國 立 交 通 大 學

機械工程學系

碩士論文

以能源分析模擬軟體(eQUEST)評估 EEWH 與 LEED 之認證

Application of Energy Simulation Tool (eQUEST) on Evaluating EEWH and LEED Performance

研究生：林彥佐

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中 華 民 國 九 十 七 年 六 月

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摘要

本論文利用動態能源模擬軟體(eQUEST)來分析建築物的整體耗能趨勢以及評估 EEWH 與 LEED 的認證。模擬的目標為台北萬華運動中心，其為地下兩層及地上七層的建築物。萬華運動中心總共採用了六個節能手法(ECMs)。為了瞭解各個節能手法的經濟效益以及耗能趨勢，本論文分析了各個節能手法的特性、初置成本以及回收年限。研究結果顯示照明密度降低(LPD)每年可節省 52,828 元，且其無須設備初置成本，為優先考慮的節能手法。可變水量系統(VWV)每年可省 129,277 元，回收年限為 2.1 年，為所有節能手法中最短，經濟效益最高的方法。反之，外氣冷房系統每年可節省 51,878 元，但其回收年限為 7.56 年，是所有節能手法中最長的，也是最後考慮採用的節能手法。為了評估 EEWH 系統的不足之處，本論文首先討論 EEWH 與 LEED 相同以及獨特的指標，然後專注於分析空調系統節能效率(EAC)的各個參數(空調節能技術效率標準)以及相對的空調節能技術，尋找改進 EEWH 評估系統的方法與策略。最後，本論文提出了許多改進的方法，提供設計者一個整體的能源分析觀念，並讓台灣未來綠建築能源分析的改進有一個參考的依據。

關鍵字：建築能源性能，綠建築，節能手法

Application of Energy Simulation Tool (eQUEST) on Evaluating EEWH and LEED Performance

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ABSTRACT

Through the use of dynamic energy simulation tool (eQUEST), this study analyzes the building integral energy consumption and evaluates EEWH and LEED performance. The simulation objective in this study is the Taipei Wan-Hua Sports Center, which includes two basements and seven floors. There are six energy conservation measures (ECMs) in this building. In order to understand the economy benefit and the energy consumption trend of these ECMs, this study analyzes the characteristic of ECM, initial cost and payback. The results show that Lighting Power Density (LPD) reduction can save 52,828 dollars per year. It is the first choice for the owner because it needs no initial cost. Variable water volume (VWV) system can save 129,277 dollars per year. Its payback is equal to 2.1, which is shortest within these ECMs, and it also has the best economy benefit. On the contrary, OA air conditioner system can save 51,878 dollars per year. However, its payback is equal to 7.56, which is longest within these ECMs. This ECM is also the last method, which designer considers adopting. In order to examine the defects and find improvement methods and strategies in EEWH system, this study compares the similar and unique indicators of EEWH and LEED assessment systems, and then it focuses on the analysis of EAC formula parameters (energy-saving efficiency) and corresponding ECM. Eventually, several improvements for EEWH are suggested. It provides an integral energy analysis concept for designer and an improvement reference for Taiwan building energy analysis in the future.

Keyword: Building Energy Performance, Green Building, ECM

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轉眼之間兩年的時光已經飛逝，縱然光陰似箭，但在這過程之中所體悟與學到的事情，卻深深的烙印在我的心中，永不抹滅。在這些光陰之中，不論是課業上的討論與互相激勵，或是論文撰寫應有的態度與技巧，都著實使我受益良多。

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NOMENCLATURE

A	Area
C_p	Heat Capacity
COP_{ci}	Coefficient of Performance Standard
ER	Energy Removal Rate
$f(Z)$	Z-Transform
F	View Factor
h	Convective Heat Transfer Coefficient
HC_i	Chiller Capacity
M	Measured Energy Consumption
PR	Design Power Ratio
Q	Instantaneous Heat Gain
Q	Cooling Load
R	Energy-Saving Efficiency
R	Thermal Resistance
S	Simulated Energy Consumption
t	Deviation of Air Temperature
T	Surface Temperature
$Y(n)$	Y-Response Factors
$Z(n)$	Z-Response Factors

Greek Symbols

σ	Stefan-Boltzmann Constant
ε	Emissivity
θ	Time
ρ	Density
v, ω	Heat Gain Weighting Factors

ν , P	Air Temperature Weighting Factors

Superscript

‘	Outside Surface

Subscript

A	Room-Air
C	Convection
D	Conduction
F	Fan System
I	Wall i
M	Other Systems
O	Outside-Air
P	Pump System
R	Radiation
S	Heat Source System
V	Infiltration

Abbreviation

AHU	Air Handle Unit
CAV	Constant Air Volume
EEWH	Ecology, Energy Saving, Waste Reduction, Health
ECM	Energy Conservation Measures
EUI	Energy Use Index
ETS	Environment Tobacco Smoke
EA	Exhaust Air

FC	Fan Coil
HVAC	Heating, Ventilating and Air-Conditioning
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
LEED	Leadership in Energy and Environmental Design
LPD	Lighting Power Density
OA	Outside Air
VAV	Variable Air Volume
VWV	Variable Water Volume
VRV	Variable Refrigerant Volume
VFD	Variable Frequency Device

CHAPTER 1

INTRODUCTION

1.1 Motivation

Because of the energy shortage crisis and the rapid change of global climate, they become the important issues for world to save energy and to reduce the emission of carbon dioxide. Generally speaking, the usage of energy is closely related to the emission of carbon dioxide. When improving energy efficiency and adopting the energy-saving design, the advantage is not only providing low operating cost for stakeholders, but also reducing the impact to the global environment, and reaching the purpose of sustainable development.

Ninety eight percent of energy resource in Taiwan is imported, and the energy consumption for building air-conditioner system occupies one-third of total peak power in summer. Furthermore, energy management of heating, ventilating and air-conditioning (HVAC) systems is a primary concern in building projects, since the energy consumption in electricity has the highest percentage in HVAC systems among all building service installations and electric appliances. The significance of energy-saving for air-conditioner system is now very obvious. Hence, it has the most investment benefit and least payback duration of the initial cost for designing energy-saving methodology on HVAC system. It is usually the most cost-effective way to improve energy efficiency of air-conditioned buildings. In addition, according to the statistics of

Taiwan Power Company, the power consumption of HVAC system nearly rises 6 percent when outside air peak temperature rises one degree of Centigrade in summer. Thus, it can be found that optimization design of HVAC system plays an important role in energy-saving.

Energy-saving assessment systems are varied in each nation. For examples, Leadership in Energy and Environmental Design (LEED) is adopted in America, whereas Green Buildings (EEWH) is used in Taiwan. These assessment systems are separated into two assessment standards for New Construction and Existing Buildings, respectively. Through the assessment procedures of EEWH and LEED, they should be able to improve the building energy consumption and the equipment efficiency. In order to promote energy-saving design and to properly select high efficiency equipments, this study focuses on New Construction with greater application range comparatively. More specifically, this study pays close attention to energy saving indicators which have direct relationship to energy consumption performance.

In the Green Building Certification in Taiwan, it has four categories: Ecology, Energy Saving, Waste Reduction, Health, abbreviated as EEWH system. These indicators can be further categorized into nine detailed indicators, which are summarized in **Table 1.1**. For the HVAC system assessment method of Energy Saving Indicator, EEWH adopts the Heat Source Capacity Density and COP Method (HDC). In other words, the intent is (1) to prevent over design of the chiller, (2) to encourage the use of high efficiency chiller, and (3) to reward the energy-saving design of air-conditioning system.

Table 1.1 EEWH System Structure

Category	Indicator
Ecology	Biodiversity
	Greenery
	Soil Water Content
Energy Saving	Energy Saving
Waste Reduction	CO_2 Emission Reduction
	Waste Reduction
Health	Indoor Environment
	Water Resource
	Sewage and Garbage Improvement

As to LEED-NC (New Construction) standard, it is categorized into six indicators, which are listed in **Table 1.2**.

Table 1.2 LEED System Structure

Indicator	Prerequisite
Sustainable Sites	• Construction Activity Pollution Prevention
Water Efficiency	N/A
Energy and Atmosphere	• Fundamental Commissioning of the Building Energy Systems • Minimum Energy Performance • Fundamental Refrigerant Management
Materials and Resources	• Storage & Collection of Recyclables
Indoor Environmental Quality	• Minimum IAQ Performance • Environmental Tobacco Smoke (ETS) Control
Innovation and Design Process	N/A

In Energy & Atmosphere Indicator, C1: Optimizing Energy Performance occupies 10 points of total score (17 points), and its assessment method is to apply energy simulation program. Such program should be a computer-based one, such as, but not limited to, DOE-2, BLAST, or Energy Plus, for the analysis of energy consumption in buildings. In order to qualify the prerequisite of Minimum Energy Performance, to comply with ASHARE Standard 90.1 is needed. If the designer wants to get more points in Energy & Atmosphere Indicator, he can apply for C1: Optimizing Energy Performance further. The score which can be obtained from this indicator is according to different energy cost savings percentage. The minimum energy cost saving percentage for each point threshold is tabulated in **Table 1.3**. Furthermore, the designer must submit the information of energy simulation parameters and related reports when he applies for this indicator.

Table 1.3 Minimum Energy Cost Savings Percentage

New Building	Existing Building Renovations	Points
10.5%	3.5%	1
14%	7%	2
17.5%	10.5%	3
21%	14%	4
24.5%	17.5%	5
28%	21%	6
31.5%	24.5%	7
35%	28%	8
38.5%	31.5%	9
42%	35%	10

1.2 Literature Review

Energy consumption is one of the major types of costs throughout the lifecycle of a building. Due to the rising cost of energy, search for efficient ways of HVAC system operation becomes an important issue for

Air-Conditioning engineers. Energy simulation tool can assist engineer for decision-making regarding various alternatives of a retrofitting project or the alteration of an existing facility. Once an energy saving plan is decided and executed, the process is difficult to be reversed or revised, so it need a convenient and accurate method to assess energy consumption at the very beginning.

Zhu [1] reported that computer-based simulation is a valuable technique to assist the air-conditioner engineers in determining energy conservation solutions. This study combined the portfolio manager developed by Environmental Protection Agency (EPA) and eQUEST developed by Department of Energy (DOE) to analyze the operation of an existing facility in order to formulate methods for reaching the Energy Star Designation, an EPA certification. Paired-samples t-tests were applied to compare the simulation data with the actual electricity bills to determine if there is a significant difference. He found that the cross-effect of two energy saving plans, such as lighting energy reduction and HVAC fan operation schedule, can be calculated by the simulation model, while a manual-based audit may overlook such effect.

Yezioro et al. [2] presented an approach for comparing simulated results with actual measurements, using 1 week of acquired data, which were assumed to be able to generate one year electricity consumption. This approach was enabled through the use of an artificial neural network (ANN), which can establish one year energy consumption through iterative procedure. In order to compare simulation results with the ones generated by ANN method, this study selected four tools: Energy_10, Green Building Studio web tool, eQUEST and EnergyPlus. The results showed that the more detailed simulation tools, such as eQUEST and EnergyPlus, have the best simulation performance and the absolute error is within 3 percent. However, they require detailed definitions of building properties. For this reason, the important subject is to simplify the inputs and to reduce processing time of detailed energy simulation tools while getting the same accuracy of results.

Medrano et al. [3] used eQUEST as energy simulation tool to analyze the effects of distributed generation (DG) of combined cooling, heat and power (CCHP) on four types of building (small office building, medium office building, hospital, and college) in southern California. The results showed that hourly load profiles for electric and thermal loads are important for better understanding the energy consumption characteristics and predicting how well DG system can be integrated. The case of hospital presents the most compatible match with DG with heat recovery integration due to a coincident and flat electric and thermal loads, and to a relatively low electric to thermal ratio (E/T ratio = 1.1). The college and the office building cases do not show such a favorable match with micro-turbines and high temperature fuel cells in terms of load profiles and E/T ratio.

The implementation of energy conservation measures (ECMs) can be served as a cost-effective means of reducing energy consumption in buildings. Iqbal et al. [4] investigated the impact of alternative ECMs on energy requirements in office buildings by using DOE energy simulation tool. In this study, ECMs were classified into the three categories of no cost, low cost and major investment measures. The results showed that no-cost measures will result in about 13% annual electric energy saving.

For low-cost measures, only energy-efficient lamps can be used and it will result in a 6% annual energy savings. For the high investment cost measures, VAV system can save about 17%. By implementing all combined ECMs, about 36% of electric energy can be saved annually. Furthermore, Paulo and Antonio [5] presented that the designed temperature should be chosen in a conservative way, higher in summer and lower in winter that is usually accepted by most designers. He indicated that control systems should be programmed to allow thermostat setting not to exceed 1 degree Centigrade in winter but to allow for a wider range in summer, from 1 to 3 degree Centigrade.

Yang [6] made the comparison between domestic and overseas Green Building assessments. He collected related results from domestic basic research to develop an assessment tool for Green Building office building. Furthermore, the practical plan case was brought into analysis and compared with other Green Building assessment tool. Besides, the characteristics of Taiwan local climate were put into consideration. The developed assessment tool had three features, (1) it can give overall assessment about environment impact influence, (2) it can guide designers to take concepts of Green Building into consideration during the initial stage of design, (3) the appearance of assessment tool includes environment burden assessment table and Green Building office building design technical examination table.

The subject of building energy saving is not only to save energy but also to consider the comfort and health of the living environment. Xiao [7] presented an optimal design for the building energy saving of commercial buildings in Taiwan. In this study, theoretical analysis and a full scale experiment were performed to validate this design. The results showed that this design is suitable for the NPTC building in the weather condition of south Taiwan and, also complies with the energy code of Taiwan.

Lin et al. [8] investigated the difference between EEWH and LEED based on their executive institute, certification process, content of each indicator or credit, and system of professional engineer signature. They selected four cases to be evaluated with LEED system. 228 Memorial Park and Taichung Winery Re-Furnishing were the two cases in Taiwan, while American HONDA Training Center and NRDC Santa Monica Office were another two cases in USA. There were several suggestions proposed for future improvement in EEWH: (1) to add the evaluation for lighting pollution reduction, (2) to set up the least number of parking capacity, (3) to encourage flexible building design, (4) to set up whole building performance evaluation instead of prescriptive guideline, (5) to subdivide the usage of building material, (6) to set up the commissioning system, (7) to add more lately green building projects as design references, and (8) finance/building cost related research in the future.

Kerrisk et al. [9] reported that the method used in DOE-2 was custom weighting factors. In principle, the custom weighting factor method was the same as the original Mitalas and Stephenson method. However, many details of the calculation had been modified. This study described the basis for the custom weighting factor method and its implementation in DOE-2. The equations used to calculate the weighting factors were developed. Besides, assumptions required for weighting factors in general, and miscellaneous assumptions and models employed in DOE-2 were also discussed.

Wen et al. [10] presented a real time system embedded with energy management control (EMC) functions. They included outside air (OA) economizer cycle, programmed start and stop lead time, load reset and occupied time adaptive control strategy. The simulation results manifested that comparing with the system without such functions, 17% of energy savings could be achieved when the system was operated with the EMC functions and optimal set points. These results did point out that the optimal set point strategy was very useful in achieving efficient energy operation of HVAC systems.

Stefano et al. [11] reported that the energy demand for heating and cooling was directly affected by the required level of thermal comfort. The connection between indoor thermal comfort conditions and energy demand for both heating and cooling was analyzed in this study. Once a range of required acceptable indoor operative temperatures were fixed in accordance with Fanger’s theory (e.g. $-0.5 < PMV < -0.5$), the effective hourly comfort conditions and the energy consumptions were estimated through dynamic simulations.

Due to the complicated interrelationship of the entire HVAC system, it is necessary to suggest optimum settings for different operations in response to the dynamic cooling loads and changing weather conditions. Fong et al. [12] investigated a meta-heuristic simulation-EP (evolutionary programming) coupling with approach using evolutionary programming. It could effectively handle the discrete, non-linear and highly constrained optimization problems, such as those related to HVAC systems. This reset scheme would have a saving potential of about 7% as compared to the existing operational settings, without any extra cost.

Pan et al. [13] reported that the proposed building was compared to an ASHRAE 90.1-2004 compliant baseline building to evaluate energy cost savings and showed the potential for LEED Credit EA1-Optimize Energy Performance through energy modeling. The whole building energy simulation results showed that the yearly energy cost saving of the proposed design would be approximately 27% from China Building Code and 21% from ASHRAE baseline building, which could gain 4 points for LEED credit due to energy performance optimization.

Pan et al. [14] introduced the method of calibrated energy simulation, and presented one case study by using that method to analyze the energy consumption of a high-rise commercial building in Shanghai. This study clearly explained the calibrated simulation steps and then used the calibrated model to analyze the ECMs performance, with using variable speed chilled water pumps instead of constant variable speed ones, free cooling during winter and mild seasons, and decreasing lighting power densities. The results showed that VWV system is the best ECM.

Viral et al. [15] reported the life cycle impacts of three residential heating and cooling systems: warm-air furnace and air-conditioner, hot water boiler and air-conditioner, and air-air heat pump over a 35-year study period. In Minnesota, Pennsylvania, and Texas, the heat pump had the highest impacts whereas in Oregon the heat pump had the lowest impacts. A second analysis showed that substitution of high-efficiency equipment could reduce the impacts of all systems, but did not affect the order of relative performance by regions. Another analysis examined the replacement of coal-generated electricity by renewable generation in regional grids. In order to reduce the impacts of the heat pump system to the lowest of the three systems, renewable sources would have to replace 42% of electricity generation in Minnesota, 15% in Pennsylvania, and 38% in Texas.

Related standards that adopted in this study include ASHARE Standard 62.1 [16], ASHARE Standard 90.1 [17], M&V Guidelines [18], LEED-NC [19], and Evaluation Manual for Green Buildings in Taiwan 2007 [20].

1.3 Scope of Present Study

The intents of this study are to analyze the indicators for both EEWH and LEED in order to let Taiwan Green Building Evaluation System become more internationalized and popular. First, this study compares the similar and unique indicators of these two assessment systems to examine the defect of EEWH. Then, this study focuses on the analysis of EAC formula parameters in order to find improvement method and strategy.

EEWH has different ECM and efficiency criteria, but it just serves as a qualified benchmark and cannot be understand the real benefit of ECM. The intent of EEWH is to encourage the establishment of Green Building so it has many weighted measures. In other words, EEWH is a broad assessment system and cannot quantify the proportion of energy saving. In contrast with EEWH, it adopts energy simulation tool to fully analyze the energy use in LEED. Through the comparison between the baseline building performance, according to ASHARE Standard 90.1, and the proposed building performance, the designer can analyze the real benefit of ECM and understand the resultant effects by using different parameters.

From above description, Taipei Wan-Hua sports center is selected to use EEWH and LEED assessment systems, respectively, to evaluate and analyze the building energy use, and then analyze defects of EEWH in practice. Eventually, several improvements for EEWH are suggested. The research flowchart is illustrated in **Fig. 1.1**.

