DESIGN STANDARD OF ENERGY CONSERVATION FOR BUILDING HVAC SYSTEM – A SIMPLIFIED METHOD OF CHILLER CAPACITY ESTIMATION BASED ON BUILDING ENVELOPE ENERGY CONSERVATION INDEX IN TAIWAN

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ABSTRACT

The research developed maximum chiller cooling capacity predicting equations with building shape factor and the ENVLOAD index which is now the building envelope energy conservation design control factor in Taiwan. The models are established base on numerous DOE-2.2 simulations and statistical multi-regression techniques. Totally, there were 21 sets of predicting models be built with a satisfactory R^2 of 0.8 to 0.9.

INTRODUCTION

Taiwan usually encounters electricity shortage in summer recently due to rising electricity consumption. In fact, one of the reasons for the power supply crisis lies in high Air-Conditioning electricity consumption of buildings, which is around 30% of total electric supply through the year, and it reaches its high of about 40% to 50% at summer peak load whilst is 20% at winter time.

Some causes of high energy consumption of air-conditioning system in Taiwan are the oversized capacity design and low efficiency of the chiller. The low efficiency of the chiller has now been governed by the chiller's COP standard norm which was legislated by Bureau of Energy in the year of 2003 to prevent purchasers from buying low efficient chillers for cutting down the energy cost. But as to the chiller capacity, there is no regulation to control the over-sizing problem, and hence the chiller capacity design is often oversized, sometimes it is twice as actual needed. One of the reasons for capacity over-sizing lies in the lacking of united and standardized chiller capacity estimation method in Taiwan. Therefore, a relatively high safety factor is often multiplied to the capacity by HVAC designers. The tendency of preferring over-design to avoid insufficient cooling is the main cause of the prevailing over-sizing problems of chiller capacity.

The development of the index of buildings' envelope energy conservation design(ie. ENVLOAD (Hsien-Te Lin, 2003)) of Taiwan has been decades by academic institution. It became Taiwan's building codes and standards for controlling building envelope energy conservation design since 1995. It is capable of preventing inappropriate building envelope design effectively, however ENVLOAD itself does not have any control over HVAC performance.

In view of the above and the prevailing situation of chiller over-sizing problem, the intension of the research is to integrate the ENVLOAD index as a predicting variable to establish maximum chiller capacity estimation equations through multi-regression method. The dependent variable which is the chiller capacity here is precisely simulated by dynamic building energy simulation program (DOE-2.2) accompanied with local HVAC design weather data. For the reason that the passing of ENVLOAD index is mandatory for every newly built building since 1995, the research is not only able to simplify the estimation procedure of maximum chiller capacity, but also help to enhance the accuracy.

AN INTRODUCTION TO ENVLOAD INDEX

In Taiwan, according to building regulation, the air-conditioning building types, such as office buildings, hospitals, hotels, and commercial buildings, all should comply with EVNLOAD index as standard for building envelope energy efficiency design. The "ENVLOAD" is actually "Envelope Load" in short. The meaning is the yearly total sensible cooling loads of the building's perimeter zones which are five meters beyond the exterior walls. Floor areas outside these five-meter enclosures are called internal zones where their cooling loads are primarily coming from internal loads.

Because the cooling loads of internal zones are not influenced by outdoor climate, they have little relevance to the building's envelope design. Hence the internal loads are not taken into consideration in ENVLOAD index. Besides, the top floor and the lifted floors directly next to outdoor airs, since their cooling loads are concerned to be affected by the outdoor climates, are also considered as perimeter zones (as shown in fig.1).

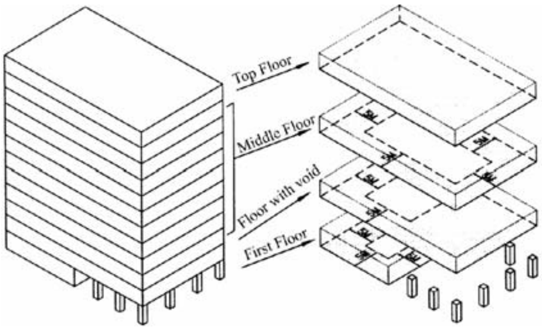

Figure 1 The definition of perimeter zones in ENVLOAD index

The form of ENVLOAD index (Eq-1) is a simple multi-regressive equation including two meteorological variables (DH, IHk) and three architectural design variables (G, L, Mk) to interpret the complicated loads behaviors in buildings. The variables of DH and IHk are stands for local meteorological conditions, which are developed from hourly weather variation theories(Diamond S.C., 1969; Yoshimura, 1978) and are arranged in tables according to various directions and locations in Taiwan. They in turn represents for yearly cumulative amounts of indoor-outdoor temperature differences (either cooling or heating situations) and solar radiation gain of various directions. The user can easily obtain the corresponding values of DH and IHk by looking up tables.

