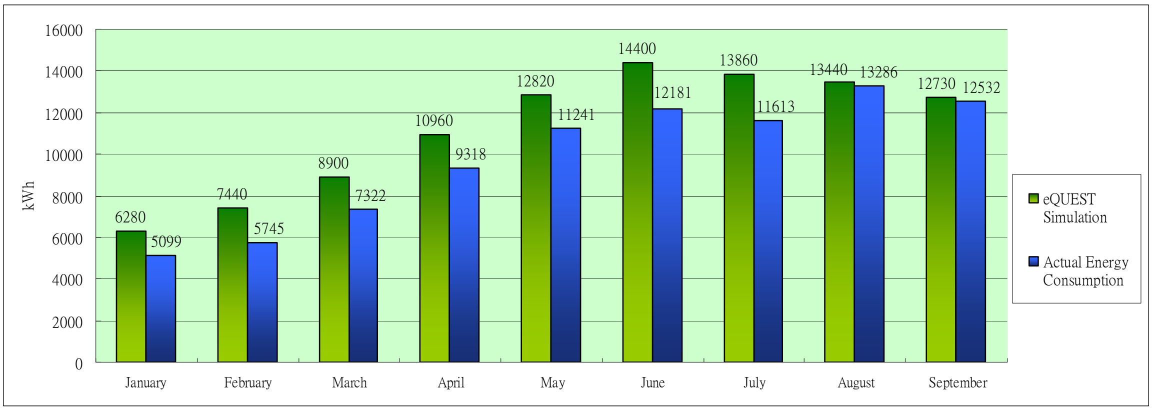

FIGURE V. DIFFERENCES BETWEEN EQUEST SIMULATION ESTIMATE AND ACTUAL ENERGY CONSUMPTION

IV. CONCLUSION AND RECOMMENDATIONS

This research is based on Taiwan's first zero-carbon green building-Magic School of Green Technology in National Cheng Kung University. Actual energy consumption will be measured to explore benefits of energy-saving. The design origin for this building encompasses 13 green energy-saving techniques. United States Department of Energy dynamic building energy analytical software, eQUEST, is used to execute the strictest energy consumption analytical assessment. It is forecasted to reach an energy-saving efficiency of 65% with energy use intensity (EUI) of 43 kWh/m².yr for the whole building, far below that of 169 kWh/m².yr found in Taiwan low/mid-rise office buildings, as shown in Table 4. The energy consumption standard in the experimental research behind the Magic School of Green Technology stands at world class.

This research is based on energy-saving of 65% as a baseline, converting carbon dioxide emission to each respective life cycle, our building releases 51% less in carbon dioxide than ordinary office buildings. The combined effort creates a world-class zero-carbon building wonder.

REFERENCES

[1] Hsien-Te Lin, Green Architecture (2006).

[2] Hsien-Te Lin, Thermal Environment of Human Habitat (2009).

[3] Hsien-Te Lin, Magic School of Green Technology (2010)

TABLE IV. TAIWAN OFFICE BUILDING EUI STATISTIC [3]

Category	Sample	Average EUI kWh/m².yr	EUI Standard Deviation
Government Office Building	20	134.42	42.99
High-Rise Office Building	132	240.94	87.01
Mid-Rise Office Building	115	225.6	115.3
Low/Mid-Rise Office Building	24	169.1	76.8
Low-Rise Office Building Without Elevator on Individual Air Conditioning Units	60t	96.7	67.9

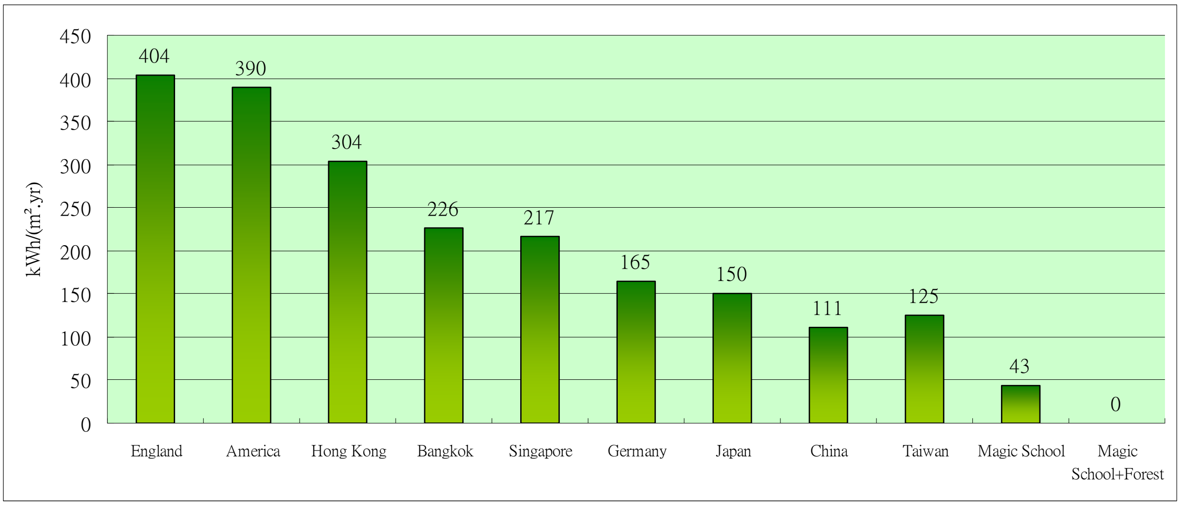

FIGURE VI. GLOBAL OFFICE BUILDING EUI COMPARISON [3]