CHAPTER 2

COMPARISON BETWEEN EEWH AND LEED

2.1 Comparison of Executive Agency

The comparison of executive agency is tabulated in **Table 2.1**.

Table 2.1 Comparison of Executive Agency

System	EEWH	LEED
Mark Drawing		
Assessment System Name	Ecology, Energy Saving, Waste Reduction, Health	Leadership in Energy and Environmental Design
Established Way	Government Guidance	Private Initiative
Application Method	Public Building: Compulsion Private Building: Voluntary	Complete Voluntary
Incentives Method	Medals Awarded Supporting Incentives	Medals Awarded No Any Incentives
Implement Structure	From the Government to the Private Enterprise	From the Private Enterprise to the Government
Agencies	TABC	USGBC

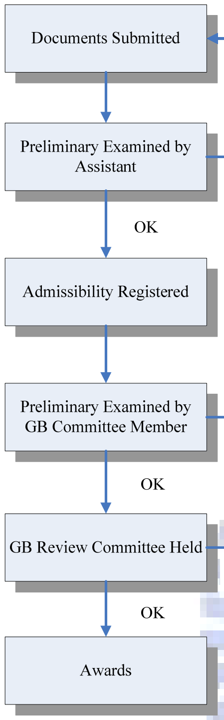
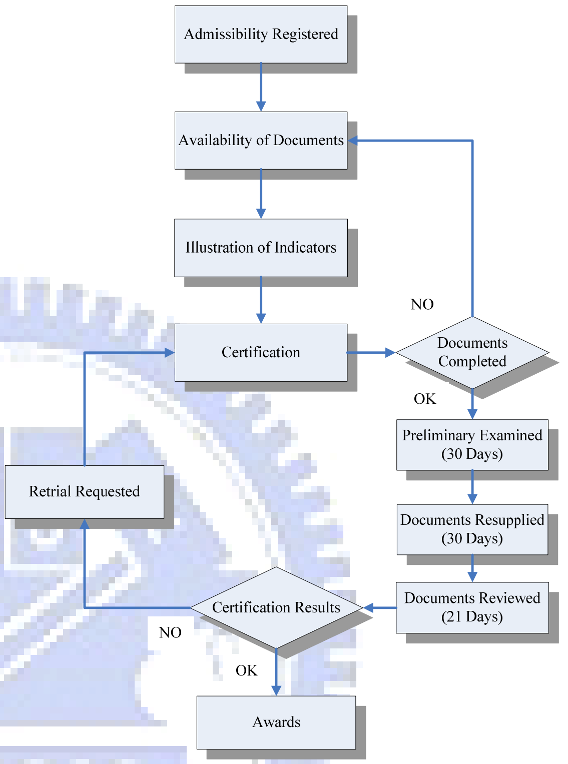
In order to promote the design and development of Green Building in Taiwan, it established EEWH assessment system in 2001. Construction and Planning Agency, Ministry of the Interior (CPAMI), appointed Taiwan Architecture and Building Center (TABC) to review and certify Green Building Certification. At the beginning, the application was completely voluntary, but it was ineffective in the end. For this reason, government decided to take the lead to set an example. In Taiwan, the government requests all public buildings, whose costs are more than 50 million NT dollars, to obtain the Green Building candidate certificate before it starts to build. Hundreds of buildings have possessed candidate certificate since June 2005. The government policy also attracts private buildings to voluntarily apply certification. Therefore, the executive track of Green Building in Taiwan now is from the Government to the private sector. However, it has many restrictions for public buildings to apply Green Building because of the intervention of government.

In contrast with EEWH led by the government, LEED assessment system in American is completely formulated by the private sector and handled by U.S. Green Building Council (USGBC) now. USGBC is a private corporation, which is not controlled by the government. It only handles with the buildings which have been built and does not have time restriction to accomplish assessment works. Besides, USGBC entrusts the assessment work to professional Commissioning Company. The benchmark is high because LEED does not force the building to apply the certification. Therefore, the buildings, which pass LEED certification and no matter what score they obtain, are perfect Green Building works. Overall, Green Building in Taiwan is a negative prevention attitude, but LEED actively encourages good design. The executive track of LEED, opposite to EEWH, is from the private sector to government. To promote Green Building market trend by the power of private sector and then attract the government's vision to follow.

2.2 Comparison of Assessment Procedure

The comparison of assessment procedure is listed in **Table 2.2**.

Table 2.2 Comparison of Assessment Procedure

<table>
<tr><th>EEWH System</th><th>LEED System</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

The assessment procedure of EEWH is divided into Green Building candidate certificate and Green Building mark. The generation of candidate certificate is because public building needs to acquire Green Building mark before it is permitted to build. In other words, candidate certificate is regarded as a quasi-mark of Green Building and the real mark should be obtained after the construction is completed.

First, the design team applies for assessment when necessary documents are collected and then hand over to TABC which will notify design team if documents have any lack. The Green Building committee member firstly certifies the case and then holds a meeting to review it. If all committee members unanimously adopt this result, TABC will hold presentation ceremony. The assessment time must be short enough to prevent the impact to project time limit. Therefore, the total review time for applying Green Building candidate certificate is about one month.

In contrast to Taiwan Green Building, whose review time is hasty, the assessment of LEED has no time restriction at all for a project because it handles the building which had been built. For the beginning of design, USGBC suggests applicant to register the case first and let committee member understand the progress of the project. After completion, designer or owner collects necessary documents and then applies for LEED certification. USGBC just reviews documents but entrusts the assessment work to professional Commissioning Company. Such Company possesses various types of professionals because LEED system has six indicators. According to the characteristics, USGBC entrusts the assessment work to different companies. The preliminary assessment time is one month and it has additional one month for design team to re-supply documents. The assessment review will be finished within three months. If owner accepts the result, USGBC will hold presentation ceremony. If owner does not accept the result, he/she can request another review but needs to pay additional cost.

2.3 Qualitative Comparison of Indicators

The contents of EEWH and LEED are different in some standards owing to the local climate and national conditions, however, the most of them are similar. In this study, it compares the indicators that both assessment systems have mentioned and then compares the ones that rather special or unique. The sequence of comparison is based on the structure of EEWH system. The comparison of indicators is listed in **Table 2.3**.

Table 2.3 Comparison of Similar Indicators

EEWH	LEED	Related Method
Biodiversity	Water Efficient Landscaping Construction Activity Pollution Prevention	Original Plant Drought-Enduring Plant Soil Protection
Greenery	Site Development Heat Island Effect Water Efficient Landscaping	Original Ecology Maintenance Artificial Destruction Reduction Original Plant Selection
Soil Water Content	Stormwater Design Heat Island Effect	Detention Pond Storage Open Space Permeable Pavement
Energy Saving (Electricity Only)	Minimum Energy Performance Optimize Energy Performance On-Site Renewable Energy Measurement & Verification	Energy-Saving Design Renewable Energy Energy Monitor System CO_2 Concentration Sensor
CO_2 Emission Reduction	Building Reuse Materials Reuse Recycled Content Regional Materials	Building Reuse Renewable Materials Regional Materials
Waste Reduction	Building Reuse Construction Waste Management Materials Reuse Recycled Content Construction Activity Pollution Prevention	Building Reuse Construction Waste Reduction Renewable Materials Construction Pollution Prevention
Indoor Environment	Rapidly Renewable Materials Certified Wood Minimum IAQ Performance Increased Ventilation Low-Emitting Materials Daylight & Views	Indoor Material Ventilation Environment Light Environment
Water Resource	Innovative Wastewater Technologies Water Use Reduction	Captured Rainwater and Recycled Wastewater Devices High Efficiency Sprinkler System Water-Saving Devices
Sewage and Garbage	Storage & Collection of Recyclables	Centralized and Classification of Garbage

2.3.1 Comparison of Similar Indicators

2.3.1.1 Biodiversity Indicator

The assessment of Biodiversity Indicator is divided into five parts. One is Plant Diversity which encourages the use of original plant or of plant which can lure birds and butterflies. In LEED system, Water Efficient Landscaping Indicator also encourages the uses of original plant and drought-enduring plant which can save water.

In another part of Biodiversity Indicator, Soil Ecology indicates that in order to protect soil during construction, workers must centralize soil and sprinkle on it. This part is the same as Construction Activity Pollution Prevention Indicator, which regulated by LEED.

2.3.1.2 Greenery Indicator

In order to maintain the original natural environment, this indicator encourages designer to maintain a site's original ecology and reduce artificial destruction. Site Development Indicator of LEED has the same viewpoint. For this reason, it encourages designer to maintain natural of open space and reduce the range of artificial destruction. However, this indicator mainly aims at a site, located in the country. If a site is located in the city, it is hard to reach this purpose because there are no such environmental conditions.

On the other hand, LEED encourages designer to plant trees in order to reduce Heat Island Effect, it is the same purpose as Greenery Indicator in EEWH which encourages designer to plant arbor. Although Water Efficient Landscaping Indicator in LEED does not encourage designer to plant a lot of area, but it is the same as EEWH which encourages designer to select original plant.

2.3.1.3 Soil Water Content Indicator

This indicator is divided into Direct Infiltration and Storage Infiltration. Storage Infiltration design method is the same as Stormwater Design Indicator in LEED which adopts detention pond and storage open space. In Direct Infiltration, it has the effect on reducing flood peak and runoff amount. Besides, this indicator sets up kinds of green space, grass ditch and permeable pavement which have the effect on reducing Heat Island Effect. It is the same idea with Heat Island Effect Reduction Indicator in LEED.

2.3.1.4 Energy Saving Indicator

In Energy Saving Indicator, it makes efforts to reduce building energy consumption in both EEWH and LEED assessment systems. For this reason, these two assessment systems both require building energy consumption to be lower than baseline and then designer can obtain rewards. However, the reduction ranges are different because of climate conditions. In LEED, it can reduce 42 percent of energy use, whereas it can only reduce 20 percent of energy use in EEWH. From viewpoint of LEED, Energy Saving Indicator belongs to integral energy use assessment, adding different energy consumption to assess it. However, EEWH is divided into Envelope, HVAC System and Lighting System, which are assessed respectively. Furthermore, LEED adds several kinds of energy, such as electric power, fuel gas and oil, and takes integral assessment, but EEWH only assesses electric power because it is the main type of energy used in Taiwan.

Both EEWH and LEED systems encourage renewable energy in order to utilize alternative energy. Because of climate conditions, the efficiency of renewable energy is low in Taiwan, and it is hard to substitute the existing building energy consumption for 5 to 20 percent. Thus the universality of renewable energy in Taiwan is still in a preliminary phase.

The different method of HVAC energy saving is encouraged by EEWH. Although a starting point of LEED is based on installing CO_2 concentration sensor, whose purpose is on considering occupants' comfort, but it still has effect on energy saving. These two assessment systems have reward for installing energy monitor system.

2.3.1.5 CO_2 Emission Reduction Indicator

Both EEWH and LEED assessment systems encourage the use of renewable materials in building. LEED divides it into four parts, which are Materials Reuse, Recycled Content, Regional Materials and Rapidly Renewable Materials. To recycle building materials and products can reduce construction waste and demand for virgin materials. For this reason, it can reduce CO_2 emission associated with the extraction and processing of virgin resources. On the other hand, to increase demand for building materials and products, which are extracted and manufactured within the region, can reduce the environmental impacts and CO_2 emission resulting from transportation.

EEWH mainly promotes renewable materials which mix with concrete because the main content of building materials in Taiwan is almost concrete. In the part of Recycled Content, EEWH does not consider the recycle of metals because it has 80 percent recycle rate in Taiwan. Although it also has high recycle rate in American, LEED considers the recycle of metals. On the other hand, EEWH promotes the use of blast furnace concrete because it has preferential calculation for the concrete, which adds ashes of a stove.

2.3.1.6 Waste Reduction Indicator

Both EEWH and LEED assessment systems pay attention to Construction Waste Management. The waste soil is not counted in LEED because it does not have many cases which dig the basement in American. In other words, the waste soil, which is cleared up for the purpose of construction, is not counted in construction waste unless the site contains trash and debris initially.

In the last item of EEWH, it encourages to prevent pollution from the generation during construction. Although it is simple pollution prevention and public health, but the meaning is the same as that of LEED.

2.3.1.7 Indoor Environment Indicator

Indoor Environment Indicator is divided into Sound Environment, Lighting Environment, Ventilation Environment and Indoor Materials. LEED has the same regulations except the Sound Environment. In the part of Ventilation Environment, EEWH includes Mechanical and Natural Ventilation. EEWH requires the same Minimum IAQ Performance and Ventilation Effectiveness as those of LEED. EEWH only uses windows' area and seal tightness to assess ventilation, whereas LEED uses experimental assessment method or computer simulation which is according to ASHRAE Standard.

In the part of Lighting Environment, it divided into Artificial and Natural Lighting. In LEED, Artificial Lighting is classified as energy-saving design and assessed with integral building energy consumption. In the part of Natural Lighting, it is related to Controllability of Systems and Daylight & Views indicators, which are regulated by LEED.

In the part of Indoor Materials, it overlaps with CO_2 Emission Reduction Indicator. LEED divides Green Materials, also promoted by Taiwan, into four parts: Materials Reuse, Recycled Content, Regional Materials and Rapidly Renewable Materials. These products enter the market for years and their prices now can be accepted by the public. However, there has no material testing certification agency in Taiwan, therefore, it only can import Green Materials from abroad that leads to higher price. For this reason, the concept of Indoor Materials is still in the very preliminary stage in Taiwan.

2.3.1.8 Water Resource Indicator

EEWH pays much more attention to the use of water-saving devices that is the same as the regulation of Water Use Reduction in LEED. Besides, EEWH requests facilities, which have large water consumptions, to install the rainwater and recycled wastewater capture devices. For the large development of green land, EEWH also requests designer to install high efficiency sprinkler system. LEED has the same regulation in Water Efficient Landscaping Indicator.

2.3.1.9 Sewage and Garbage Improvement Indicator

In this indicator, it is divided into Sewage and Garbage parts. LEED focuses on the centralized handling and classification of garbage, but it does not emphasize the importance of beautification surroundings. Besides, LEED does not emphasize sewage treatment device either because American homes usually have laundry room.

2.3.2 Comparison of Unique Indicators

In this study, it finds that EEWH and LEED have their own unique indicators, which are not included in both assessment systems simultaneously. The reasons are that different areas have different climate conditions, and some standards of EEWH are regulated by other laws, such as Environment Protection Code. The unique indicators in EEWH and LEED are listed in **Table 2.4** and **Table 2.5**, respectively.

Table 2.4 Unique Indicators in EEWH

Category	Indicator	Illustration
Biodiversity	Ecological Network Biological Habitat Plant Diversity Soil Ecology	N/A
Greenery	Plant Arbor To Green a lot of Area	LEED Pays Attention to Water Efficiency
Indoor Environment	Sound Environment Indicator	N/A

Table 2.5 Unique Indicators in LEED

Category	Indicator	Illustration
Sustainable Sites	Site Selection	Regulated by Other Related Laws
	Development Density	
	Brownfield Redevelopment	Urban Renewal
	Alternative Transportation	Parking Area
	Light Pollution Reduction	Classified to Biodiversity Indicator
Energy and Atmosphere	Fundamental Commissioning	Project Management
	Enhanced Commissioning	
	Fundamental Refrigerant Management	Environment Protection Code
	Green Power	No Contract
IEQ	ETS Control	HVAC Systems of Smoking Room
	Construction IAQ Management Plan	
	Indoor Pollutant Source Control	
	Controllability of Systems	
	Thermal Comfort	

2.3.2.1 Unique Indicators in LEED

2.3.2.1.1 Sustainable Sites

LEED requests owner to avoid development of inappropriate sites and reduce the environment impact from the location of a building on a site. Designer needs to select a developed area, if the site is located in the city. On the contrary, if the site is located in the country, designer must maintain the original open space and reduce the artificial destruction. LEED has many criteria to regulate the development in a sensitive area, whereas it is regulated by the other related laws in EEWH. Besides, the Brownfield Redevelopment is encouraged by LEED. It is the same as urban renewal but is hard to execute for building industry in Taiwan.

It has criteria of Alternative Transportation in LEED, the intent is to reduce pollutions and land development impacts from the use of automobiles. There are some advantages, such as installation of Bicycle Storage & Changing Rooms and reduction of Parking Capacity, which EEWH can follow.

LEED also pays attention to the part of Light Pollution Reduction, whose intent is to minimize light trespass from the building and site and reduce development impact on nocturnal environments. Light Pollution is categorized into Biodiversity Indicator in EEWH, but it just has qualitative regulation and needs modification in the future.

2.3.2.1.2 Energy and Atmosphere

In American, it has Commissioning Team, whose feature is similar to project management, to help owner to apply LEED. However, it does not have such company in Taiwan now. In fact, EEWH is still in the preliminary stage in this part. LEED also has criteria of Fundamental

Refrigerant Management to prevent CFC from destroying ozonosphere. In this regard, it is regulated by environment protection standard in Taiwan. For the development of Green Power, it cannot be executed in Taiwan because there is no corresponding law yet.

2.3.2.1.3 Indoor Environmental Quality

It only requests to set up smoking room in EEWH, but it does not have any regulation for HVAC system of smoking room. The smoke may spreads from smoking room to the other rooms by HVAC system. On the contrary, LEED has criteria of Environment Tobacco Smoke (ETS) Control, whose intent is to minimize the smoke spread to building occupants, indoor environment, and ventilation air distribution systems. Besides, LEED requests the separated IAQ managements during construction and before occupancy. Construction IAQ management before occupancy is very important because it has effect on the health of occupants. However, it does not have related regulation in EEWH.

In the subject of thermal comfort, LEED pays attention to the controls of temperature and humidity. The intent is to provide a comfortable thermal environment that supports the productivity and well-being of building occupants. On the contrary, it does not consider the thermal comfort in EEWH.

2.3.2.2 Unique Indicators in EEWH

2.3.2.2.1 Biodiversity Indicator

In order to reduce the environment impact and reach the sustainable purpose, EEWH uses ecological network, biological habitat, plant diversity, and soil ecology to assess a site. In comparison with EEWH, LEED does not mention this subject except soil protection.

It seems not to concern about natural environment in LEED, but it is not the truth. America has broad land, fine ecological environment, and many places even are original woodlands and not developed yet. Thus, the intent of LEED is to maximize open space and reduce a site disturbance, which is the best way for local ecological environment.

2.3.2.2.2 Greenery Indicator

This indicator basically encourages designer to plant arbors and greens in a lot of area. From another viewpoint, LEED pays attention to water efficiency. It will waste more water if afforests too many or choose inappropriate trees. These two assessment systems start from different viewpoints so lead to opposite assessment indicators.

2.3.2.2.3 Indoor Environment Indicator

LEED does not have the regulation in Sound Environment, but it can apply for Innovation and Design Process Indicator.

2.4 Quantitative Comparison of Indicators

In order to understand the difference between EEWH and LEED, this study displays not only the meanings of indicators but also quantification measures of indicators. The scoring tables are given in **Table 2.6** and **Table 2.7**. In this study, it analyzes indicators according to the structure of EEWH.