The variable of L is the heat insulation performance of building envelope, whereas the variable of Mk is the actual solar radiation gain coefficient of building envelope in various directions. While calculating Mk, there is a special discount factor which is an encouragement for utilizing external shading of fenestration since it is crucial in the subtropics such as Taiwan to reduce envelope's solar radiation gain when external sun-shadings are utilized. The good or bad design of building envelope will directly reflect on these two variables. Moreover, the meaning of variable G is the cumulative values of internal loads and heating time-lags effect within perimeter zones. It varies in different building types and HVAC time zones and is related to variable L. In short, the compound variable of L×DH represents for yearly heat gain or heat loss from building envelope's temperature difference, namely the heat insulation properties of the envelope, and ΣMk×IHk is solar radiation gain from exterior surfaces and the openings, namely the sun-shading performance of the envelope (as shown in figure 2).

The constant a_0 and coefficients a_1-a_3 were derived from multi-regression method based on hundreds of building samples simulated by HASP8001 program, which is a dynamic HAVC energy simulation software developed by Japan, accompanied with typical meteorological years of 18 places globally (Hsien-Te Lin, 1985). Four sets of multi-regression equations for four different HVAC time zones of offices, hospitals, hotels and commercial buildings were established, each sets includes coefficients for cooling and heating loads. The values of these equations' coefficient of determination (R^2) range from 0.86 to 0.95 which are of high credibility.

The yearly energy consumptions of building envelope of newly built offices, hospitals, hotels, commercial buildings is today regulated by "Taiwan's Building Technical Code" with ENVLOAD index. Only when the calculated value of ENVLOAD is less than the standards shown in table 2, can it further apply for building license issuing. The location of Taiwan Island extends from north latitude of 22.5 to 25 degrees, for this reason the ENVLOAD standards are divided into three groups corresponding to northern, central and southern Taiwan. The two meteorological variables of DH and IHk are also divided into seven climate zones (fig.3), these meteorological values are tabled and should be read respectively according to in which zone the building is situated.

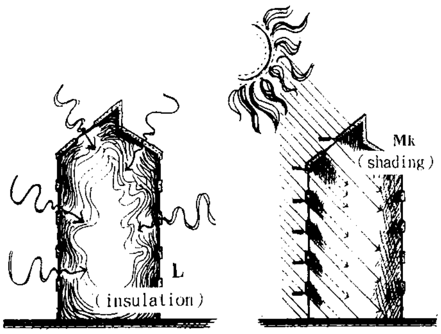

Figure 2 The diagram for L×DH and Mk×Ihk

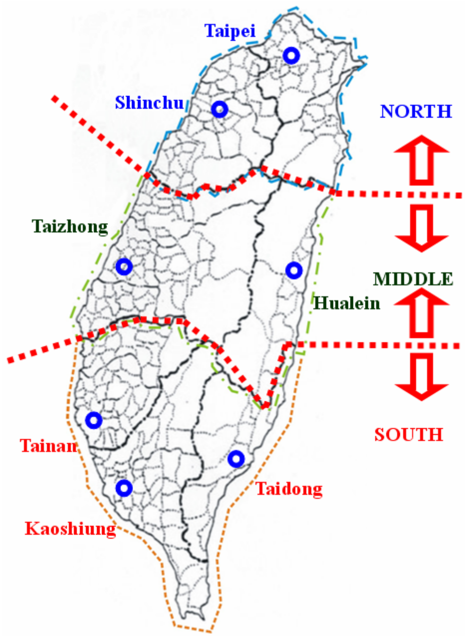

Figure 3 Taiwan's administration and Building Energy Regulation zoning

METHOD

The common ways of HVAC load calculation are as follows: 1) Dynamic Computer HVAC Load Simulation, 2) Degree Days & Degree Hours Approximation (Hsien-Te Lin, 1987), 3) Expended Degree Day Method ,4) Modified Bin Method (Knebel, 1983), 5) Multi-regression Method, etc. Only the one who has abundant background knowledge is qualified to utilize the methods from 1 to 4. However, for the reason of easy to use and to be publicly applicable, considering between the estimation accuracy and the applicability, the Multi-regression Method which has slightly acceptable bias is the most ideal way to establish HVAC load predicting model. To achieve this goal, the research establish the maximum chiller capacity estimation equations by multi-regression with the help of dynamic computer energy simulation program (ie. DOE-2.2).