Table 2.6 EEWH System

Category	Indicator		Weighting		
			Benchmark	Highest	Total
Ecology	Biodiversity		2	9	27
	Greenery		2	9	
	Soil Water Content		2	9	
Energy Saving	Energy Saving	EEV	2	12	28
		EAC	2	10	
		EL	2	6	
Waste Reduction	CO_2 Emission Reduction		2	9	18
	Waste Reduction		2	9	
Health	Indoor Environment		2	12	27
	Water Resource		2	9	
	Sewage and Garbage Improvement		2	6	

Table 2.7 LEED System

Indicator	Prerequisite	Total Score
Sustainable Sites	• Construction Activity Pollution Prevention	14 (20%)
Water Efficiency	N/A	5 (7%)
Energy and Atmosphere	• Fundamental Commissioning of the Building Energy Systems • Minimum Energy Performance • Fundamental Refrigerant Management	17 (25%)
Materials and Resources	• Storage & Collection of Recyclables	13 (19%)
Indoor Environmental Quality	• Minimum IAQ Performance • Environmental Tobacco Smoke (ETS) Control	15 (22%)
Innovation and Design Process	N/A	5 (7%)

2.4.1 Ecology Indicator Groups

Indicators in LEED related to Biodiversity Indicator are Water Efficient Landscaping (Credit) and Erosion & Sedimentation Control (Prerequisite). However, Water Efficient Landscaping has direct relationship with Greenery Indicator, and it doesn't count in Biodiversity Indicator to avoid repetition. Thus, EEWH has 9 points in this subject, but it has no point in LEED correspondently.

The related indicators in the part of Greenery Indicator in LEED are Reduced Site Disturbance (Credit) and Water Efficient Landscaping (Credit). Those indicators totally have 4 points and count approximately 6% of total score in LEED. On the other hand, the indicator counts 9% of total score in EEWH. Apparently, the proportion of this indicator in EEWH is higher than that in LEED.

The related indicators in the part of Soil Water Content Indicator in LEED are Stormwater Management (Credit) and Heat Island Effect (Credit). Those indicators totally have 4 points and count approximately 6% of total score in LEED. This indicator occupies the same percentage as Greenery Indicator, so it also has higher proportion in EEWH.

The Ecology Indicator Groups show that the maximum point that the designer can get possibly in LEED is 8 points, and it occupies 12% of total score. On the other hand, the corresponding possible maximum point in EEWH is 27 point, which occupies 27% of total score. Therefore, the proportion of ecology indicator in EEWH is higher than that in LEED. However, it does not mean that America does not pay attention to the ecology indicator just because the national conditions and local climates. There are not many areas developed in America, and the best way to protect the ecology is not to destroy the local environment and maximize the open space. On the contrary, the environment in Taiwan needs to restore to the original ecology because it has been destroyed in many area.

2.4.2 Energy-Saving Indicator Groups

Indicators in LEED which related to Energy-Saving Indicator are Minimum Energy Performance (Prerequisite), Optimize Energy Performance (Credit), Renewable Energy (Credit), Measurement & Verification (Credit), and Carbon Dioxide Monitoring (Credit). Those indicators totally have 15 points and occupy approximately 22% of total score. The proportion in Energy Saving Indicator is higher than Ecology Indicator.

The Energy-Saving Indicator in EEWH is divided into Envelop (12 points maximally), HVAC system (10 points maximally), and Lighting System (6 points maximally). Those indicators totally have 28 points and occupy 28% of total score. The proportion in EEWH is higher.

It can be found that the proportion in Energy-Saving Indicator is the most important one in both EEWH and LEED. Although the proportion of Energy-Saving Indicator in LEED does not reach quarters, but it does not mean that LEED does not pay attention to Energy-Saving just because some indicators are not considered in EEWH, therefore, the direct comparison is not so fair.

2.4.3 Waste Reduction Indicator Groups

The indicator groups include CO_2 Emission Reduction Indicator and Waste Reduction Indicator in EEWH. Those two indicators totally have 18 points and occupy 18% of total score.

Indicators in LEED which related to waste reduction indicator groups are Building Reuse (Credit), Recycled Content (Credit), Regional Materials (Credit), Construction Waste Management (Credit), Resource Reuse (Credit), and Erosion & Sedimentation Control (Credit). Those indicators totally have 11 points and occupy 16% of total score. Overall, the proportion in LEED is similar to the one in EEWH.

2.4.4 Health Indicator Groups

The indicator groups include Indoor Environment Indicator, Water Resource Indicator, Sewage and Garbage Improvement Indicator in EEWH. In the part of Indoor Environment Indicator, those indicators totally have 12 points and occupy 12% of total score. The related indicators in LEED are Rapidly Renewable Materials (Credit), Certified Wood (Credit), Minimum IAQ Performance (Prerequisite), Ventilation Effectiveness (Credit), Low-Emitting Materials (Credit), and Daylight & Views (Credit). Those indicators totally have 9 points and occupy 13% of total score.

In the part of Water Resource Indicator, those indicators totally have 9 points and occupy 9% of total score in EEWH. The related indicators in LEED are Innovative Wastewater Technologies (Credit) and Water Use Reduction (Credit). Those indicators totally have 3 points and occupy 4% of total score. The proportion in LEED is smaller than that in EEWH just because it has 5 indicators and two of them are related to Greenery Indicator.

In the part of Sewage and Garbage Improvement Indicator, those indicators totally have 6 points and occupy 6% of total score in EEWH. The related indicator in LEED just has Storage & Collection of

Recyclables, and it is prerequisite indicator which does not have any point.

Overall, in the part of Health Indicator Groups, it totally has 27 points and occupies 27% of total score in EEWH. On the other hand, those indicators totally have 12 points and occupy 18% of total score in LEED.

2.4.5 Innovation and Design Indicator

In Innovation and Design Indicator, it has 4 points in LEED. This indicator encourages designer and owner to find another design method, which LEED does not mention. EEWH also has this indicator and can obtain 10 to 15% extra points.

According to LEED, if the total points are higher than 38%, it is a certified building, 48% is Silver level certification, 57% is Gold level certification, and 75% is Platinum level certification. In EEWH, if the point is higher than 12 points, it is a certified building, 31 points is Copper level certification, 37 points is Silver level certification, 43 points is Gold level certification, 53 points is Diamond level certification. In EEWH, it is not strict with score requirement because the certification level is a preliminary practice.

CHAPTER 3

ENERGY SIMULATION TOOL

3.1 The Introduction of Simulation Tool

In this study, it uses dynamic energy simulation tool (eQUEST) to evaluate building energy consumption performance. eQUEST consists of DOE-2, Wizards and Graphics. DOE-2 is the most widely recognized and respected building energy analysis program. It was first released in the late 1970's, used as beginning of earlier simulation tools. It was developed and funded by ASHRAE, NASA, the U.S. Postal Service, and the electric and gas utility industries. During the first half of the 1980's, it continued under DOE support, but decreasing national concern about energy created the need for industry support, which became its principal source of support through much of the 1990's. Through this long time of history, DOE-2 has been widely reviewed and validated in the public domain.

The simulation engine within eQUEST is derived from the latest official version of DOE-2. However, its engine extends DOE-2's capabilities in several important ways, including: interactive operation, intelligent defaults, and improvements to many defects in DOE-2.

It is designed to perform detailed analysis of advanced building technologies using most sophisticated building energy simulation technique, without requiring extensive experience of building performance modeling. This is because its simulation engine is combined with a building creation wizard, an energy efficiency measure (EEM) wizard, industry standard input defaults, and a graphical results display module. It will be able to provide professional-level results in an affordable level of effort.

3.2 Simulation Engine Structure

The flowchart of the simulation engine is illustration in **Fig. 3.1.** Basically, the program has one subprogram for translation of designer input (BDL Processor), and three simulation subprograms (LOADS, HVAC, and ECON). The LOADS subprogram executes first for the entire simulation period, and its hourly data stored in a disk file for the HVAC simulation. Next the HVAC subprogram executes for the entire simulation period, with its hourly results stored in a disk file for the ECONOMICS calculations. Finally, the ECON (economics) subprogram executes. Each of the simulation subprograms also produces printed reports of the results of its own calculations. The main components are illustration as follows:

(1) BDL Processor

The Building Description Language (BDL) processor reads the flexibly formatted input data that user supply and translates it into computer recognizable form. It also calculates response factors for the transient heat flow in walls and weighting factors for the thermal response of building spaces.

(2) LOADS

The LOADS simulation subprogram calculates the sensible and latent components of the hourly heating or cooling load for each space in the building, assuming that each space is kept at a constant designer-specified temperature. LOADS is responsive to weather and solar conditions, to schedules of people, lighting and equipment, to infiltration, to heat transfer through walls, roofs, and windows and to the effect of building shades on solar radiation.

(3) HVAC

The HVAC simulation subprogram is divided into a secondary systems simulation (SYSTEMS) and a primary systems simulation (PLANT). The secondary HVAC systems simulation calculates the performance of air-side equipment (fans, coils, and ducts). It corrects the constant-temperature loads calculated by the LOADS subprogram by taking into account outside air requirements, hours of equipment operation, equipment control strategies, and thermostat set points. The output of the secondary HVAC system simulation is air flow and coil loads. The primary HVAC system simulation calculates the behavior of boilers, chillers, cooling towers, storage tanks, etc., in satisfying the secondary systems heating and cooling coil loads. It takes into account the part-load characteristics of the primary equipment in order to calculate the fuel and electrical demands of the building.

(4) ECON

The economic analysis subprogram calculates the cost of energy. It can also be used to compare the cost-benefits of different building designs or to calculate savings for retrofits to an existing building.

(5) Weather Data

The weather data for a location consists of hourly values of outside dry-bulb temperature, wet-bulb temperature, atmospheric pressure, wind speed and direction, cloud cover, and solar radiation. Weather data suitable for use in the program is produced by running the weather processor on raw weather files provided by the U.S. National Weather Service and other organizations. In this study, it uses typical meteorological year (TMY) which consists of 8760 hourly weather data and is sieved out from the last ten years hourly weather data (1997-2006) which were recorded by Central Weather Bureau and can be directly utilized for DOE-2 to carry out building energy simulation.

(6) Standard Library

The program comes with a library of input components. The elements in this library are wall materials, layered wall constructions, and windows. Other elements include HVAC performance curves, glass layers, between-glass gas fills, window blinds, pull-down shades, and lamps.

(7) User Library

The User Library contains building elements such as walls, windows, schedules, and HVAC systems which designer create.

3.3 The Custom Weighting-Factor Method

The DOE-2 computer program is a public-domain program for energy analysis of commercial or residential buildings. DOE-2 calculates hour-by-hour energy use of a building from information about building location, construction, and operation. It employs weighting-factor for calculation of thermal loads and room air temperature.

The weighting-factor method of calculating instantaneous space sensible load is a compromise between simpler methods (e.g., steady-state calculation) which ignore the ability of building mass to store energy, and more complex methods (e.g., complete energy balance calculations). Space heat gains at constant space temperature are determined from a physical description of the building, ambient weather conditions, and internal load profiles. Along with the characteristics and availability of heating and cooling systems for the building, space heat gains are used to calculate air temperatures and heat extraction rates.

The weighting factors represent Z-transfer functions. The Z-transform is a method for solving differential equations with discrete data. Two groups of weighting factors are used: heat gain and air temperature. The weighting factors method is illustrated in appendix.

3.4 Applications of Simulation Tool

Because of the scope and flexibility of its input, eQuest can be used in many applications, especially those involving design of the building envelope and HVAC systems, and selection of energy conserving or peak demand reduction alternatives. For example:

(1) Energy Conservation Studies

1. Effect of the thickness, order, type of materials, and orientation of exterior walls and roofs.
2. Effect of thermal storage in walls and floors, and in energy storage tanks coupled to HVAC systems.
3. Effect of occupant, lighting, and equipment schedules.
4. Effect of intermittent operation, such as the shutdown of HVAC systems during the night, on weekends, holidays, or for any hour.

5. Effect of reduction in minimum outside air requirements and the scheduled use of outside air for cooling.
6. Effect of internal and external shading, tinted and reflective glass, and use of daylighting.

(2) Building Design Studies

1. Initial design selection of the basic elements of the building, primary and secondary HVAC systems, and energy source.
2. During the design stage, evaluating specific design concepts such as system zoning, control strategies, and systems selection.
3. During construction, evaluating contractor proposals for deviations from the construction plans and specifications.
4. A base of comparison for monitoring the operation and maintenance of the finished building and systems.
5. Analysis of existing buildings for cost-effective retrofits.

3.5 The Preparation to Apply eQUEST Model

eQUEST calculates hour-by-hour building energy consumption over an entire year (8,760 hours) using hourly weather data for the location under consideration. The input parameters consist of detailed description of the building, hourly scheduling of occupants, lighting, equipments and thermostat settings. It provides accurate simulation of building features, such as shading, fenestration, interior building mass, envelope building mass and dynamic response of different heating and air conditioning systems and controls.

The simulation process begins with developing a virtual model of the building based on architecture plans. In this study, it collects all architecture plans, architecture lateral view drawing, air-duct plans, and pipe-duct plans of Taipei Wan-Hua sports center. Alternative analyses are made by changing the efficiency measures of model that could be implemented in the building. These results of alternative analyses can be used to determine the payback, life-cycle cost (LCC), etc., and the best combination of alternatives. The preparations of modeling the building include:

(1) Analysis Objective

Clearly understand the design questions that wish to answer by using simulation model. In this study, the designer discusses with air-conditioner engineer to fully understand analysis objective in advance.

(2) Building Site and Weather Data

Important building site characteristics include latitude, longitude and elevation. In this study, the TMY weather data are adopted from Professor Lin [21].

(3) Building Shell, Structure, Materials and Shades

eQUEST analyzes walls, roof, and floors of the building in heat transfer and storage effects. Designer needs to provide the information for the heat transfer surfaces of the geometry and construction materials of the building to eQUEST.

(4) Building Operations and Scheduling

A clear understanding of the schedule of operation of the existing building is important to the overall accuracy of simulation model. This includes information about when building occupancy begins and ends, indoor thermostat setting points for the rooms under use, and HVAC and internal equipment operations schedules.

(5) Internal Loads

Heat gain from internal loads (occupants, lights, and equipments) can constitute a significant portion of the utility requirements in buildings. When defining internal load for each thermal zone, designer needs to specify geometric information about the thermal zones, energy consumptions for equipments and lighting systems, infiltration methods and day lighting.

(6) HVAC Equipments and Performance

HVAC systems include air-side and water-side equipments, designer needs to specify a lot of parameters in chiller, cooling tower, boiler, air handle units (AHU), fan coils (FC), and pumps, etc. These data for simulating the operation of HVAC equipments are obtained from equipment specifications and design documents.

Data required in eQuest is summarized as shown in **Table 3.1**, which illustrates the data should be collected prior to developing simulation or confirmed in the course of modeling.

Table 3.1 Data Requirements

Item	Source	Schematic	Design Development	Construction Documents
Architectural				
building and zone areas	plan sheets	x	x	x
envelope construction materials	wall sections		x	x
surface areas (by orientation)	building elevations	x	x	x
fenestration areas (by orientation)	building elevations	x	x	x
fenestration u-value & SC	window schedule			x
	or specifications			x
Mechanical				
HVAC zoning	HVAC plans		x	x
design flow rates	HVAC plans		x	x
equipment descriptions	equipment schedules			x
	or specifications			x
control sequences	control diagrams			x
	or specifications			x
Electrical				
lighting equipment	lighting layout		x	x
	or lighting schedule			x
Internal Loads				
peak occupancy (by zone)	owner, operator	x	x	x
peak lighting (by zone)	lighting plans		x	x
peak equipment (by zone)	mech or owner		x	x
Operations				
per zone:				
occ, lights, equip schedules	owner or operator	x	x	x
thermostat schedules	owner or operator	x	x	x
per terminal system:				
outside air operations	HVAC equip schedule			x
hot & cold deck temperatures	HVAC equip schedule			x
fan schedules	owner or operator	x	x	x
fan kW	HVAC equip schedule		x	x
per primary system:				
lock-out schedules	control sequences			x
Economic				
utility schedules (all fuels)	utility representative	x	x	x
equipment costs	designer or manufacturer		x	x
life-cycle cost parameters	owner	x	x	x

3.6 Simulation Reports

After all of the simulations have completed, designer can review the results and reports from the analysis tool bar. The contents of report include:

1. Monthly energy consumption.
2. Annual energy consumption.
3. Monthly utility bills, all rates.
4. Monthly peak demand.
5. Annual peak demand.
6. Monthly peak day electric load profiles.
7. Monthly total energy consumption.
8. Annual utility bills.
9. Monthly utility bills.
10. Annual energy.
11. Annual electric use.
12. Annual building energy and demand summary.

CHAPTER 4

BUILDING ENERGY CONSUMPTION ANALYSIS

4.1 Background of Taipei Wan-Hua Sports Center

The simulation objective in this study is Taipei Wan-Hua Sports Center. The building geometry information is summarized in **Table 4-1.** This sports center is located in Taipei (N 24.15, E 120.68), and is adjacent to Ximen metro station. It inaugurates to public in May, 2007. Taipei Wan-Hua Sports Center has seven floors and two basements. The total floor area is 12,336 square meters (132,783 square foot), and air conditioning floor area is 7,847 square meters (84,464 square foot) (B2 parking area is not included). The opening time is from 7:00 to 22:00. In this sports center, the B2 basement is used as parking lot and air-conditioner utility room, and B1 has a 25M warming-water pool, children & practice pool, SPA area, sauna & steam bath room, and aid & life guard room. 1F has administration office, play room, canteen and chess & reading room, 2F is physical fitness center and dance studio and 3F is golf practicing room, gymnasium and table tennis room. The floors from 4F to 6F are multi-function basketball & badminton court and rock climbing wall, and 7F is 30-meter outdoor archery range.

Table 4-1 Building Geometry Information

Category	Design Parameters	Wan-Hua Sports Center
Building Geometry and Envelope	Building Direction	Face to east
	Air Conditioner Floor Area	7847 square meter
	Length and Wide	50m × 25m
	Number of Floors	7 floors and 2 basements
	Longitude and Latitude	Taipei, N 24.15, E 120.68
	Window Insulation Condition	See Table 4-11
	Window U-Value	
	Window Properties	
	Glass Percentage of Wall Area	
	Roof Insulation Condition	
	Floor Insulation Condition	No insulation
	Envelope Constructions	Reinforced Concrete
Air Condition	Temperature Setpoint	Summing pool : 26C Other spaces : 25C
	Equipment Efficiency	ASHRAE Standard 90.1
	Capacity Design Method	Safety factor : 1.1
	Minimum Ventilation	ASHRAE Standard 62
	Outdoor Air Intake	ASHRAE Standard 62
	Occupied Heat Gain	ASHRAE Fundamental
	Occupied Density	See Table 4-2 to 4-10
	Building Schedule	See Table 4-11 to 4-15
	Air Change Rate	0.4
Lighting	Lighting Density	See Table 4-2 to 4-10
	Automatic Lighting Control	Yes
Others	Equipment Density	See Table 4-2 to 4-10
Simulation	Engine	DOE 2.2

4.2 Energy Consumption Analysis by EEWH System

Energy Saving Indicator in EEWH system is divided into three parts: Building Envelope, HVAC System and Lighting System. This study focuses on HVAC Energy-Saving. ECM is divided into four parts: Heat Source System, Fans system, Pumps System and Renewable Energy system. This sports center is classified as Large Space Building category in EEWH. According to different ECMs, EEWH will provide designer efficiency baseline values to calculate different coefficients, such as Energy-Saving Efficiency (R_s, R_f, R_p) and utility rate (γ), which is equal to the ratio of ECM adoption air-conditioned area to total air-conditioned area, and then the EAC formula can be calculated. The EAC formula and the related coefficients are calculated by following equations:

$$R_s = 1 - \sum\left(\alpha_j \times \gamma_j\right) \tag{4.1}$$

$$R_f = 1 - \alpha_{10} \times \gamma_{10} \tag{4.2}$$

$$R_p = 1 - \sum\left(\alpha_j \times \gamma_j\right) \tag{4.3}$$

$$R_m = 1 - \sum \beta_k \tag{4.4}$$

$$PR_s = \frac{P_s}{P_s + P_f + P_p} \tag{4.5}$$

$$PR_f = \frac{P_f}{P_s + P_f + P_p} \tag{4.6}$$

$$PR_p = \frac{P_p}{P_s + P_f + P_p} \tag{4.7}$$

$$EAC = \left\{PRs \times \left[\frac{\Sigma\left(HC_i \times COP_{ci}\right)}{\Sigma\left(HC_i \times COP_i\right)}\right] \times R_s + \left(PR_f \times R_f\right) + \left(PR_p \times R_p\right)\right\} \times R_m \tag{4.8}$$

where EAC is HVAC system energy-saving efficiency, PR_s PR_f PR_p are design power ratio, HC_i is chiller capacity (USRT), COP_{ci} is coefficient of performance standard, R_s R_f R_p are energy-saving efficiency, and R_m is other systems energy-saving efficiency. α and β are air-conditioner energy saving design efficiency standard, which are according to Evaluation Manual for Green Buildings in Taiwan 2007, pp. 81 [20].

4.3 Energy Use Index (EUI) Calculation

Comparing with office building, Wan-Hua sports center is a special type of building and is rarely seen in Taiwan. This sports center is designed to apply EEWH, and there are several ECMs in this building. In order to understand the features of energy saving efficiency, this study analyzes Energy Use Index (EUI) first. The definition of EUI is an annual energy use over total floor area. High EUI value indicates more energy consumption in building. This study compares Wan-Hua sports center with Zhong-Shan sports center, which has same type of use. The EUI information of Zhong-Shan sports center is obtained from K.P. Lee, who is an assistant professor in National Taipei University of Technology (NTUT). The EUI formula is given by the following:

$$EUI = \frac{EC}{A} \tag{4.9}$$

where EC is annual energy use (kWh/year) and A is total floor area (m^2). In order to calculate EUI difference between Wan-Hua and Zhong-Shan sports centers, the EUI saving percentage formula is introduced:

$$EUI_S = \frac{EUI_Z - EUI_W}{EUI_Z} \times 100 \tag{4.10}$$

where EUI_S is EUI saving percentage, EUI_Z and EUI_W are EUI's of Wan-Hua and Zhong-Shan sports center, respectively.

4.4 Energy Consumption Analysis by LEED System

LEED adopts energy simulation tool to analyze the energy use fully. The first work before modeling is to collect related data, described in section 3.3. The data substantially cover fundamental building characteristics, such as geometrical configuration, internal loads and building shell, and energy systems, which include the water-side and the air-side of the HVAC systems and operations. After collecting all related information, designer can start to build a model. The simulation procedure in this study is illustrated as following:

4.4.1 Geometric Modeling

In order to create a building model for the eQUEST simulation, a geometric model of the building is installed. The layout of the geometric model and thermal zones is based on the architectural and the HVAC drawings. The first work is to build building footprints. According to architecture plans, designers can import DWG files into eQUEST and then they can be traced around the drawing by selecting correct units and coordinates (to ensure the right building size). Following some rules which indicated below, the building footprints can be completed.

1. The maximum number of vertices for any one polygon is 120.
2. The orders to create vertices are enumerated in counter clockwise.
3. A building footprint polygon cannot have any cutouts, and no line

segments can cross another segment in the same polygon.

4.4.2 HVAC Zoning

HVAC zoning recognizes that load profiles seen by different spaces in a building are different. Identifying those areas with similar load profiles and grouping them under the same thermostat control improve comfort level and reduce energy use. For the purpose of control, HVAC thermal zoning seeks to group together those rooms that share similar load and usage characteristics. There are some rules for HVAC zoning:

1. When modeling existing buildings, refer to the actual zoning indicated by the HVAC plans.
2. One exterior zone per major orientation (12 to 18 feet deep).
3. One internal zone per use schedule.
4. One plenum zone (if plenum returns) for each air handler to be modeled separately.
5. One zone each for special uses (e.g., conference rooms, cafeterias, etc).
6. Separate ground and top floor zones.

This study creates each zone according to actual HVAC plans. For HVAC system, designer creates air-side system based on the using type of zone. The building space conditions are summarized in **Table 4-2** to **4-10.** The space schedules are summarized in **Table 4-11** to **4-15.**

Table 4-2 B2 Space Conditions

Space	Lighting (W/m^2)	People	Equipment (W/m^2)	Area (m^2)	Volume (m^3)
B2 Machine(B201)	2.15	1	0	168.67	760.99
B2 Machine(B202)	2.15	1	0	151.52	683.61
B2 Elevator(B203)	0.00	0	0	27.41	123.68
B2 Elevator Wait (B204)	5.38	1.9	0	17.98	81.10
B2 Stair(B205)	6.46	3.1	0	28.90	130.39
B2 Machine(B206)	2.15	1	0	51.67	233.11
B2 Machine(B207)	2.15	1	0	53.58	241.72
B2 Electric (B208)	2.15	1	0	13.09	59.07
B2 Elevator(B209)	0.00	0	0	11.59	52.31
B2 Stair (B210)	6.46	4.7	0	43.31	195.38
B2 Store (B211)	3.23	1.4	0	12.61	56.89
B2 Parking (B212)	2.15	10	4.31	1608.65	7257.72

Table 4-3 B1 Space Conditions

Space	Lighting (W/m^2)	People	Equipment (W/m^2)	Area (m^2)	Volume (m^3)
B1 Machine(B101)	2.15	1	2.15	140.01	631.66
B1 Machine(B102)	2.15	1	2.15	63.88	288.21
B1 Oven-M(B103)	2.15	5	2.15	13.45	60.71
B1Stream-M(B104)	2.15	5	2.15	16.22	73.17
B1 Machine(B105)	2.15	1	2.15	105.56	476.24
B1 CarLane(B106)	2.15	0	2.15	182.78	824.64
B1Stream-F(B107)	2.15	5	2.15	15.38	69.38
B1 Oven-F (B108)	2.15	5	2.15	19.72	88.98
B1 Stair (B109)	6.46	3.1	0.00	28.72	129.61
B1 Pipeline (B110)	0.00	0	0.00	7.99	36.05
B1Infirmary(B111)	13.99	3.2	2.15	29.87	134.76
B1 Toilet (B112)	9.69	1.2	2.15	11.15	50.32
B1 Store (B113)	3.23	4.6	2.15	42.37	191.16
B1 Elevator(B114)	0.00	0	2.15	31.40	141.67
B1 Electric (B115)	2.15	1	0.00	12.99	58.61
B1 Stair (B116)	6.46	2.8	2.15	26.26	118.47
B1 Electric (B117)	2.15	1	2.15	12.60	56.82
B1 Elevator(B118)	0.00	0	2.15	35.68	161.00
B1 Stair (B119)	6.46	4.5	2.15	41.81	188.65
B1 Toilet (B120)	9.69	7.5	2.15	69.41	313.12
B1 Toilet (B121)	9.69	4	2.15	37.09	167.31
B1 Swimming Pool (B122)	15.07	134	2.15	1244.50	5614.79

Table 4-4 1F Space Conditions

Space	Lighting (W/m^2)	People	Equipment (W/m^2)	Area (m^2)	Volume (m^3)
1F Store (101)	3.23	1.8	0.00	16.38	78.39
1F Electric (102)	2.15	1	0.00	23.76	113.75
1F Electric (103)	2.15	1	0.00	10.30	49.31
1F Elevator (104)	0.00	0	0.00	32.14	153.85
1F Stair (105)	6.46	3.1	0.00	28.99	138.78
1F M-Shower (106)	9.69	8.1	2.15	75.30	360.40
1F M-Toilet (107)	9.69	5.7	2.15	52.76	252.51
1F M-Change (108)	6.46	5.1	2.15	47.60	227.81
1F Stair (109)	6.46	3.0	0.00	27.69	132.53
1F F-Shower (110)	9.69	11.1	2.15	103.18	493.82
1F F-Makeup (111)	9.69	4.9	2.15	45.94	219.89
1F F-Change (112)	6.46	3.2	2.15	29.99	143.55
1F Corridor (113)	5.38	3.6	2.15	33.12	158.50
1F Reading (114)	13.99	15.7	2.15	145.96	698.54
1F Center (115)	15.07	10.6	20.02	98.69	472.32
1F Child (116)	15.07	16	2.15	148.32	709.90
1F Sale (117)	18.30	7.8	2.15	72.67	347.78
1F Toilet (118)	9.69	5.1	2.15	47.17	225.78
1F Electric (119)	2.15	0.9	0.00	8.76	41.95
1F Elevator (120)	0.00	0	0.00	19.96	95.57
1F Stair (121)	6.46	3.4	0.00	31.60	151.21
1F Dining (122)	9.69	12	2.15	111.81	535.17
1F Corridor (123)	5.38	7.9	1.08	73.47	351.65
1F Lobby (124)	13.99	16.1	1.08	149.62	716.12

Table 4-5 2F Space Conditions

Space	Lighting (W/m^2)	People	Equipment (W/m^2)	Area (m^2)	Volume (m^3)
2F Store (201)	3.23	7.8	2.15	72.33	346.20
2F Electric (202)	2.15	1.1	0.00	10.66	51.01
2F Elevator (203)	0.00	0	0.00	41.92	200.59
2F Stair (204)	6.46	3.8	0.00	35.42	169.52
2F Dancing (205)	15.07	13.5	2.15	125.49	600.60
2F Dancing (206)	15.07	14.6	2.15	135.68	649.38
2F Shower (207)	9.69	6.3	2.15	58.53	280.12
2F Toilet (208)	9.69	6	2.15	55.86	267.36
2F Electric (209)	2.15	1.2	0.00	10.80	51.70
2F Elevator Wait (210)	5.38	4.8	2.15	44.52	213.08
2F Elevator (211)	0.00	0	0.00	19.92	95.31
2F Stair (212)	6.46	3.4	0.00	31.64	151.45
2F Bicycle (213)	15.07	9.2	2.15	85.08	407.19
2F Fitness Center (214)	15.07	59.4	16.15	551.69	2640.41
2F Dancing (215)	15.07	15.9	2.15	147.76	707.16

Table 4-6 3F Space Conditions

Space	Lighting (W/m^2)	People	Equipment (W/m^2)	Area (m^2)	Volume (m^3)
3F Machain (301)	2.15	7.9	0.00	73.65	442.31
3F Electric (302)	2.15	1.1	0.00	10.66	64.01
3F Elevator (303)	0.00	0	0.00	16.74	100.52
3F Elevator Wait (304)	5.38	1.8	2.15	16.64	99.89
3F Stair (305)	6.46	3.2	0.00	29.95	179.85
3F Stair (306)	6.46	3.4	0.00	31.64	190.04
3F Elevator (307)	0.00	0	0.00	19.92	119.59
3F Electric (308)	2.15	1.2	0.00	10.80	64.87
3F Bunk (309)	5.38	1	2.15	39.05	234.51
3F Simulation (310)	15.07	2.6	16.15	24.28	145.83
3F Shower (311)	9.69	4.5	2.15	41.92	251.74
3F Toilet (312)	9.69	4.4	2.15	40.65	244.13
3F Elevator Wait (313)	5.38	4.8	2.15	44.52	267.37
3F Golf (314)	15.07	41.4	2.15	385.01	2312.17
3F Martial Art (315)	15.07	26.3	2.15	244.09	1465.81
3F Table Tennis (316)	15.07	42.8	2.15	397.78	2388.86

Table 4-7 4F Space Conditions

Space	Lighting (W/m^2)	People	Equipment (W/m^2)	Area (m^2)	Volume (m^3)
4F Toilet (401)	9.69	7.8	2.15	72.14	224.30
4F Electric (402)	2.15	1.1	2.15	10.66	33.14
4F Elevator (403)	0.00	0	0.00	16.74	52.05
4F Elevator Wait (404)	5.38	1.8	2.15	16.64	51.72
4F Stair (405)	6.46	3.2	0.00	29.95	93.12
4F Store (406)	3.23	3.4	2.15	31.56	98.14
4F Electric (407)	2.15	1.2	0.00	10.80	33.59
4F Elevator (408)	0.00	0	0.00	19.92	61.92
4F Elevator Wait (409)	5.38	3.6	2.15	33.51	104.20
4F Stair (410)	6.46	3.4	0.00	31.64	98.40
4F Gym (411)	15.07	1.2	2.15	1153.74	7174.92

Table 4-8 5F Space Conditions

Space	Lighting (W/m^2)	People	Equipment (W/m^2)	Area (m^2)	Volume (m^3)
5F Classroom (501)	15.07	3.4	2.15	31.70	98.57
5F Electric (502)	2.15	1.1	0.00	10.66	33.14
5F Elevator (503)	0.00	0	0.00	16.74	52.05
5F Rest Room (504)	9.69	3.2	2.15	29.65	92.22
5F Corridor (505)	5.38	1.1	2.15	9.93	30.87
5F Elevator Wait (506)	5.38	2.3	2.15	21.66	67.35
5F Stair (507)	6.46	3.1	0.00	28.79	89.53
5F Elevator (508)	0.00	0	0.00	19.92	61.92
5F Stair (509)	6.46	3.4	0.00	31.64	98.40
5F Non (510)	0.00	0	0.00	29.11	90.53
5F Non (511)	0.00	0	0.00	10.80	33.59
5F Non (512)	0.00	0	0.00	33.51	104.20

Table 4-9 6F Space Conditions

Space	Lighting (W/m^2)	People	Equipment (W/m^2)	Area (m^2)	Volume (m^3)
6F Machain (601)	2.15	1	2.15	71.29	328.15
6F Electric (602)	2.15	1.1	0.00	10.66	49.06
6F Elevator (603)	0.00	0	0.00	16.74	77.05
6F Stair (604)	6.46	3.1	0.00	28.79	132.54
6F Elevator Wait (605)	5.38	2.3	2.15	21.62	99.50
6F Electric (606)	2.15	1.2	0.00	10.80	49.72
6F Machine (607)	2.15	1	0.00	33.51	154.26
6F Elevator (608)	0.00	0	0.00	19.92	91.67
6F Stair (609)	6.46	3.4	0.00	31.64	145.67
6F Gym (610)	0.00	126.5	2.15	1174.79	5407.74
6F Non (611)	0.00	0	0.00	3.46	15.90

Table 4-10 7F Space Conditions

Space	Lighting (W/m^2)	People	Equipment (W/m^2)	Area (m^2)	Volume (m^3)
7F Machain (701)	2.15	1	0.00	118.53	567.31
7F Electric (702)	2.15	1.1	0.00	10.66	51.01
7F Elevator (703)	0.00	0	0.00	17.46	83.54
7F Elevator Wait (704)	5.38	2.5	2.15	22.82	109.21
7F Stair (705)	6.46	3	0.00	27.86	133.35
7F CT (706)	2.15	1	0.00	161.75	774.15
7F Electric (707)	2.15	1.2	0.00	11.04	52.83
7F Elevator (708)	0.00	0	0.00	19.81	94.79
7F Stair (709)	6.46	3.4	0.00	31.64	151.45
7F Stair (710)	6.46	1.2	0.00	10.99	52.61
7F Elevator Wait (711)	5.38	3.7	2.15	34.28	164.06
7F Rest Room (712)	9.69	7.8	2.15	72.28	345.93
7F Toilet (713)	9.69	3.9	2.15	36.01	172.32

Table 4-11 Building Operating Schedule (Swimming Pool)

Swimming pool occupant schedule																								
For days: SUN. SAT. HOL.																								
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Fraction	0	0	0	0	0	0	0.3	0.3	0.5	0.7	0.8	0.5	0.5	1	1	1	1	1	1	1	0.8	0.3	0	0
For days: MON. to FRI.																								
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Fraction	0	0	0	0	0	0	0.3	0.3	0.6	0.6	0.6	0.3	0.3	0.3	0.3	0.3	0.6	0.7	1	1	1	0.5	0	0

Table 4-12 Building Operating Schedule (Other Space)

Other space occupant schedule																								
For days: SUN. SAT. HOL.																								
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Fraction	0	0	0	0	0	0	0.1	0.1	0.3	0.5	0.8	0.8	0.6	0.8	1	1	1	0.6	0.8	1	1	0.5	0	0
For days: MON. to FRI.																								
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Fraction	0	0	0	0	0	0	0.1	0.1	0.3	0.3	0.3	0.3	0.5	0.5	0.5	0.5	0.5	0.7	0.8	1	1	0.5	0	0

Table 4-13 Building Operating Schedule (Lighting)

Lighting schedule																								
For days: SUN. SAT. HOL.																								
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Fraction	0.05	0.05	0.05	0.05	0.05	0.05	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.05	0.05
For days: MON. to FRI.																								
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Fraction	0.05	0.05	0.05	0.05	0.05	0.05	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.05	0.05

Table 4-14 Building Operating Schedule (Fans)

Fans schedule																								
For days: SUN. SAT. HOL.																								
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
ON/OFF	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
For days: MON. to FRI.																								
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
ON/OFF	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0

Table 4-15 Building Operating Schedule (Equipment)

Equipment schedule																								
For days: SUN. SAT. HOL.																								
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Fraction	0.05	0.05	0.05	0.05	0.05	0.05	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.05	0.05
For days: MON. to FRI.																								
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Fraction	0.05	0.05	0.05	0.05	0.05	0.05	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.05	0.05

4.4.3 Building Externals

After completing building footprints, designer can build windows and doors based on architectural lateral view drawing. Ensure the location and dimension of windows being correct so the simulation program can obtain accurate solar heat gain. Designer also needs to set up material parameters of walls, windows and doors, and ensures the U-value is fit the actual conditions. From the building 3D View model presented from **Fig. 4.1 to 4.3**, the building externals are obviously shown up and then designer can check with architectural drawing. The related parameters are tabulated in **Table 4-16**. The actual site views are shown from **Fig. 4.4 to 4.5.**

Table 4-16 Building Envelope Information

Direction	Window U-value (W/m^2-K)	Window Area (m^2)	Glass Percent of Wall Area (percent)	Wall U-value (W/m^2-K)	Wall Area (m^2)
North	8.35	365.86	20%	0.585	1891.29
South	8.35	504.67	36%	0.585	1414.51
East	8.35	565.42	65%	0.585	871.12
West	8.35	105.12	11%	0.585	994.16
Roof	N/A	N/A	N/A	0.585	1408.41
Int. Wall	N/A	N/A	N/A	3.861	N/A
Basement	N/A	N/A	N/A	0.585	N/A

4.4.4 Internal Loads

After completing the building externals, the next step is to adjust the parameters of internal loads. The types of internal loads considered in the model include human occupants, lighting systems, ventilation and equipments. The occupant density and ventilation ratio are based on ASHRAE Standard 62, and lighting power density is based on ASHRAE

Standard 90.1. Besides, this study sets up schedule and equipment density according to actual conditions. For the occupant load, **Table 4-17** gives typical values for different activity levels.