The geological location of Taiwan is in the neighbors of the Tropic of Cancer at where is subtropical climate area, the HVAC use is cooling mainly; contrarily, heating is rarely used here. For the reason, the topic of the research is mainly focus on cooling capacity, the HVAC capacity discussed here is indicated to the capacity of HVAC chiller.

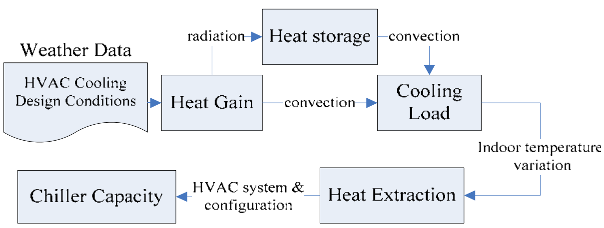

Figure 4 Flow chart of HVAC Loads to Chiller Capacity

The estimation of HVAC capacity either manually or computationally the maximum HVAC load should firstly be estimated can the final maximum HVAC capacity be determined. This process is flow-charted in figure 4.

The prototype equation of ENVLOAD is as following:

ENVELOPE LOAD ("ENVLOAD" in short)

$$= a_0 + a_1 \times \underline{G} + a_2 \times \underline{L} \times \underline{DH} + a_3 \times \Sigma \underline{Mk} \times \underline{IHk} \quad \text{...(Eq-1)}$$

The explanation of the variables are listed in the nomenclature section.

Table 2 ENVLOAD standards for central air-conditioning buildings in Building Energy Conservation Regulation

Building Types	Climate Zones	ENVLOAD Standards kWh／(m^2year)
Offices	North District	80
	Central District	90
	South District	115
Commercial Buildings	North District	240
	Central District	270
	South District	315
Hotels	North District	100
	Central District	120
	South District	135
Hospitals	North District	140
	Central District	155
	South District	190

The discussion of HVAC loads in the research can be divided into internal and perimeter zones following the concept of HVAC zoning. The definition of perimeter zone here is the same as is given in the EVNLOAD index. The influential factors of HVAC loads within the perimeter zone not only include internal loads, but also outdoor climate and building envelope design which is considered to be more influential to the loads. The factors of building envelope design includes building orientation, opening ratio, types of glass and exterior wall constructions, external shading etc. as in table 3,

Table 1 Coefficients of ENVLOAD equation

Equation Prototype	$ENVLOAD=a_0+a_1\times G+a_2\times L\times DH+a_3\times(\Sigma Mk\times IHk)$						
Building Types	HVAC Time Zone	Cooling or Heating	Constant	Coefficients			R^2
			a_0	a_1	a_2	a_3	
Guest rooms of hotel buildings, wards & emergency rooms of hospitals	24hrs system 0:00-24:00	Cooling	-20947	0.250	-0.054	1.127	0.86
		Heating	2291	0.068	0.954	-0.636	0.95
Restaurants, banquet hall of hotel buildings & commercial buildings	12hrs system 10:00-22:00	Cooling	-10070	1.713	0.413	1.457	0.91
		Heating	22756	-1.351	1.105	-0.457	0.86
Offices, administrative department of hotels or hospitals	10hrs system 8:00-18:00	Cooling	-20370	2.512	-0.326	1.079	0.88
		Heating	14208	-1.493	1.484	-0.423	0.92
Saloon, dance hall and other entertainment rooms of hotels	6hrs system 18:00-24:00	Cooling	-21093	1.523	0.309	0.911	0.89
		Heating	13173	-0.657	1.935	-0.573	0.94

are all considered in ENVLOAD index. Comparing to perimeter zones, the HVAC loads in internal zones are purely internal loads including lighting heat load, human heat discharge and equipment heat loads. For the reason of not being influenced by outdoor climate, the cooling loads in internal zones vary less than those in perimeter zones; therefore, it can be seen as a stable value differentiating from among building usage types.