Table 4-17 People Heat Gain for Different Activity Levels

Degree of Activity	Typical Application	PEOPLE-HEAT-GAIN[b] Btu/hr	PEOPLE-HEAT-GAIN[b] W
Seated at Theater	Theater	350	103
Seated/Very Light Work	Offices, Motels, Apts	400	117
Moderately Active Office Work	Offices, Hotels, Apts	450	132
Standing, Light Work, Walking	Department/Retail Store	450	132
Walking, Standing	Drugstore, Bank	500	147
Sedentary Work	Restaurant	550	161
Light Bench Work	Factory	750	220
Light Machine Work	Factory	1000	293
Heavy Work	Factory	1450	425
Athletics	Gymnasium	1800	527

[a]From 1997 ASHRAE Handbook of Fundamentals, Table 3, Chapter 28
[b]Based on a normal percentage of men, women, and children for the application listed

4.4.5 HVAC Systems

HVAC system is divided into water-side and air-side systems. In the part of water-side system, designer needs to build the pipe loop and the attached equipments, such as pump, chiller, cooling tower, heat pump and boiler. On the other hand, in the part of air-side system, designer needs to build air handle unit (AHU), fans and fan coil (FC), and assigns each zoon to its corresponding air-side system. Besides, all systems are needed to assign schedule to decide whether this system is on or off. The HVAC systems are shown in **Fig. 4.6** and **4.7**. There are 86 FCs, 5 AHUs, 7 pumps, 1 cooling tower and three chillers (80t, 80t, 200t) in this sports center.

If the designer completes the procedures described above, then, the building model is completely finished. Thus, the designer can evaluate energy consumption and then review the reports to analyze energy performance. However, simulation procedure will cause errors and breakdown if the installation of model is not correct. The program will automatic generate .SIM file displays where the error occurs, and designer can follow this illustration to debug the set-up of parameters, and then the simulation program can continue to evaluate energy consumption.

4.5 Model Calibration

The model is calibrated based on the electricity bill, which is collected from June 2007 to May 2008 because this sports center has just opened in May 2007. Annual measured energy consumption collected from site detector and annual simulated energy consumption are tabulated in **Table 4-18**. In this study, it uses Federal Energy Projects M&V Guidelines (statistics method) to compare these two electricity bills to ensure the accuracy of the simulation model.

Table 4-18 Electricity Data for Model Assessment (Units: kWh × 105)

Month	Actual	Simulated
6	211,972	208,319
7	222,084	220,443
8	216,523	221,269
9	205,234	210,499
10	192,009	208,560
11	186,127	194,347
12	194,461	189,192
1	190,076	186,135
2	166,447	168,315
3	192,304	190,676
4	190,541	192,817
5	197,701	205,174

4.5.1 Calibrated Computer Simulation Analysis

Selecting an approach to calibrate a building model depends on many factors. After consideration of these approaches and other factors, one of the following three approaches must be selected for calibration:

1. Calibration at the whole building level, comparing model monthly usage predictions to monthly utility bill data.
2. Calibration at the whole building level, comparing model monthly usage predictions to monthly utility bill data in combination with calibration at their subsystem level (i.e., comparing model sub-system usage predictions to measured hourly data).
3. Calibration at the whole-building level, comparing model hourly usage predictions to hourly utility bill data.

In this study, method one is used, which compares model monthly usage predictions to monthly utility bill data. It is because the monthly data are available via building energy detection system.

4.5.2 Whole Building Level Calibration with Monthly Data

First, the model is developed and carried out by using the weather data that correspond to the monthly utility billing periods. Next, monthly simulated energy consumption and monthly measured data are plotted against each other for every month in the data set, as shown in **Fig. 4.8.** Be sure to calculate the model's whole building energy usage over the same calendar days as for each month's utility bill. The errors in the monthly and annual energy consumption are calculated by the following equations:

$$ERR_{month}(\%) = \frac{M - S_{month}}{M_{month}} \times 100 \tag{4.11}$$

$$ERR_{year} = \sum_{year} \frac{ERR_{month}}{N_{month}} \tag{4.12}$$

where M indicates the measured kWh or fuel consumption and S indicates the simulated kWh or fuel consumption. N_{month} is the number of utility bills in the year. The monthly differences between measured and simulated energy consumption may cancel each other, resulting in a smaller annual ERR. The coefficient of variation of the root-mean-squared monthly errors must also be checked.

The root-mean-squared monthly error is calculated by the following equation:

$$RMSE = \sqrt{\frac{\sum_{month}(M - S)_{month}^{2}}{N_{month}}} \tag{4.13}$$

The mean of the monthly utility bills is:

$$A_{month} = \frac{\sum_{year} M_{month}}{N_{month}} \tag{4.14}$$

The CV (RMSE) for the monthly billing data is:

$$CV(RMSE_{month}) = \frac{RMSE_{month}}{A_{month}} \times 100 \qquad (4.15)$$

The combination of ERR and the CV (RMSE) can determine how well the model predicts whole-building energy usage. The lower the ERR and CV (RMSE) are, the better the calibration is. **Table 4-19** specifies the acceptable tolerances for monthly and yearly values of ERR for monthly data calibration.

Table 4-19 Acceptable Tolerances for Monthly Data Calibration

Index	Value
ERR_{month}	±15%
ERR_{year}	±10%
$CV(RMSE_{month})$	±10%

4.6 The Analysis of Alternative ECMs

In Wan-Hua sports center, it adopts six ECMs, including VAV System, VWV System, Lighting Power Density (LPD) Reduction, High COP Chiller, CO_2 Concentration Control System, and OA Air Conditioning System. The analyses of different ECMs are illustrated as following:

4.6.1 Variable Air Volume (VAV) System

Air-side HVAC system total has 86 FCs and 5 AHUs in this building. In this ECM, the comparison between constant air volume (CAV) and variable air volume (VAV) is analyzed by using eQUEST computerized simulation program. In the CAV system, all AHUs and FCs fans operate with constant speed. These systems supply conditioned air through a constant volume air supply system to the conditioned rooms. The system is designed to supply enough air to cool each room under design conditions. On the other hand, VAV system will reduce the amount of air supply as a function of room load, resulting in less energy consumption. In VAV system, the variable frequency device (VFD) is installed in these air-side HVAC systems.

4.6.2 Variable Water Volume (VWV) System

Water-side HVAC system total has 7 pumps in this building. Like VAV system, this ECM installs VFD in each pump. The VWV system can change flow rate according to variable load and reduces energy consumption.

4.6.3 Lighting Power Density (LPD) Reduction

This study sets LPD (W/m^2) of baseline building equal to the maximum allowed value, regulated by ASHARE Standard 90.1 section 9.5. In this ECM, LPD is set to half of the maximum allowed value in stair space because it has automatic lighting control system which can detect people coming or not. LPD in other space is smaller than maximum allowed value and it is according to actual design.

4.6.4 High Coefficient of Performance (COP) Chiller

There are three chillers (80t, 80t, 200t) in Wan-Hua sports center. The COP’s of chillers in baseline building are provided according to ASHARE Standard 90.1 section 6.4 minimum efficiency levels. Their COP’s are 4.45, 4.45, and 4.9, respectively. In this ECM, it raises COP to a higher level and results in less energy consumption. The COP of chillers in the building are 4.9, 4.9, and 5.5, respectively.

4.6.5 CO_2 Concentration Control System

For the health purpose, CO_2 concentration in air-conditioned rooms must be below 1000ppm. In other words, the outdoor-air (OA) amount must be equal to 20 m^3/hr per person. However, the occupant number is variable and CO_2 concentration is often below 1000ppm. For this reason, the maximum OA intake system will suck too much OA in off-peak occupant period, resulting in high energy consumption. The capability of CO_2 concentration control system is to change OA flow rate according to CO_2 concentration. The related equipments in this ECM are CO_2 concentration sensor, damper, and control system. In this building, it has 5 AHUs and 3 FAHs installed in this control system.

4.6.6 OA Air Conditioner System

The purpose of OA air conditioner system is to totally suck OA when outside enthalpy is lower than inside one. This method can reduce energy consumption in HVAC air return system. The related equipments in this ECM are enthalpy sensor, damper, and control system. In this building, it has 5 AHUs and 3 FAHs installed in this control system.

4.7 The Analysis of Payback

By use of energy simulation tool, designer can obtain the information of energy saving percentage, which is compared between baseline building and proposed building, and can acquire energy saving amount (kWh) in different ECMs. In this study, it uses peak and off-peak time electricity costs to evaluate payback. The electricity cost is tabulated in **Table 4-20.** According to Taiwan Power Company (TPC), the electricity cost is divided into two calculation seasons, summer and winter. Furthermore, the electricity cost is also divided into normal days

(Mon. to Fri.) and holidays (Sat. and Sun.). In the period of 8:00am to 23:00pm, the electricity cost belongs to peak time, and other belongs to off-peak time. In other words, the electricity cost totally has ten calculation periods.

Table 4-20 Electricity Cost

Category				Summer (Jun. to Sep.)	Winter (Others)
Electricity Cost	Mon. to Fri.	Peak Time	07:30~22:30	2.32	2.24
		Off-Peak Time	00:00~07:30 22:30~24:00	0.91	0.84
	Sat.	Peak Time	07:30~22:30	1.42	1.35
		Off-Peak Time	00:00~07:30 22:30~24:00	0.91	0.84
	Sun.	Off-Peak Time	All Day	0.91	0.84

This study uses eQUEST to evaluate annual (8760 hours) energy saving amount, and then sorts these data by seasons (summer and winter). According to different electricity charges of TPC, the annual energy cost saving can be evaluated. The definition of annual energy cost saving (NT/year) is equal to the annual energy saving amount (kWh/year), which is saved by ECM, multiplied by peak and off-peak electricity charges (NT/kWh). Thus, designer can obtain accurate energy cost saving, which is use peak and off-peak electricity charges, to compare with the estimated energy cost saving, which uses average (3NT/kWh) electricity charge.

The information of initial equipment costs are collected from Shang-Ya Air Conditioner Company, and these initial costs are divided into installation and demolition. The installation and demolition costs are summarized in **Table 4-21**.

Table 4-21 Installation and Demolition Cost

ECMs	Device	Installation Cost (NT/Unit)	Demolition Cost (NT/Unit)	Number
VAV	VFD	5000,1000	2000,1000	5,86
VWV	VFD	5000	2000	7
Lighting Power Density	Number	N/A	N/A	N/A
High COP	Chiller	20000	15000	3
CO_2 Concentration Control	Sensor	5000	3000	8
OA Air Condition System	Sensor	5000	3000	8

In VAV system, the installation and demolition cost are 5,000 and 2,000 dollar for VFD in AHU while these two costs are both 1,000 for VFD in FC. In VWV system, the installation and demolition costs of VFD in pump are 5,000 and 2,000 dollars respectively. The installation and demolition costs in chiller are 20,000 and 15,000 respectively. There are two HVAC control systems in this sports center, CO_2 concentration control system and OA air conditioner system. These two control systems have the same installation and demolition costs which are 5,000 and 3,000 dollars respectively.

The definition of payback (year) is equal to the ratio of initial cost (NT) to annual energy cost saving (NT/year). This index is often used to evaluate the totally benefit in different ECMs. Through the analysis of payback, designer can understand the relationship between energy saving amount and equipment initial cost. Eventually, designer can understand which ECM has least payback and the most economic benefits. The order of ECM adoption can also be calculated.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 EEWH System Calculation

According to Eqs. (4.1) to (4.8), the designer can calculate EAC value. The calculation of utility rate is summarized in **Table 5.1**. The definition of utility rate is air-conditioned area of ECM over total air-conditioned area. From this table, it can be seen that VAV system and CO_2 concentration control system have the maximum utility rates which are equal to 1, meaning that the whole air-conditioned area adopts this ECM. The utility rates of VWV system and OA air-conditioned system are equal to 0.78 and 0.39, respectively. The OA air-conditioned system has the minimum utility rate, representing that this building just has 39 percent of air-conditioned area adopts this ECM.

In EEWH system calculation, designer can obtain EAC equal to 0.64, but it does not mean that Wan-Hua sports center can save 36% of energy use. It is because EEWH system is just served as a qualified benchmark and cannot understand the real benefit of ECM. For this reason, some defects exist in EEWH system and need to be analyzed and discussed.

Table 5-1 Calculation of Utility Rate

Energy-Saving Target	ECM	Air-Conditioned Area (m^2)	System Description	Utility Rate
Heat Source System	CO_2 Concentration Control System	In this ECM: 6362.2 Total:6362.2	1. Adopting Fan Coil (FC) and Air Handel Unit (AHU) to supply air-conditioned air. 2. AHU control outside air according to CO_2 concentration.	$\gamma = \frac{6362.2}{6362.2} = 1$
	OA Air-Conditioner System	In this ECM: 2503.5 Total:6362.2	1. 3F and 4F spaces use HVAC system, which can base on different season and enthalpy suck outside air.	$\gamma = \frac{2503.5}{6362.2} = 0.39$
Fans System	VAV System	In this ECM: 6362.2 Total:6362.2	1. B1, 3F and 4F spaces use AHU which can change fan speed according to room load demand. Other spaces adopt FC.	$\gamma = \frac{6362.2}{6362.2} = 1$
Pumps System	VWV System	In this ECM: 4943.8 Total:6362.2	1. All system adopts VWV system except swimming pool area.	$\gamma = \frac{4943.8}{6362.2} = 0.78$

5.2 Energy Use Index (EUI) Calculation

According to Eqs. (4.9) and (4.10), designer can calculate the EUI's of Wan-Hua and Zhong-Shan sports centers, and the results are summarized in **Table 5.2.**

Table 5-2 Calculation of EUI

Sports Center	Floor Area (m2)	Annual Energy Consumption (kWh)	EUI
Wan-Hua	12367.76	2,395,746	193.7
Zhong-Shan	8895.59	2,599,069	292.17
EUI Saving Percentage	N/A		33.7%

The results show that the EUI's in Wan-Hua and Zhong-Shan sports centers are 193.7 and 292.2, respectively. Furthermore, it can also understand that the EUI saving percentage for Wan-Hua sports center can be more than 33.7% relatively comparing to that of Zhong-Shan sports centers is.

Wan-Hua sports center totally has six ECMs, but Zhong-Shan sports center does not have any at all. Thus, the EUI saving percentage can be approximated as energy saving percentage in Wan-Hua sports center. In other words, Wan-Hua sports center can save 33.7% annual energy consumption by using EUI approximate method. The energy saving percentage in EUI approximation method and EEWH system have the similar results, which are 33.7% and 36%, respectively. Similar to EEWH system, EUI formula just is a simple method, which let designer have a rough concept of energy saving percentage but not a real building energy consumption.

5.3 LEED System Calculation

LEED adopts energy simulation tool to fully analyze energy usage. After completing the baseline model, the first work is to calibrate the model and ensure its accuracy.

5.3.1 Model Calibration

According to Federal Energy Projects M&V Guidelines, this study can obtain the monthly errors, which are tabulated in **Table 5.3**.

Table 5-3 Monthly Errors

Year	Month	Actual (kWh)	Simulated (kWh)	ERR_{month}(%)
2007	6	211,972	208,319	1.72
	7	222,084	220,443	0.74
	8	216,523	221,269	-2.19
	9	205,234	210,499	-2.57
	10	192,009	208,560	-8.62
	11	186,127	194,347	-4.42
	12	194,461	189,192	2.71
2008	1	190,076	186,135	2.07
	2	166,447	168,315	-1.12
	3	192,304	190,676	0.85
	4	190,541	192,817	-1.19
	5	197,701	205,174	-3.78

The monthly errors in this sports center are between 0.74 to 8.62 percent and are qualified (below 15%). The maximum monthly error (8.62%) occurred in October 2007 due to the climate conditions. The related climate information is tabulated in **Table 5.4** and the trend of energy consumption is shown in **Fig. 5.1**.

Table 5-4 Related Climate Information

Number	Chinese Name	English Name	Alarm Period	Intensity
200715	柯羅莎	KROSA	10/04～10/07	Strong
200712	韋帕	WIPHA	09/17～09/19	Middle
200708	聖帕	SEPAT	08/16～08/19	Strong

After collecting the climate information from Central Weather Bureau, it can find that KROSA typhoon (Strong one) came to Taiwan during Oct. 4 to Oct. 7. Wan-Hua sports center was not open in these days that led to low energy consumption. The same condition also happened in August 18 and September 18 2007 because SEPAT (Strong one) and WIPHA (Middle one) typhoons came to Taiwan, respectively. Although these typhoons resulted in high monthly errors but their values still could be acceptable (below 15%). The annual error is 1.32% (below 10%) and CV (RMSE) is 0.96% (below 10%), these two indexes are also qualified in this study. From the results described above, it can find that this model has good calibration.

5.3.2 Evaluation of Alternative ECMs

The annual energy saving percentages for each ECM are summarized in **Table 5.5**.

Table 5-5 Annual Energy Saving Percentage in Each ECM

Categories	ECM	Energy Saving Percentage
Heat Source System	CO_2 Concentration Control	63,349 (4%)
	OA Air Condition System	29,006 (2%)
	High COP Chiller	38,439 (3%)
Fan System	VAV System	134,149 (9%)
Pump System	VWV System	71,927 (5%)
Lighting System	Lighting Power Density	29,583 (2%)

The simulation results show that VAV system has the maximum annual energy saving percentage, which is equal to 9% comparing with baseline building, and this ECM reduces 134,149 kWh per year. On the other hand, VWV system has 5% annual energy saving percentage and it reduces 71,927 kWh per year. In the third ECM, LPD Reduction does not require extra cost for implementation. The simulation results show that this ECM has 2% annual energy saving percentage and it reduces 29,583 kWh per year. In ECM of High COP chiller, it has 3% annual energy saving percentage and it reduces 38,439 kWh per year. In control systems, the CO_2 concentration control system has 4% energy saving percentage and OA air-conditioner system has 2% energy saving percentage, and the annual energy saving amounts are 63,349kWh and 29,006 kWh, respectively.