The loads calculated in ENVLOAD index are simply total yearly sensible cooling loads in perimeter zones. To further estimate the maximum HVAC capacity of the whole building with ENVLOAD index, multi-regression analysis method is introduced to build up the predicting model. The dependent variable which is the maximum chiller cooling capacity is acquired case-by-case through computer dynamic simulation using DOE-2.2 program. To establish the interrelationship between the cooling loads in perimeter and internal zones, the research newly defined "coefficient of perimeter zone (γ)" as another predicting variable, in addition to the ENVLOAD index. The definition of γ is the ratio with which the total floor areas of perimeter air-conditioning zones is divided by the total air-conditioning floor areas of the building.

$$\gamma = \frac{Afp}{Afp + Afi} \qquad \text{...(Eq-2)}$$

The effects of the factor γ to the physical form of buildings are as follows:

Table 3 The composition of HVAC loads

HVAC Loads			
Exterior Loads	Heat transmission from walls	sensible
	Heat transmission from glass panel	sensible
	Heat gain through fenestration	sensible
Internal Loads	Human body heat discharge	sensible
		latent
	Lighting heat discharge	sensible
	Equipment heat discharge	sensible
		latent
	Heat loads from out-door air	sensible
		latent

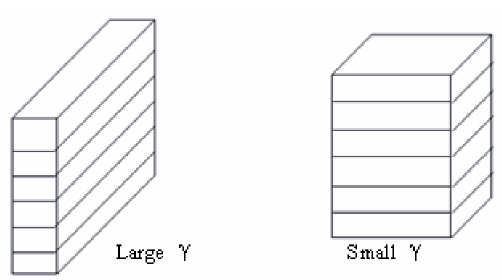

Figure 5 The γ value of different building shape

1. The larger the γ is, the more proportions the floor areas of air-conditioning perimeter zones are. In other words, the plan shape of the building will be more slender if comparing to smaller γ . HVAC loads of the building with larger γ value have to do with the outdoor climate more than the smaller ones.

2. The factor γ is related with total floor areas, the length-width ratio of the plan, and the number of the storey.

The reasons to predict the maximum HVAC capacity by variables ENVLOAD and γ are as follows:

1. Internal loads of various building types are rarely concerned with outdoor climate, consequently the fluctuation is small. As long as we clearly acquainted with the general condition of internal loads among various building types, the internal loads of the target building will spontaneously includes in the coefficient of variable γ and the constant term of the predicting model.

2. ENVLOAD index itself is provided with the characteristic of the cooling load variation in perimeter zones, and is capable of reflecting the designing factor of the building's envelope. With the help of γ with which it bridges the cooling load relationship between internal and perimeter zones, the maximum chiller capacity of the whole buildings hence become predictable.

THE HVAC CAPACITY SIMULATION TOOLS: DOE-2.2

The study adopted dynamic building energy simulation program (DOE-2.2) developed by Lawrence Berkeley Lab in USA as a tool for HVAC loads simulation to retrieve maximum chiller cooling capacity. The program is able to simulate energy performance and HVAC loads of a building hour by hour for each of the 8760 hours in a year. The DOE-2.2 program is composed of four modules that are executed sequentially (Shobhakar Dhakal, 2003). The LOADS module calculates the hourly cooling and heating loads using algorithms suggested by the American Society for Heating Ventilation and Air-Conditioning Engineers (ASHRAE). The SYSTEMS module simulates the performance of secondary HVAC equipment under conditions of maintaining indoor comfort within the building. The PLANT module simulates the energy performance of primary HVAC equipments, such as chiller, boiler, cooling tower, on the basis of operating conditions and part load performance characteristics. The maximum chiller capacity which is our objective can be acquired from PLANT module. The fourth module ECONIMICS that does energy economical benefit analysis was not included in the current study.

HVAC-DESIGN-USED METEOROLOGICAL DATA

The DOE-2.2 program should operate with meteorological data to acquire accurate and local climatically responsive HVAC loads. For the reason that the latitude of Taiwan island is stretching from north 22 to 25.8 degree, and to simulate out accurate maximum chiller capacity from north to south Taiwan accordingly, the study proceed the simulation works with Taiwan's HVAC-design-used meteorological data (Hsien-Te Lin, 1986) of north 23, 24, 25 degree respectively. The HVAC-design-used meteorological used data contains hourly weather information of outdoor dry and wet bulb temperatures, relative humidity, total horizontal solar radiation and normal solar radiation in one day. The purpose of this kind of meteorological data is for equipment sizing. The twenty-four hourly value of each weather element is chosen from long-term hourly original weather recordings based on the method suggested by Technical Advisory Committee (TAC) of ASHRAE. The method suggested by TAC for developing HVAC-design-used meteorological data is taking 2.5% risky value as the deisgn value. For retrieving each simulated cases' maximum chiller capacity with the consideration of thermal time-lag effect, letting the DOE-2.2 run seven loops with the HVAC-design-used meteorological data.