From the simulation results, designer can understand the benefits from the different ECMs. According to energy saving percentage, the best ECM is VAV system and the descending order is VWV system, CO_2 concentration control system, High COP chiller, LPD reduction, and OA air-conditioner system. For the new construction case, LPD Reduction is the first choice for the owner because it needs no initial cost. However, LPD Reduction method must to change electricity system and needs initial cost in the existing building case. Thus, designer needs to determine the economic benefit of this ECM in the design beginning. VAV and VWV systems can change the flow rate according to room load, resulting in less energy consumption. These systems have large energy saving potential, but designer must consider initial cost at the beginning as well. Through the payback analysis, designer can understand the relationship between energy saving amount and equipment initial cost, and then judges whether these ECMs are worth or not. CO_2 concentration control system can save a lot of energy consumptions, caused by OA loads. This ECM is also worthy to install. High COP chiller has some energy saving potential, but the benefit is low. This is because it only uses one high level COP chiller in this study, and there are still many high level COP chillers available in the market. To install high level COP of chiller may obtain more energy saving percentage. However, similar to variable frequency system, designer must consider initial cost first. Eventually, OA air-conditioner system has the least energy saving percentage because the climate in Taiwan is hot and humid. This ECM only has benefit in winter and does not have large energy saving amount comparing to other ECMs.

The annual energy use for the combined ECMs is shown in **Fig. 5.2.** In this study, the simulation results showed that by implementing all the combined ECMs, about 25% of electric energy can be saved annually. To compare with EEWH system (36%) and EUI approximate method (33%), LEED system seems to have the lowest energy saving percentage. It is because that the intent of EEWH is to encourage the establishment of Green Building and it just serves as a qualified benchmark and cannot really evaluate the real benefit of ECM. For the EUI approximate method, it just is a simple method, which let designer have a rough concept of energy saving percentage. Thus, both EEWH system and EUI approximate method overestimate the energy saving percentage in a building. For this reason, the use of energy simulation tool can obtain more accurate energy consumption results.

5.3.3 The Analysis of Payback

The calculation procedure of payback has been illustrated in section 4.7. The annual energy cost saving in different ECMs is summarized in **Table 5.6**.

Table 5-6 Annual Energy Cost Saving in Different ECMs

ECMs	Annual Energy Saving Amount (kWh)	Annual Energy Cost Saving (NT)
VAV System	134,149	245,679
VWV System	71,927	129,277
CO_2 Concentration Control System	63,349	113,856
High COP Chiller	38,439	71,846
Lighting Power Density Reduction	29,583	52,828
OA Air-Conditioner System	29,006	51,878

The results show that the annual energy cost saving is directly proportional to annual energy saving amount, because there are no HVAC systems, which use off-peak time electricity charges in this study. For example, the efficiency of ice-storage AC system is low and it needs more energy consumption comparing to normal AC system. However, this system takes the advantage of off-peak time electricity charge and results in less energy cost. In other words, the annual energy cost saving is positive value, whereas the annual energy saving amount is negative value (energy waste). In the user's viewpoint, ice-storage AC system needs more energy consumption. However, in the viewpoint of TPC, to shift energy use from peak time to off-peak time will save a lot of energy cost. Thus, if designers want to understand the actual economic benefit of this ECM, they need to analyze the overall electricity systems. This study just analyzes this ECM from user's viewpoint, the analysis of overall electricity systems are not discussed here.

The energy cost saving in VAV system is 245,679 (NT/year), in VWV system is 129,277 (NT/year), in CO_2 concentration control system is 113,856 (NT/year), in High COP chiller is 71,846 (NT/year), in LPD reduction is 52,828, and in OA air-conditioner system is 51,878 (NT/year).

The paybacks in different ECMs are summarized in **Table 5.7**. The adoption order of ECMs is shown as **Fig. 5.3**.

Table 5-7 Paybacks in Different ECMs (Unit: year)

ECMs	**Average (3NT/kWh)**	**Paybacks (peak and off-peak)**	
		Installation	**Installation + Demolition**
VAV System	2.43	4.45	4.86
VWV System	1.09	2.10	2.22
Lighting Power Density Reduction	N/A	N/A	N/A
High COP	3.80	6.93	7.56
CO_2 Concentration Control System	1.37	2.63	2.85
OA Air Condition System	4.04	7.56	8.02

The results shows that the payback, which only considers installation cost, is 2.1 years in VWV system, 2.63 years in CO_2 concentration system, 4.39 years in VAV system, 6.93 years in High COP chiller, and 7.56 years in OA air-conditioner system. According to the experience of Energy Service Company (ESCOs), the equipment life times in these ECM are longer than those of paybacks, which are reasonable in practice. Basically, the payback is directly proportional to annual energy saving amount. However, there is an exception in this study. VAV system has the highest energy saving amount but the payback is 4.39 years, which is ranked as third in this study. This is because the totally installation cost (1,094,310NT) is too expensive. There are 86 FCs and 5 AHUs in this building. All of these systems install VFD that result in high initial cost. In order to reduce the initial cost, this study suggests that engineer should install VFDs only in main equipments. This method will lead to best benefit in VAV system. For the payback which considers both installation and demolition costs, it is 2.22 years in VWV system, 2.85 years in CO_2 concentration control system, 4.86 years in VAV system, 7.56 years in High COP chiller, and 8.02 years in OA air-conditioner system. From these results, it can find that the paybacks rise proportionally comparing to the ones, which only consider the installation cost. These two paybacks have the same energy saving trend. On the other hand, when the oil cost rises, it will lead to higher electricity cost and higher energy cost saving. Annual energy cost saving will rise and result in less payback. Thus, these ECMs have higher energy saving benefit in the future.

5.4 The Improvement in EEWH System

5.4.1 Improvement Strategies in EEWH System

Because EEWH system just serves as a qualified benchmark and cannot identify the real benefit of ECM, this study suggests several improvements for EEWH system. The defects of EEWH and corresponding improvement strategies are summarized in **Table 5.8**.

In EEWH system, chiller number control system is divided into three control methods: manual ON-OFF control, automatic control, and tactic automatic control. The efficiency baseline values for each control systems are 0.05, 0.1, and 0.15, respectively. However, these three control methods cannot represent the integral energy consumption features. The interactive effects on different chillers are not included in EEWH system so that it cannot analyze the real energy saving potential. On the contrary, dynamic energy simulation tool, such as eQUEST, can analyze interactive effects on different chillers. This simulation tool can analyze part load ratio (PLR) and different chiller control methods, so designer can understand the totally energy consumption in this ECM.

Table 5-8 Improvement Strategies in EEWH System

Heat Source System		
ECM	**Problem**	**Strategy**
Chiller Number Control	**1. This ECM is divided into three control methods, but it cannot analyze the real energy saving potential.**	**The strategy is to use energy simulation tool which can analyze part load ratio (PLR).**
Ice-Storage AC System	**2. EEWH cannot evaluate peak and off-peak electricity consumption.** **3. EEWH cannot analyze the real benefit of control system.**	**The strategy is to use energy simulation tool which can analyze hourly energy consumption and control system.**
VRV System	**4. This ECM just has one efficiency parameter, and it cannot response to real condition in EEWH.**	**The strategy is to use energy simulation tool which can analyze VRV system, such as EnergyPlus.**
CO_2 Concentration Control System	**5. EEWH cannot analyze the interactive effect between CO_2 concentration control system and IEQ.**	**The strategy is to use energy simulation tool which can analyze interactive operation in different ECM.**
Enthalpy Heat Exchanger System	**6. If the enthalpy difference between indoor and outdoor is small, the system resistant will lead to energy consumption.**	**The strategy is to use energy simulation tool which can analyze overall energy efficiency.**

The efficiency of ice-storage AC system is lower than the one of normal air conditioner system, but ice-storage AC system can take the advantage of off-peak time electricity charge and it has the function of saving operation cost. EEWH system has automatic control and tactic automatic control methods. The efficiency baseline values for both control systems are 0.1 and 0.2, respectively. However, it cannot evaluate the integral energy consumption just based on these two control methods and the corresponding efficiency baseline values. Another defect in EEWH system is that this assessment system cannot evaluate hourly electricity consumption. The analysis of peak and off-peak time electricity costs can really identify the actual economic benefits in ice-storage AC system. In order to analyze the actual economic benefits in ice-storage AC system, designer needs to evaluate hourly energy consumption and it can rely on eQUEST simulation tool. This simulation tool can analyze annual (8760 hours) hourly energy consumption and alternative control system. Thus, designer can calculate the peak and off-peak energy costs and analyzes the economic benefit in this ECM.

Variable refrigerant volume (VRV) system is a method which changes refrigerant flow rate according to room thermal load. The benefit of this system is that it just has one heat exchange (from refrigerant to room air). On the contrary, the normal central air-conditioner system has two heat exchanges (from refrigerant to chiller water, and then from chiller water to room air). Thus, VRV system has higher efficiency comparing to normal central air-conditioner system. In EEWH system, it only has one efficiency baseline value, which is equal to 0.3. However, designing VRV system must consider a lot of conditions, such as the length of refrigerant pipe and the vertical distance between inside and outside equipments. These parameters will affect the performance in VRV system. This system just has one efficiency baseline value that it cannot response to real condition in EEWH. Besides, it cannot analyze the performance of VRV system by using eQUEST simulation tool. The analogy method is used to adjust the chiller's performance, but this method is not so accurate. The improvement strategy is to use simulation tool which can analyze VRV system, such as EnergyPlus.

The CO_2 concentration control system is closely related with IEQ and energy consumption. The more OA is sucked, the better IEQ is. However, sucking too much OA will lead to higher energy consumption. Thus, designer needs to achieve a balance between these two issues. EEWH assessment system cannot analyze the interactive effect between CO_2 concentration control system and IEQ. This system also just has one efficiency baseline value, which is equal to 0.15, and cannot obtain the real energy consumption. Designer can analyze the relationship between CO_2 concentration and energy consumption by using eQUEST simulation tool. To maintain room CO_2 concentration in different IEQ level, such as 1000ppm, 800ppm, or 600ppm, designer can obtain different energy consumptions. Thus, designer can choose the proposed IEQ level, and the energy consumptions are also within acceptable range.

The intent of enthalpy heat exchanger system is to exchange heat between exhaust air (EA) and outdoor air (OA). Basically, EA has the same condition as room air (designed condition). If air-side systems exchange heat between EA and OA before directly sucking OA, which is hot and humid comparing to EA, it can reduce the OA thermal load and results in less energy consumption. However, this system does not have any benefit if the enthalpy difference between EA and OA is too small. On the contrary, the system resistance will lead to large energy waste. Thus, designer needs to analyze the interactive effect between energy saving potential and system resistance first. EEWH assessment system cannot analyze these interactive effects and the real benefit cannot be obtained. According to TMY weather data, it can evaluate annual energy consumption by using eQUEST simulation tool. This simulation tool can analyze the interactive effects between outside weather condition and equipment resistance. In other words, it can analyze the energy performance which has this ECM or not. Thus, designer can determine the real benefit of this ECM and understand whether this ECM is worth or not.

5.4.2 The Analysis and Discussion of Energy Saving Percentage

Now, the designer analyzes the difference between EEWH and LEED systems, and then finds improvement method and strategy in EEWH system. This study calculates each ECM by using EEWH and LEED assessment systems first. After completing the calculations, it compares these ECMs each other and analyzes the reasons for different energy saving. The calculated energy saving percentage in EEWH and LEED system are tabulated in **Table 5.9**.

Table 5-9 Energy Saving Percentage in EEWH and LEED System

Energy-Saving Target	ECMs	EEWH	LEED
Heat Source System	CO_2 Concentration Control System	10.7%	4%
	OA Air Conditioner System	1.7%	2%
	High COP Chiller	7.2%	3%
Fan System	VAV System	8.9%	9%
Pump System	VWV System	4.4%	5%
Lighting System	Lighting Power Density	N/A	2%
Energy-Saving Analysis	$EAC = \left\{ PRs \times \left[\frac{\Sigma(HC_i \times COP_{ci})}{\Sigma(HC_i \times COP_i)} \right] \times R_s + (PR_f \times R_f) + (PR_p \times R_p) \right\} \times R_m = 0.64 = 36\%$		25%

From this table, it can find that CO_2 concentration control system and High COP chiller has the greatest energy saving differences between EEWH and LEED systems. EEWH overestimates 6.7% and 4.2%, respectively comparing to these of LEED. It is also the reason, which causes large difference between EEWH and LEED systems. This is because the energy-saving efficiency (R_s) in CO_2 concentration control system in EEWH is too high, which is equal to 0.15. Besides, the design power ratio in heat source system (PR_s), fan system (PR_f), and pump system (PR_p) are 0.711, 0.1776, and 0.11124, respectively in EEWH. The heat source system occupies the largest ratio (0.711). Thus, it can calculate that this ECM can save a lot of energy (10.7%) according to EAC formula. However, the results show that it overestimates in this ECM and needs to improve. In order to obtain more accurate results, this study adjusts energy-saving efficiency from 0.15 to 0.06 (the same as OA air-conditioner system). The energy saving percentage will become to 4.2%, which is close to 4% evaluated by LEED system. On the other hand, High COP chiller also has high energy saving percentage. This is because the design power ratio in heat source system (0.711) and the COP ratio (0.9) are too high. It needs to adjust COP ratio, and then the accurate results may be obtained. This study adjusts COP ratio from 0.9 to 0.95. The energy saving percentage will become to 3.5%, which is close to 3% evaluated by LEED system. In OA air conditioner system, VAV system, and VWV system, the results show that the energy saving percentages in EEWH and LEED system are similar, it is 1.7%, 8.9%, and 4.4% in EEWH, respectively. This is because the VAV and VWV system are easy to estimate and there are no significant defects in EEWH system. Furthermore, it has higher energy saving percentage (36%) in combined ECMs, comparing to sum of each ECM (32.9%). This is because it has interactive effect in different ECMs. However, it will overestimate the energy saving percentage.

From the discussions described above, it can understand that the main defect in EEWH system is that it cannot analyze the integral energy consumption. This assessment system just serves as a qualified benchmark. Although EEWH system can roughly evaluate energy saving percentages in different ECMs, they are not accurate enough. In order to obtain accurate energy saving percentage, this study suggests designer to adopt energy simulation tool, such as eQUEST.

CHAPTER 6

CONCLUSIONS

This study utilizes dynamic energy simulation tool, eQUEST, to simulate the energy consumption in Taipei Wan-Hua sports center and the energy performance for alternative energy conservation measures (ECMs). The calculation of EEWH and LEED performance are analyzed. The related parameters, such as energy use index (EUI), monthly errors, evaluation of ECMs, and payback, are also analyzed. Eventually, several improvements for EEWH are suggested to provide a concept for designer and the improvement for building energy analysis in Taiwan. The conclusions are summarized as following:

1. In the calculation of EEWH, EUI, and LEED systems, the energy saving percentages are 36%, 32%, and 25%, respectively. EEWH and EUI methods are just simple methods, they will overestimate the energy saving. On the contrary, LEED system which use energy simulation tool can obtain more accurate energy consumption results.
2. The climate conditions will affect the results of monthly errors. Although these typhoons resulted in high monthly errors in August (2.19%), September (2.57%), and October (8.62%), but their values still could be acceptable (within 15%). The annual error is 3% (below 10%) and CV (RMSE) is 2% (below 10%) and it can find that this model has good calibration.
3. According to energy saving percentage, the best ECM is VAV system (9%) and the descending order is VWV system (5%), CO_2

concentration control system (4%), High COP chiller (3%), LPD reduction (2%), and OA air-conditioner system (2%).

4. To consider the equipment initial cost and annual energy cost saving, this study analyzes the payback. The adoption order of ECMs is LPD reduction (need no initial cost), VWV system (2.1), CO_2 concentration system (2.63), VAV system (4.45), High COP chiller (6.93), and OA air-conditioner system (7.56).
5. VAV system has the highest energy saving amount (134,149 kWh) but the payback is ranked as fourth in this study. This is because the totally installation cost (1,094,310NT) is too expensive.
6. When the oil cost rises, it will lead to higher electricity cost and higher energy cost saving. Annual energy cost saving will rise and result in less payback. Thus, these ECMs have higher energy saving potential in the future.
7. According to the analysis in this study, it can understand that the main defect in EEWH system is that it cannot analyze the integral energy consumption.
8. It can find that the energy saving percentage in CO_2 concentration control system and High COP chiller will overestimate by using EEWH assessment system. EEWH overestimates 6.7% and 4.2%, respectively comparing to these of LEED.
9. After adjusting the CO_2 concentration control system and High COP chiller, it can obtain more accurate energy saving percentages, which are equal to 4.2% and 3.5%, respectively.
10. In OA air conditioner system, VAV system, and VWV system, the results show that the energy saving percentages in EEWH and LEED

system are similar, it is 1.7%, 8.9%, and 4.4% in EEWH, respectively. This is because the VAV and VWV system are easy to estimate and there are no significant defects in EEWH system.

11. In EEWH system, it has higher energy saving percentage (36%) in combined ECMs, comparing to sum of each ECM (32.9%). This is because it has interactive effect in different ECMs. However, it will overestimate the energy saving percentage.

Based on the above-mentioned conclusions and defects, some recommendations are suggested in this study. These recommendations are summarized as following:

1. In order to reduce the initial cost of VAV system, the improvement method is to install VFDs only in main AHU equipments. This method will reduce the initial cost and has the similar energy saving effect on VAV system.
2. In order to obtain accurate energy saving percentage, this study suggests designer to adopt energy simulation tool, which can analyze part load ratio (PLR), hourly energy consumption, interactive operation in different ECM, and overall energy efficiency.
3. It is strongly recommended that VWV system and LPD reduction are employed.
4. In order to obtain more accurate results, this study suggests designer to adjust energy-saving efficiency in CO_2 concentration control system from 0.15 to 0.06 and High COP chiller from 0.9 to 0.95.
5. There are several ECMs in EEWH system, in order to analyze detail effects on different parameters, this study suggests designer to

analyze individual ECM by using energy simulation tool, and then find more improvement methods for EEWH assessment system.