THE ESTABLISHMENT OF SAMPLES FOR SIMULATION

As previously mentioned, the maximum chiller capacity comes from interior maximum loads which closely related to building's envelope and its type of usage. To give consideration to all possible building forms during simulation, building samples were generated via Taguchi's Experimental Design Method (EDM). Each sample is decided from a combination of nine building factors according to every factor's level arrangement of orthogonal array in EDM. The basic concept of EDM is to reach a roughly result by utilizing finite runs of experiment instead of accomplishing all possible experimental runs, so as to reduce the simulation works in the study. The research adopted the orthogonal array with 3 levels in each factor to prepare simulation models. The actual orthogonal array we chose in the study, as shown in table 4, is modified from the original L_{27} orthogonal array to incorporate with the two factors of building orientation and plan geometry with eight levels and nine levels accordingly.

Each numeral in the array indicates at which level of every building control factor's value is. According to the rationale of EDM, the results derived from the 27 simulation runs with the use of L_{27} orthogonal array is supposed to be able to represent for $8 \times 9 \times 3^7$=157,464 runs of simulation works.

Building Control Factors

From previous studies, we can conclude that the factors related to HVAC loads in subtropical areas are building orientation, opening ratio, glass solar radiation gains, glass thermal insulation, and wall insulation properties sequentially listed by its influence intensities. Therefore, we chose nine easy-to-use factors from above as building control factors for model generation. The followings are descriptions of these nine factors:

1) Building Orientation: The amount of solar radiation that reaches to the building is closely related to its orientation. The definition of building orientation in the study is the facing direction of the longer side of the building plan, as shown in figure 4. There are 8 levels for this factor.

2) Floor Plan Geometry: This controlling factor is actually the ratio of the longer side divided by the shorter side of the building floor plan. There are 9 levels in this factor to reflect various rectangular plan shapes.

3) Depth of the Shading: Regulates the amount of solar radiation that incident to interior.

4) Floor Areas of Standard Floor: This factor not only determines the scale of the building, but is also relevant to the coefficient of the perimeter (γ).

5) Opening Ratio: The definition of opening ratio is total opening areas divided by the areas of total exterior facades. The more it is the more solar radiation the building gains.

6) Type of Glass: This controlling factor uses shading coefficient value (SC) to specify the heat-gain property of glass panes.

7) Numbers of Opening Sides: This factor indicates the numbers of building facades that have openings. Fig.4 demonstrates the definition of it.

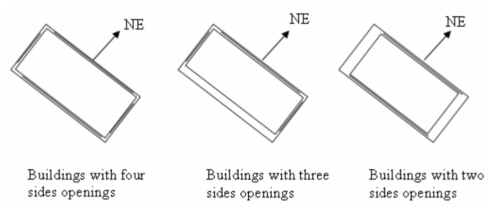

Figure 4 The definition of building controlling factor "Numbers of Opening Sides"

8) Numbers of Building Storey: The total stories of the building above the ground. The height of the building is determined together with the below factor of average floor height.

9) Average Floor Height: This factor not only directly affects the total areas of the building exterior surfaces, but also determines the volumes of the interior for air-conditioning.

Before applying the orthogonal array for model generation, the base case value (ie. value of level 2) of each building control factor should be determined firstly. According to the value of level 2, each control factor perturbs upwardly and downwardly to decide level 1 & 3 values under reasonable perturbation range of itself for diverse model generating. For the reason that buildings in Taiwan are mostly reinforced-concrete (RC) constructed, and the reason that heat conduction property of walls is usually somewhat identical. Moreover, the insulation property is far less influential to HVAC loads than direct solar radiation gain through openings while cooling loads are the only consideration. This can also be proved from comparing the values of a_2 and a_3 coefficients in ENVLOAD equations. To simplify model description, the walls and roofs take 3.49W/m^{2}K and 1.49W/m^{2}K as its overall heat thransfer coefficient (U-factor) respectively which are the often seen construction in Taiwan.

Furthermore, in consideration of extensive representation, five major building types are categorized from various types of central air-conditioning time zones of buildings in the status quo market. Each building type applies to the same L_{27} orthogonal array but has different base case value and level perturbation range which is decided according to its general building configuration. In other words, there are five sets of different values be given to each building control factor to cover all kinds of central air-conditioning buildings in the market as possible as it can. The content of every factor's value and the building classification are shown in table 5. Except for factors of building orientation and floor plan geometry with levels more than three; the other factors all have three levels in itself.