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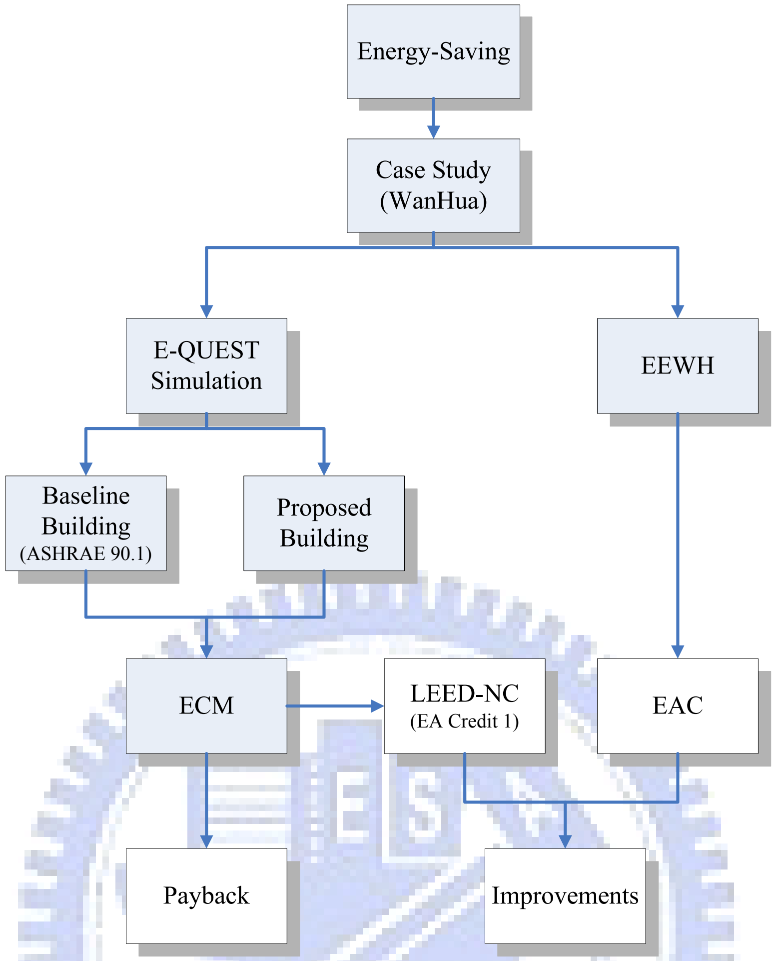

Fig. 1.1 The Research Flowchart

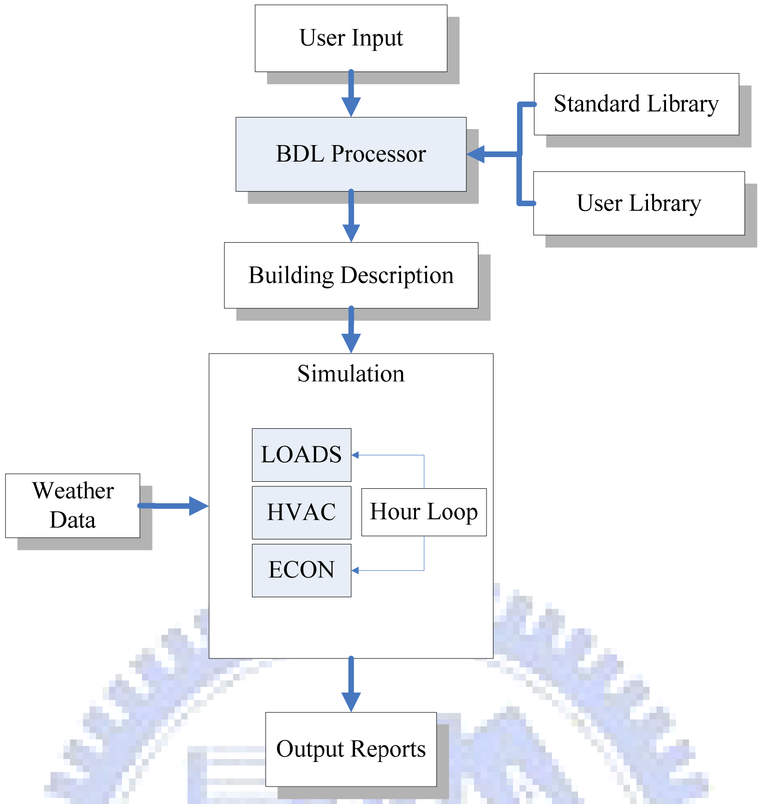

Fig. 3.1 Simulation Engine Structure

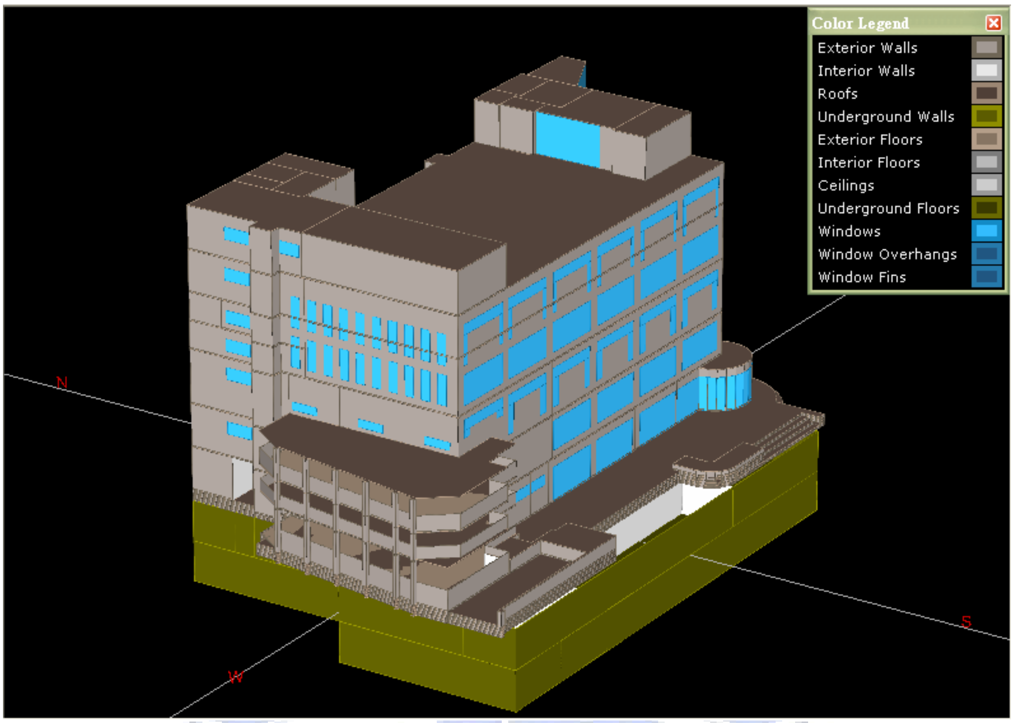

Fig. 4.1 Southwest View of Wan-Hua Sports Center

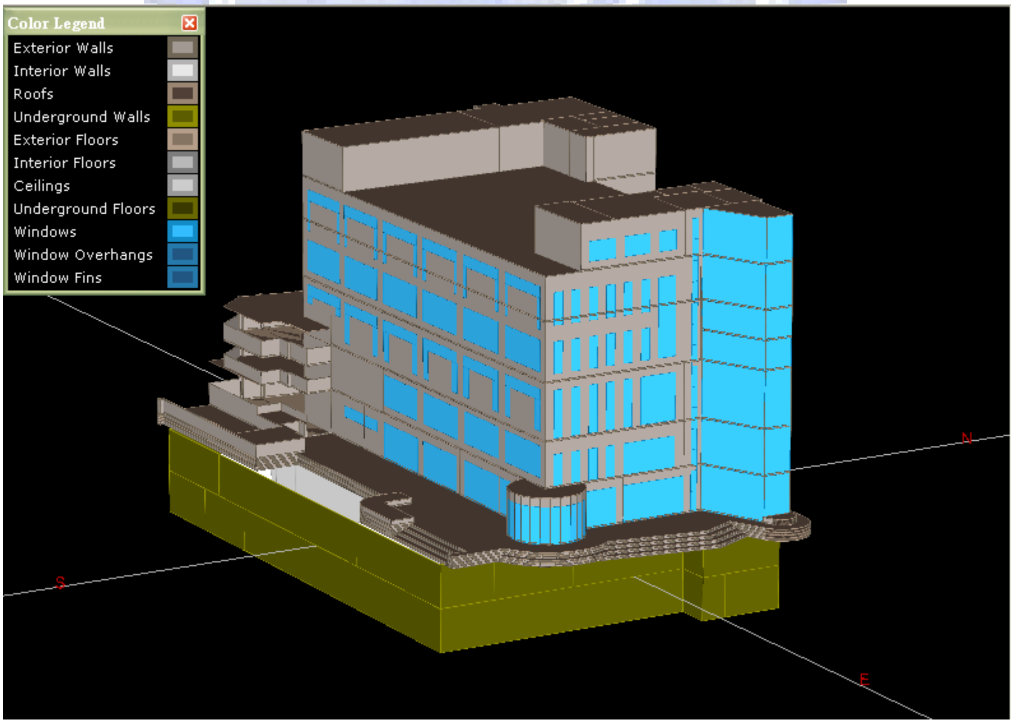

Fig. 4.2 Southeast View of Wan-Hua Sports Center

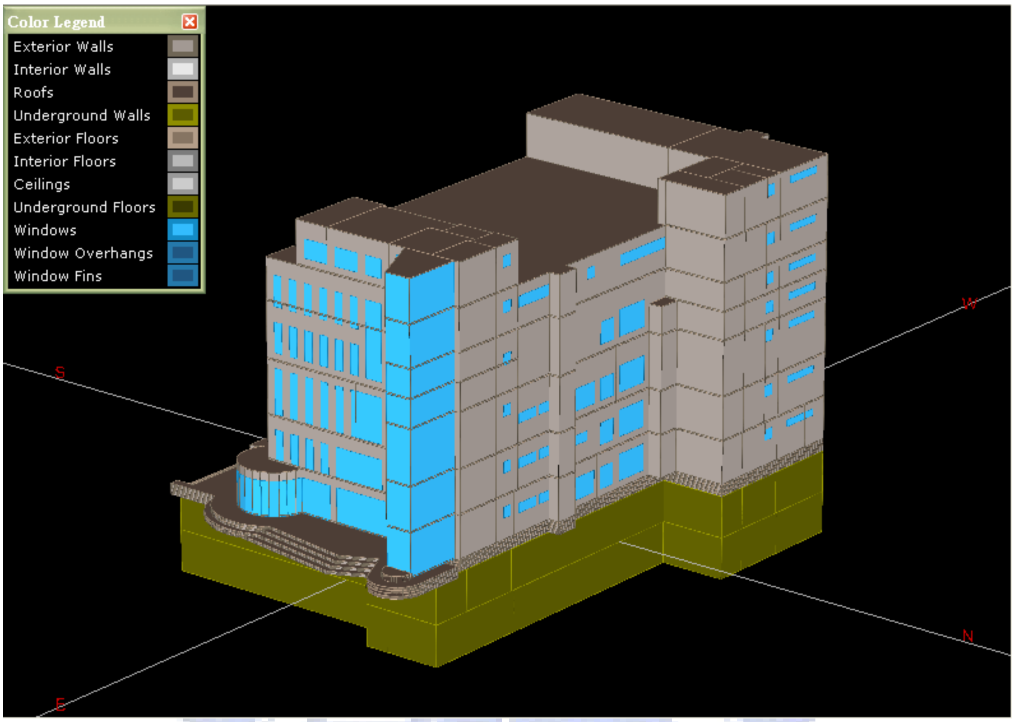

Fig. 4.3 Northeast View of Wan-Hua Sports Center

Fig. 4.4 Actual Site View (Front Door)

Fig. 4.5 Actual Site View (Motorcycle Parking)