Table 4 L27 orthogonal array and the assignment of controlling factors

Field	1&2	4-7-9-11	3	5	6	8	10	12	13
No.	BO	FPG	SH	FA	OR	GSC	NOA	NBS	FH
1	1	1	1	1	1	1	1	1	1
2	1	2	1	2	2	2	2	2	2
3	1	3	1	3	3	3	3	3	3
4	2	5	2	1	1	2	2	3	3
5	2	6	2	2	2	3	3	1	1
6	2	4	2	3	3	1	1	2	2
7	3	9	3	1	1	3	3	2	2
8	3	7	3	2	2	1	1	3	3
9	3	8	3	3	3	2	2	1	1
10	4	8	2	1	2	1	3	2	3
11	4	9	2	2	3	2	1	3	1
12	4	7	2	3	1	3	2	1	2
13	5	3	3	1	2	2	1	1	2
14	5	1	3	2	3	3	2	2	3
15	5	2	3	3	1	1	3	3	1
16	6	4	1	1	2	3	2	3	1
17	6	5	1	2	3	1	3	1	2
18	6	6	1	3	1	2	1	2	3
19	7	6	3	1	3	1	2	3	2
20	7	4	3	2	1	2	3	1	3
21	7	5	3	3	2	3	1	2	1
22	8	7	1	1	3	2	3	2	1
23	8	8	1	2	1	3	1	3	2
24	8	9	1	3	2	1	2	1	3
25	1	2	2	1	3	3	1	1	3
26	3	3	2	2	1	1	2	2	1
27	5	1	2	3	2	2	3	3	2

Building Orientation (BO); Floor Plan Geometry (FPG); Depth of the Shading (SH); Floor Areas of Standard Floor (FA); Opening Ratio (OR); Shading Coefficient of Glass (GSC); Number of Opening Sides (NOA); Numbers of Building Storey (NBS); Floor Height (FH)

ASSUMPTIONS OF INTERNAL HEAT GAIN

The research covers four major types of central air-conditioning buildings which are offices, hotels, hospitals, commercial buildings in Taiwan. The internal heat gain vary with the character of building usage behavior. According to the concept of HVAC time zone, the classification of the four major types can be subdivided into 7 HVAC zones each has its own internal heat gain property. For example, hospitals can be separated into 3 different HVAC time zones. The wards in hospital are 24-hour air-conditioning while the administrative section and the out-patient department are 10 hours, and the cafeteria is 12 hours. The internal heat gain primarily come from the heat discharge from human, lights, and equipments. The heat gain from human has two components: sensible and latent. The total and proportion of sensible and latent heat vary depending on the level of activity. The internal heat gains are assumed to be fixed and are with the same values as defined in ENVLOAD index. There are two reasons for this. One is to correspond with assumptions having been made in ENVLOAD. The other reason is that internal heat gains fluctuate slightly among buildings of similar usage behavior. Besides, regards to fresh outdoor air supply and the set point of internal design temperature, they were set at 20m^3/person and 26℃ accordingly during DOE-2.2 simulation.

THE ESTABLISHMENT OF PREDICTING MODELS

The prototype of predicting model of chiller cooling capacity takes the form as equation shown below. The dependent variable of chiller cooling capacity is expressed as HVAC supplying floor areas per U.S. refrigeration tons (m^2/USRT). The predictors are ENVLOAD index and the coefficient of perimeter zone (γ).

Chiller Cooling Capacity= $a_0+a_1\times$ENVLOAD$+a_2\times\gamma$

The coefficients of a0 to a3 are established by means of statistical multi-regression method. For the sake of extending the application scope, the predicting models are divided by latitude into 3 geological sections (Northern, Central, and Southern Taiwan), each section with 7 different HVAC time zones. In other words, there will be 21 sets of coefficients waiting to be built. The establishments of each set of the coefficients are based on the 27 simulation models. Each simulation model's values of ENVLOAD and γ are calculated case by case manually, while the predicting value of chiller cooling capacity are simulated sequentially through DOE-2.2 simulation. A total of $21\times27=567$ simulations were carried. Figure 5 is the diagram of correlation between the simulated and the estimated values of chiller capacity. The standard deviation is 17.25 and the coefficient of determination (R^2) is 0.95, which is satisfactory. For the purpose of regression model validation, while focusing on the Office Type ,additional 81 cases of building models for offices type, which are totally different from the original ones that be used for building up regression models, are newly developed. These models are built via the same L_{27} orthogonal array, but have changed each original assigned factor's level value. Fig. 6 demonstrates how well the correlation the estimated values derived from regression models between the DOE-2.2 simulated values.