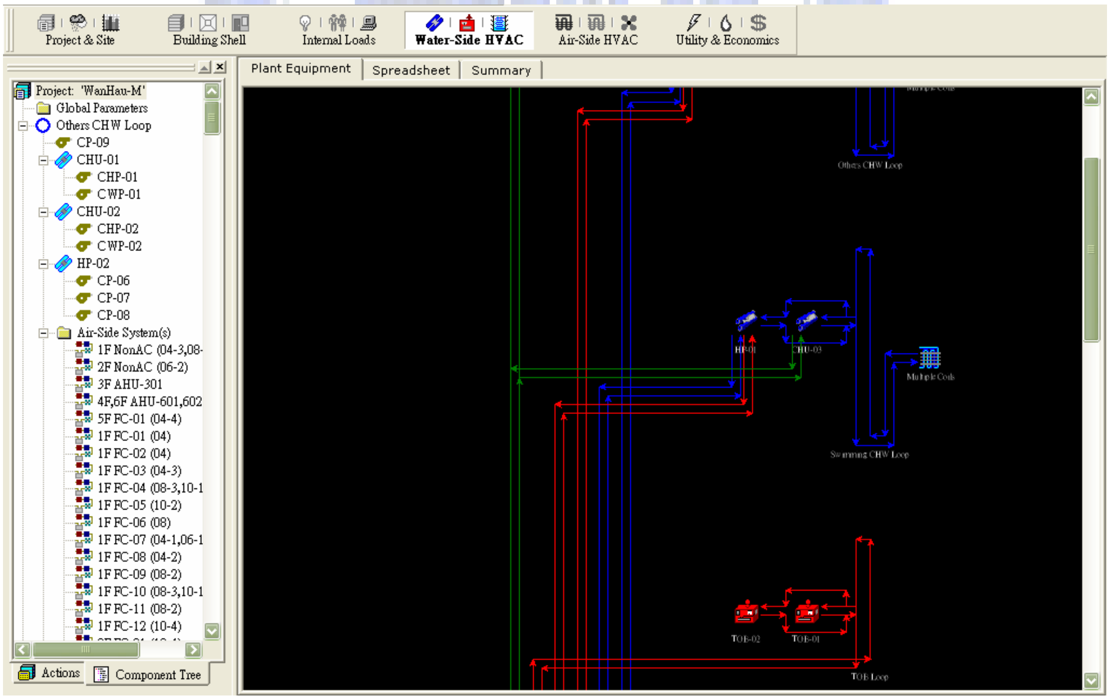

Fig. 4.6 HVAC Water-Side Systems

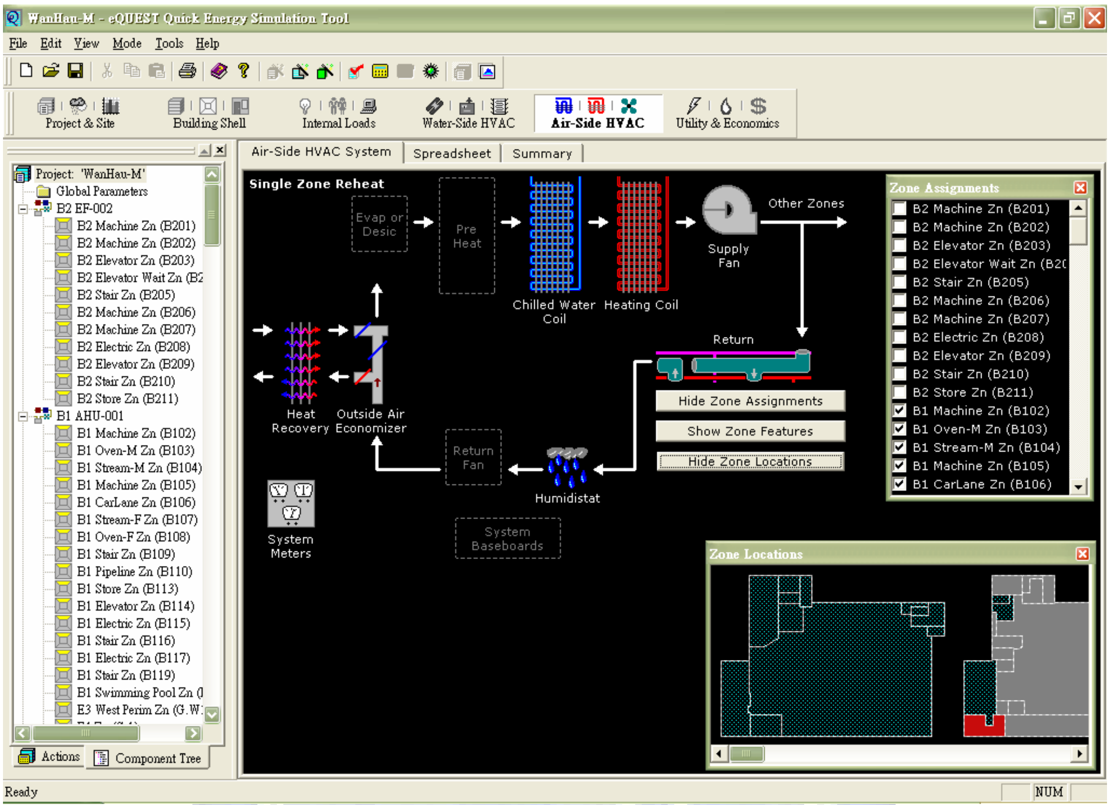

Fig. 4.7 HVAC Air-Side Systems

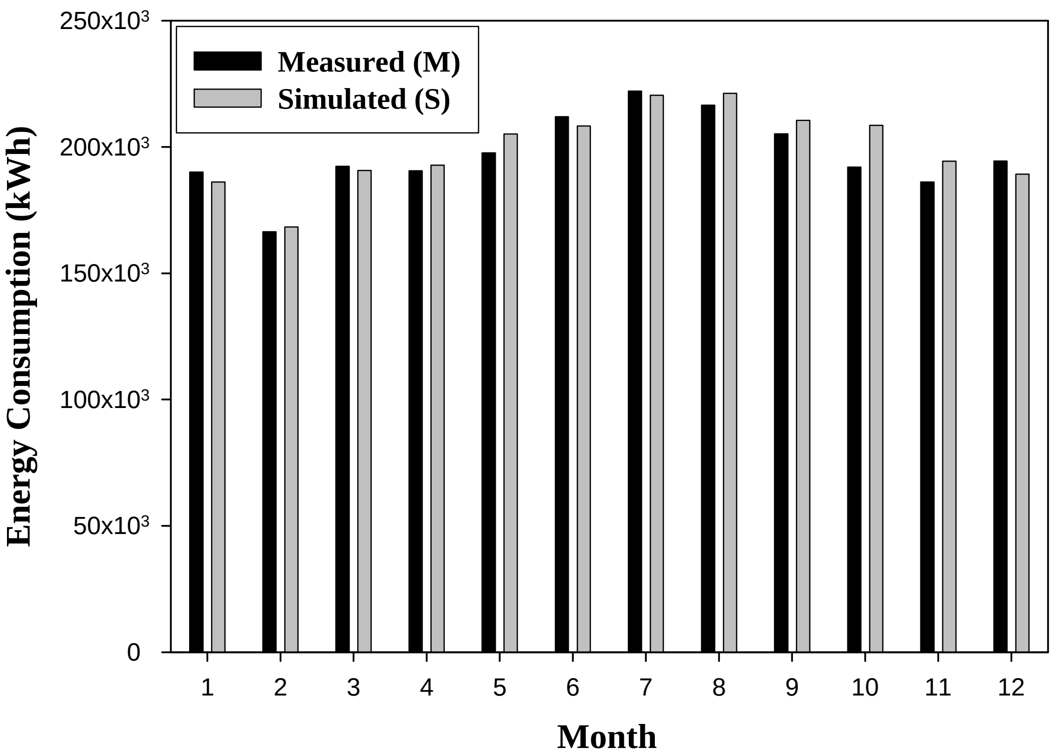

Fig. 4.8 Comparison of Measured and Simulated Results

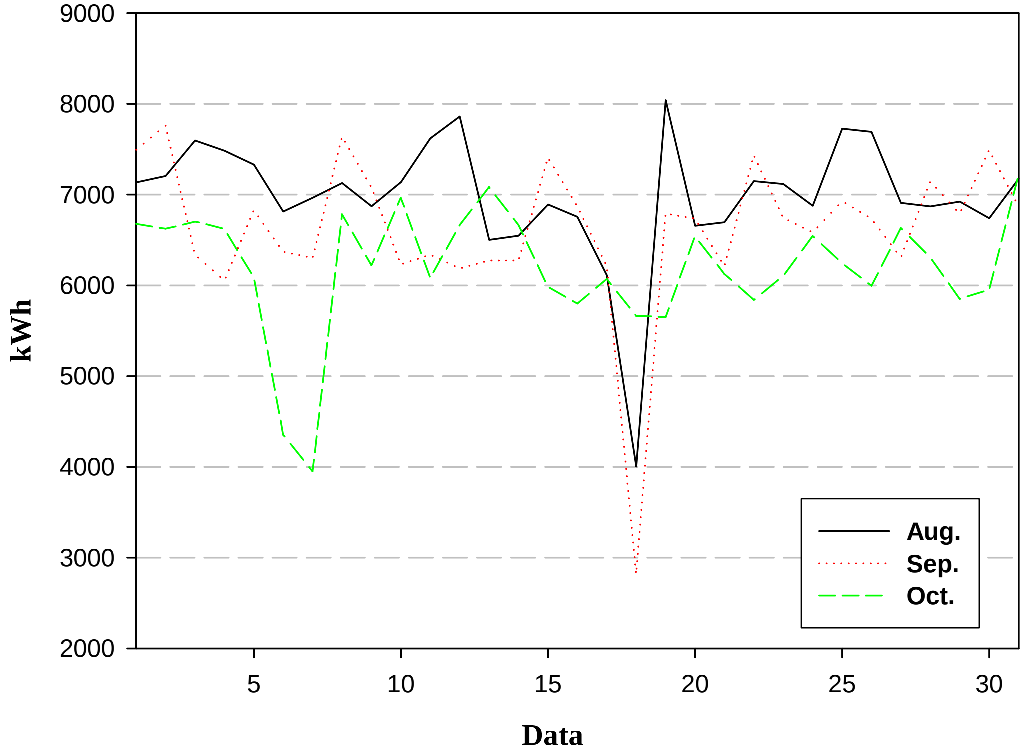

Fig. 5.1 Trend of Energy Consumption

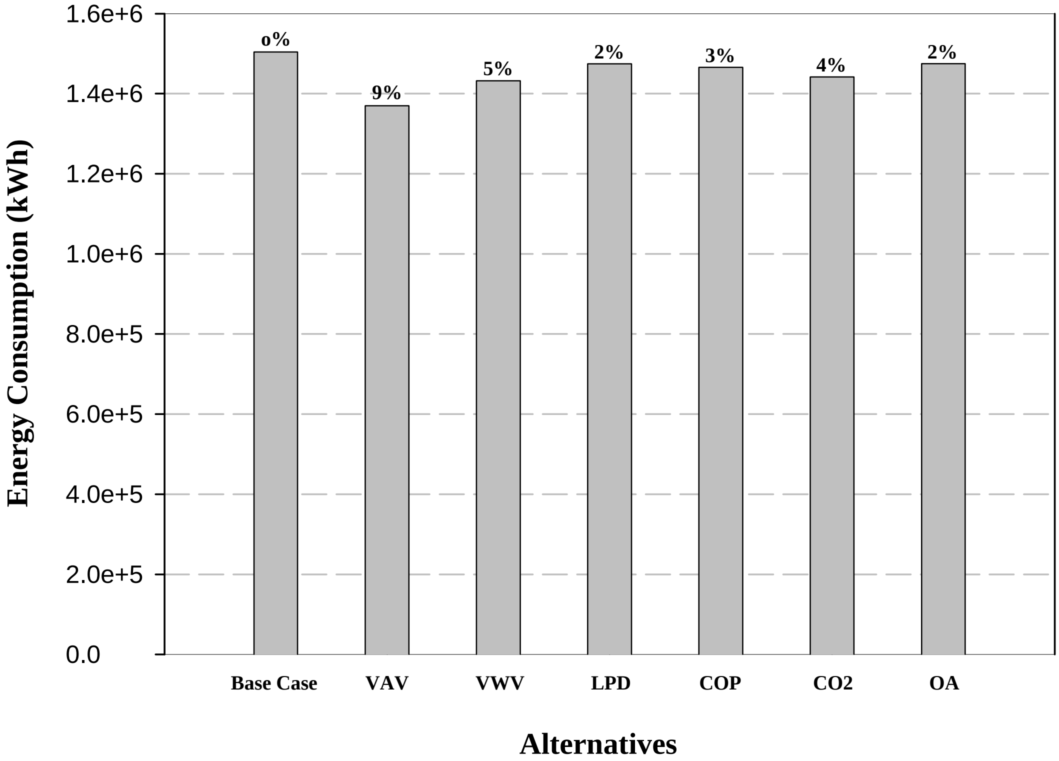

Fig. 5.2 Annual Energy Use for Combined ECMs

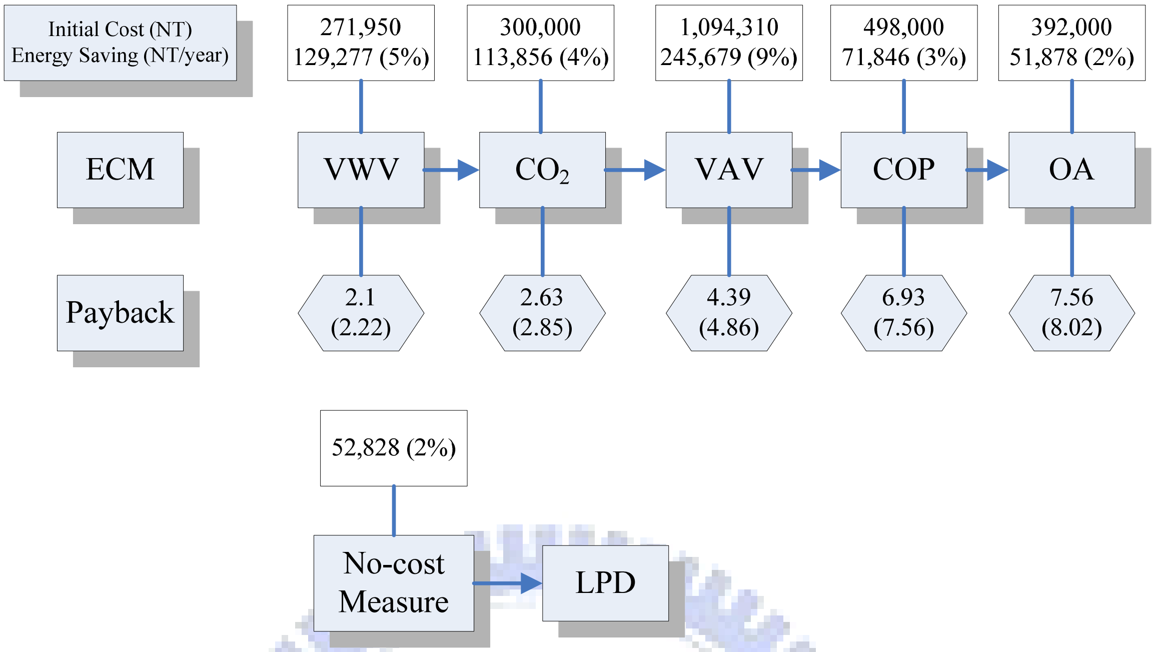

Fig. 5.3 Adoption Order of ECMs

APPENDIX

Heat gain weighting factors represent transfer functions which relate space cooling load to instantaneous heat gains. A set of weighting factors is calculated for each group of heat sources which differ significantly in the (1) relative amounts of energy appearing as convection to the air versus radiation, and (2) distribution of radiant energy intensities on different surfaces.

Air temperature weighting factors represent a transfer function which relates room air temperature to the net energy load of the room. Weighting factors for a particular heat source are determined by introducing a unit pulse of energy from that source into the room's network. The network is a set of equations that represents a heat balance for the room. At each time step (1 hour intervals), the energy flow to the room air represents the amount of the pulse which becomes a cooling load. Thus, a long sequence of cooling loads can be generated, from which weighting factors are calculated. Similarly, a unit pulse change in room air temperature can be used to produce a sequence of cooling loads.

A two-step process is used to determine the air temperature and heat extraction rate of a room for a given set of conditions. First, the room air temperature is assumed to be fixed at some reference value, usually the average air temperature expected for the room over the simulation period. Instantaneous heat gains are calculated based on this constant air temperature. Various types of heat gains are considered. Some heat gains are independent of the reference temperature, such as solar energy entering through windows or energy from lighting, people, or equipment. Others, such as conduction through walls, depend directly on the reference temperature.

A space sensible cooling load for the room, defined as the rate at which energy must be removed from the room to maintain the reference value of the air temperature, is calculated for each type of instantaneous heat gain. The cooling load generally differs from the instantaneous heat gain because some energy from heat gain is absorbed by walls or furniture and stored for later release to the air.

At time θ, the calculation uses present and past values of the instantaneous heat gain ($q_\theta, q_{\theta-1}$), past values of the cooling load ($Q_{\theta-1}$, $Q_{\theta-2}$, ...), and the heat gain weighting factors (v_0, v_1, v_2, ..., ω_1, ω_2, ...) for the type of heat gain under consideration. Thus, for each type of heat gain q_θ, cooling load Q_θ is calculated as:

$$Q_\theta = v_0 q_\theta + v_1 q_{\theta-1} + \cdots - \omega_1 Q_{\theta-1} - \omega_2 Q_{\theta-2} - \cdots \qquad \text{(A.1)}$$

The heat gain weighting factors are a set of parameters that determine how much of the energy entering a room is stored and how rapidly stored energy is released later. Mathematically, the weighting factors are parameters in a Z-transfer function relating the heat gain to the cooling load.

These weighting factors differ for different heat gain sources because the relative amounts of convective and radiative energy leaving various sources differ and because the distribution of radiative energy can differ. Heat gain weighting factors also differ for different rooms because room construction affects the amount of incoming energy stored by walls or furniture and the rate at which it is released.

In the second step, the total cooling load is used (with information on the room's HVAC system and a set of air temperature weighting factors) to calculate the actual heat extraction rate and air temperature. The actual heat extraction rate differs from the cooling load (1) because, in practice, air temperature can vary from the reference value used to calculate the cooling load, or (2) because of HVAC system characteristics. Deviation of air temperature t_θ from the reference value at hour θ is calculated as:

$$t_\theta = 1/g_0 + \begin{bmatrix} (Q_\theta - ER_\theta) + P_1(Q_{\theta-1} - ER_{\theta-1}) + P_2(Q_{\theta-2} - ER_{\theta-2}) \\ + \cdots - g_1 t_{\theta-1} - g_2 t_{\theta-2} - \cdots \end{bmatrix} \quad \text{(A.2)}$$

where ER_θ is the energy removal rate of the HVAC system at hour θ, and g_0, g_1, g_2, …, P1, P2, … are air temperature weighting factors, which incorporate information about the room, particularly thermal coupling between the air and the storage capacity of the building mass.

Two assumptions are made in the weighting-factor method. First, the processes modeled are linear. This assumption is necessary because heat gains from various sources are calculated independently and summed to obtain the overall result (i.e., the superposition principle is used). Therefore, nonlinear processes such as radiation or natural convection must be approximated linearly. This assumption is not a significant limitation because these processes can be linearly approximated with sufficient accuracy for most calculations. The second assumption is that system properties influencing the weighting factors are constant (i.e., they are not functions of time). This assumption is necessary because only one set of weighting factors is used during the entire simulation period. This assumption can limit the use of weighting factors in situations where important room properties vary during the calculation (e.g., the distribution of solar radiation incident on the interior walls of a room, which can vary hourly, and inside surface heat transfer coefficients).

The transfer function concept implies that a system output (Y) can be related to the input or driving force (G) through a transfer function (K), as

$$Y = K \times G \tag{A.3}$$

When dealing with continuous variables, the Laplace transform is employed. On the other hand, the analysis performed by DOE-2 uses discrete data. For discrete data, the z transform is the analog of the Laplace transform.

Four heat transfer processes are considered: (1) conduction through walls, (2) convection from inside surfaces to the room air, (3) radiation among inside surfaces in the room, and (4) radiant sources impinging on interior surface such as solar radiation or energy from lights. For any wall, energy reaching the inside surface by conduction can be written in terms of a transfer function as:

$$Q_{Di}(z) = K_{Di}(z)T_i(z) - K'_{Di}(z)T'_i(z) \tag{A.4}$$

where $Q_{Di}(z)$ is the z-transform of heat flow to the inside surface of wall i by conduction; $T_i(z)$ and $T'_i(z)$ are the z-transforms of inside and outside surface temperatures of wall i and $K_{Di}(Z)$ and $K'_{Di}(Z)$ are z-transfer functions, which relate the conduction energy flow at the inside surface of wall i (output) to temperature changes of the inside and outside surfaces of the wall (input). For delayed walls, $K_{Di}(Z)$ can be written in terms of the Z-response factors of the wall as:

$$K_{Di}(z) = A_i \sum_{j=0}^{\infty} Z_i(j) z^{-j} \tag{A.5}$$

where $Z_i(0)$, $Z_i(1)$, $Z_i(2),\cdots$, are the Z-response factors of wall i and Ai is the wall area.

$$K'_{Di}(z) = A_i \sum_{j=0}^{\infty} Y_i(j) z^{-j} \tag{A.6}$$

where $Y_i(0)$, $Y_i(1),\cdots$, are the Y-response factors for wall i. For a quick wall (with negligible thermal storage),

$$K_{Di}(z) = U_i A_i = \frac{1}{R_i} \tag{A.7}$$

where Ri is the thermal resistance of wall i. This relation holds for any heat flow path with no thermal storage (pure resistance). Furniture can be treated in the same manner as a wall.

Convective heat transfer between wall surfaces and room air can be written as:

$$Q_{ci}(z) = K_{ci}(z)\left[T_a(z) - T_i(z)\right] \tag{A.8}$$

where $Q_{ci}(z)$ is the z-transform of heat flow from the room air to the inside surface of wall i, $T_a(z)$ and $T_i(z)$ are z-transforms of the air temperature and the surface temperature of wall i, and $K_{ci}(z)$ is the z-transfer function for the process. Because this process involves no energy storage (the heat capacity of the air is considered negligible compared with the walls and furniture),

$$K_{ci}(z) = h_{ci} A_i \tag{A.9}$$

where h_{ci} is the convective heat transfer coefficient for wall i.

Radiative heat transfer between two surfaces can be written as:

$$Q_{Rim}(z) = K_{Rim}(z)\left[T_i(z) - T_m(z)\right] \tag{A.10}$$

where $Q_{Rim}(z)$ is the z-transform of radiative heat flow from surface i to surface m, $T_i(z)$ and $T_m(z)$ are z-transforms of the surface temperatures, and $K_{Rim}(z)$ is the z-transfer function for the process. In DOE-2, $K_{Rim}(z)$ is approximated as:

$$K_{Rim}(z) = 4(\varepsilon_i)\sigma(T_R^3)(F_{im})(A_i) = G_{im} \tag{A.11}$$

where ε_i is the emissivity of surface i, σ is the Stefan-Boltzmann constant, T_R is a reference temperature in absolute units, F_{im} is the view factor between surfaces i and m, and A_i is the area of the radiating surface.

Infiltration provides a direct heat-flow path between outside air and room air. This can be written as:

$$Q_v(z) = K_v(z)\left[T_a(z) - T_o(z)\right] \tag{A.12}$$

where $Q_v(z)$ is the z-transform of heat flow from the room air to the exterior, $T_a(z)$ and $T_o(z)$ are z-transforms of room-air temperature and outside-air temperature, and $K_v(z)$ is the z-transfer function for the process. Infiltration rates are usually estimated as a volumetric flow of exterior air into the room (V_{in}). For this case,

$$K_v(z) = \rho_a C_{p_a} V_{in} \quad \text{(A.13)}$$

where ρ_a and C_{p_a} are the density and heat capacity of the exterior air.

There are numerous sources of radiant energy in a room such as solar energy or radiation from people or equipment. The z-transforms of these sources are known from hourly input values from the solar routines or from schedules, which have been specified for source in the room. These sources can be used directly in an energy balance. They will be designated as $Q_{si}(z)$ for the z-transform of total source energy on the inside surface of wall i.

The heat balance figure is shown in **Fig. A-1.** An energy balance on the inside surface of wall i results in

$$Q_{Di}(z) = Q_{Ci}(z) - \sum_{m=1}^{N} Q_{Rim}(z) + Q_{Si}(z) \quad \text{(A.14)}$$

where N is the number of surfaces in the room. Infiltration does not appear in this energy balance as it is a direct communication between room air and the exterior. In terms of z-transfer functions, it can be rewritten as:

$$\begin{aligned} &K_{Di}(z)T_i(z) - K'_{Di}(z)T'_i(z) = \\ &K_{ci}(z)[T_a(z) - T_i(z)] - \sum_{m=1}^{N} K_{Rim}(z)[T_i(z) - T_m(z)] + Q_{Si}(z) \end{aligned} \quad \text{(A.15)}$$

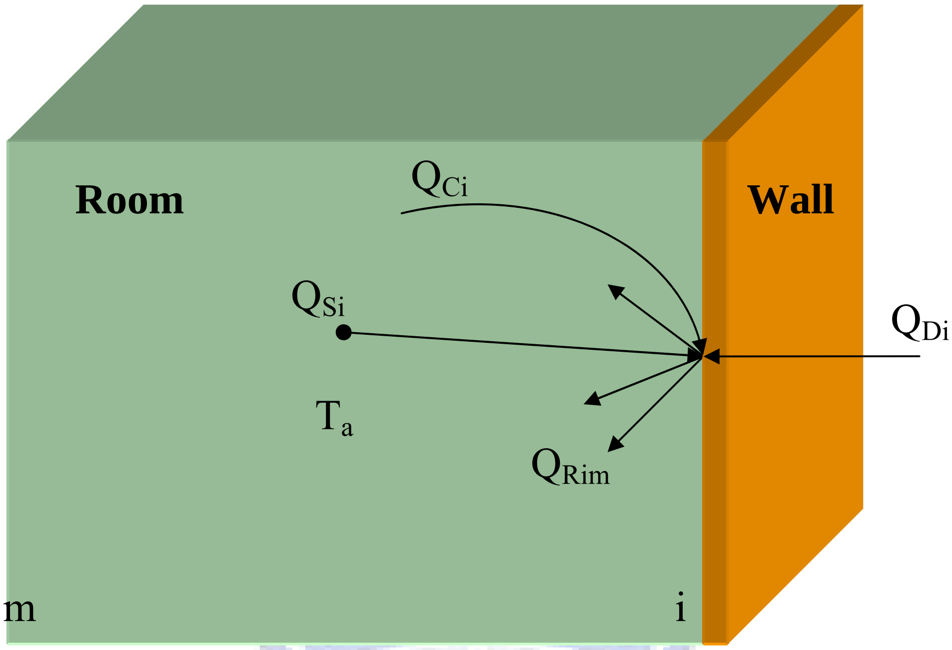

Fig. A.1 Heat Balance in a Room