CONCLUSION AND APPLICATION

The maximum chiller cooling capacity prediction models are developed partly with prevailing building energy conservation regulation (ENVLOAD) and partly with DOE-2.2 dynamic simulation in the study. The definition and classification of HVAC time zones as well as the calculation procedure of ENVLOAD index are of the same definition and should comply with the ENVLOAD regulation. In addition, a new predicting variable γ was introduced to set up relationships of HVAC loads between the perimeter and the internal zones. The intension of this paper is to provide a method for estimating reasonable chiller cooling capacity to reduce the prevailing capacity over-design problem. The established multi-regression models use simple and easy-to-use variables to estimate complicated and hard-to-acquire reasonable maximum chiller capacity. It also reduces the difficulties of general capacity estimation procedure.

The coefficients of the multi-regression models are shown in table 8. They are grouped in 7 HVAC time zones, each zone with 3 latitudinal levels. Consequently, the influence intensity of ENVLOAD to the chiller cooling capacity is much dropped in the predicting model.

The coefficients of determination (R^2s) among the predicting models are as high as 0.8 to 0.9.The reason why the R^2 is relatively low of the predicting model for the 6-hour HVAC time zone is probably because the 6 hours' air-conditioning time span are all in the nighttime which having no solar radiation. The variance of the predictor ENVLOAD, which is much relevant to solar radiation, is smaller while in nighttime.

Table 8 The predicting models of each HVAC time zones

Capacity Predicting Equation	$Y=a_0+a1\times ENVLOAD+a_2\times\gamma$				
HVAC Time Zones	**Location***	**a_0**	**a_1**	**a_2**	**R^2**
6hrs system (Entertainments)	North	36.0	-0.100	-5.68	0.73
	Central	37.2	-0.076	-6.73	0.74
	South	37.1	-0.065	-6.62	0.75
10hrs system (Offices)	North	63.7	-0.179	-30.8	0.90
	Central	63.4	-0.127	-31.5	0.90
	South	62.8	-0.110	-31.3	0.90
10hrs system (Administrative & OPD of Hospitals)	North	105.7	-0.148	-101.4	0.82
	Central	103.5	-0.105	-101.5	0.82
	South	102.7	-0.091	-101.7	0.82
12hrs system (Commercial buildings)	North	39.6	-0.057	-9.417	0.84
	Central	38.1	-0.040	-9.430	0.84
	South	37.7	-0.034	-9.28	0.84
12hrs system (Hotel cafeterias)	North	45.5	-0.074	-12.3	0.86
	Central	43.7	-0.051	-12.3	0.86
	South	43.1	-0.044	-12.2	0.87
24hrs system (Hotel guest rooms)	North	152.7	-0.236	-166.5	0.82
	Central	153.9	-0.170	-167.0	0.81
	South	154.3	-0.147	-167.1	0.81
24hrs system (Wards & Emergency Department of Hospitals)	North	62.7	-0.148	-30.5	0.90
	Central	62.1	-0.107	-30.5	0.90
	South	61.7	-0.092	-30.2	0.90

Table 5 Various orthogonal arrays developed in the study and the factors' assignment

Orthogonal Array No.	Building Orienta-tion (8 levels)	Floor Plan Geometry (9 levels in ratio)	Single floor areas (m^2)		Number of the storey	Floor Height (m)	Opening Ratios (%)	NOA*	SC value of glass	SH** (m)
L27-1 (6hrs system) Entertainments	N,NE,E, SE,S,SW ,W,NW	1.1;1.45;1.75 ;2;2.35; 2.65;3;3.5;4	Level 1	420	5	4.6	70	4	0.98	0
			Level 2	800	3	4	50	3	0.70	0.5
			Level 3	1200	1	3.4	30	2	0.34	1.0
L27-2 (10hrs system) Office types***	N,NE,E, SE,S,SW ,W,NW	1.1;1.45;1.75 ;2;2.35; 2.65;3;3.5;4	Level 1	900	10	4.0	70	4	0.98	0
			Level 2	1600	18	3.6	50	3	0.70	0.5
			Level 3	2500	25	3.2	30	2	0.34	1.0
L27-3 (12hrs system) Commercial Bldings	N,NE,E, SE,S,SW ,W,NW	1.1;1.45;1.75 ;2;2.35; 2.65;3;3.5;4	Level 1	2000	6	4.2	50	4	0.98	0
			Level 2	3500	9	3.8	30	3	0.70	0.5
			Level 3	5000	12	3.4	10	2	0.34	1.0
L27-4 (12hrs system) Hotel cafeterias	N,NE,E, SE,S,SW ,W,NW	1.1;1.45;1.75 ;2;2.35; 2.65;3;3.5;4	Level 1	420	4	4.6	80	4	0.98	0
			Level 2	700	2	4.0	60	3	0.70	0.5
			Level 3	1000	1	3.4	40	2	0.34	1.0
L27-5 (24hrs system) Hotel Gests Rooms & Hospitals wards	N,NE,E, SE,S,SW ,W,NW	1.1;1.5;2;2.5 ;3;4;5;6;7	Level 1	1600	3	4.2	70	4	0.98	0
			Level 2	3000	8	3.7	50	3	0.70	0.5
			Level 3	5000	12	3.2	30	2	0.34	1.0

* NOA: Number of opening sides
** SH: Depth of shading

***Office types include General Offices, Administrative Department of Hotels & Hospitals, Out-door patients department of Hospital

As regards to actual application, first to identify the type of the building and the HVAC time zones of the building. Secondly, applies to the equation that is coping with the building location in latitude. Complex building or buildings that have different HVAC time zones are calculated separately with its responding equations. Owing to regulation stated that central air-conditioning type buildings should conform to ENVLOAD criteria before applying for building license.

The passing of ENVLOAD index of the building is mandatory, and can be directly used in chiller capacity predicting equations. Finally, the amount of reasonable maximum chiller cooling capacity can be obtained by multiplying the total air-conditioning floor areas with the reciprocal of chiller cooling capacity (m^2/USRT) derived from the predicting models.

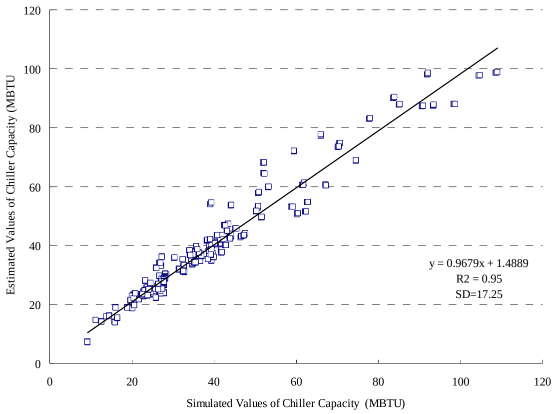

Figure 5 The correlation between the simualted and the estimated values of chiller capacity

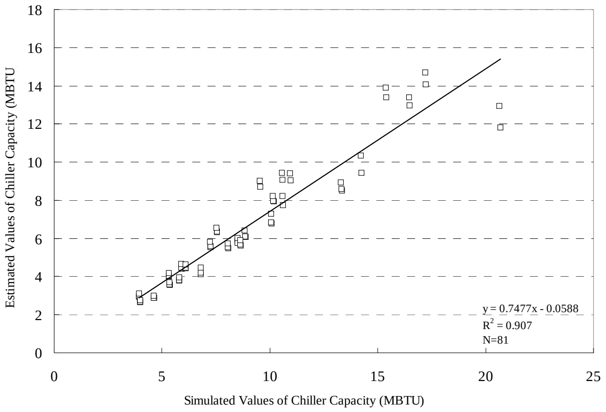

Figure 6 The correlation between simulated and the estimated values of chiller capacity using 81 samples of office type different from the original

NOMENCLATURE

BO : Building Orientation
FPG : Floor Plan Geometry (ratio)
SH : Depth of the Shading (m)
FA : Floor Areas of Standrad Floor (m^2)
OR : Opening Ratio (%)
GSC : Shading Coefficient of Glass
NOA : Numbers of Opening Sides
NBS : Numbers of Building Storey
FH : Floor Height (m)
ENVLOAD : annual cooling sensible heat load (kWh/m^2year)
G :Annual indoor dispersing heat(Wh/m^2year)
L :Heat loss of the envelope(Wh/m^2℃)
DH :Degree-hours based on monthly temperature averages (℃・h/yr)
Mk :Coefficient of solar heat gain on k orientation of the envelope, dimensionless
Ihk :Isolation-hours based on monthly weather averages on k orientation (W・h/yr)
a_0-a_3 : Regression coefficients, dimensionless
Y :Maximum supply floor areas of chiller cooling capacity（m^2/USRT）
γ :Coefficient of perimeter zone=AFp/(AFp+AFi)
AFp :Total air-conditioning floor areas in perimeter zones (m^2)
AFi :Total air-conditioning floor areas of internal zones (m^2)

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