THE DESIGN INDEX OF BUILDING ENERGY CONSERVATION AND CAD PROGRAM BEEP IN TAIWAN

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ABSTRACT

The purpose of this research is to develope a simplified method to predict the relationship between the design of architecture envelope and the air-conditioning load in Taiwan. Four types of buildings including Office, Hospital, Hotel and Commercial Buildings with 4 regression formulas were established. The R-square value lies between 0.86 and 0.91 which is convincible. The norm „Regulations of Building Energy Conservation Design in Taiwan" also referenced the results of this research. According to the cooling load predicting model developed in the research, we also found some efficient ways to decrease the cooling load by changing the design of the building envelope.

INTRODUCTION

This paper is divided into three main parts. The first part introduces the development of the simplified estimation method for calculating cooling load. The second part explains how the „Regulations of Building Energy Conservation Design in Taiwan" come from based on the method. The last part discuss what kind of building envelope design will be better in order to reduce the cooling load.

FOREWORD

The north tropic of Cancer (23.5° N) running across Taiwan's middle section and divides Taiwan into two climatic zones which are the tropical monsoon climate in the south and the subtropical monsoon climate in the north. High temperature and humidity, massive rainfall and gusty winds characterize the climate of Taiwan. Therefore, it is very important for a building designer to design an efficient building envelope suitable for its thermal environmental terms in Taiwan. However, it is very complicated to predict the annual cooling load because it needs a sophisticated dynamic thermal simulation computer program (such as DOE, BLAST, DEROB in USA or HASP in Japan). It also needs local meteorological year which comprises of hourly solar radiation and meteorological elements of a year for the simulation. So it is not convenient for the designer to operate.

In order to help the designer facilitate the evaluation process, a simplified method which can predict the building's annual cooling load appears to be indispensable and thus become the main theme of this paper.

SIMULATION & ANALYSIS

The simplified estimation method was based on dynamic thermal simulation computer program HASP. Therefore, it is necessary to introduce this program in brief.

HASP

This program was developed by „The Society of Heating, Air-conditioning and Sanitary Engineers of Japan". It was mainly designed with the Response Factor Method in calculating unsteady heat flow of building envelope and with the Weighting Factor Method in calculating the time-lag effect of internal load. Its accuracy and reliability had been verified through the model experiment. To implement HASP, it needs an annual 8760 hourly weather data additionally which is called AYWD and will be described later in the article.

WEATHER DATA

Every record of the hourly weather data must consist 7 weather elements which are temperature, humidity, direct normal radiation, diffuse horizontal radiation, wind direction, wind volicity, and cloudy factor. These elements are essential input data for energy calculation.

The weather data adopted by this research included 18 cities. Among them, 6 cities are distributed in North America, including Tampa, Boston, San Antonio, Oklahoma, Phoenix and Salt Lake City. Twelve of them are located in East Asia, including 7 in Japan (Sapporo, Akita, Niigata, Tokyo, Osaka, Kagoshima, Okinawa), 3 in Korea (Kang-nung, Inchow, Mokpo), and 2 in Taiwan (Taipei, Tainan). These cities have different climatic characteristics, that could prove the Simplified Estimation Method reliable and applicable.

At the begining of this research, several groups of building variations and air-conditioning sets needed to be assumed. These variables presented most of the building conditions in Taiwan. Then, the variables along with the Average Year Weather Data (AYWD) comprises the input information for the need of HASP program. The input contents are as follows:

1. Weather

The Average Year Weather Data (AYWD) was aimed to establish for energy simulation of buildings in Taiwan. The AWYD which consists 8760 hourly weather data in a year is obtained by analyzing the characteristics of the climatic changes. Its hourly data is formed on the basis of the long-term weather data from 1975 to 1984. It is considered to be an indispensable input weather data for dynamic energy simulation program. This research adopted seven weather areas representing seven administrations from the northern Taiwan to the south which latitude is ranging from Taipei City (25.03°N) to Kaoshiung City (22.58°N).

2. Building unit as an input for simulation

The unit is assumed as Fig 1 and Fig 2. The design is originated from office building unit that could represent most of the common cases in Taiwan.

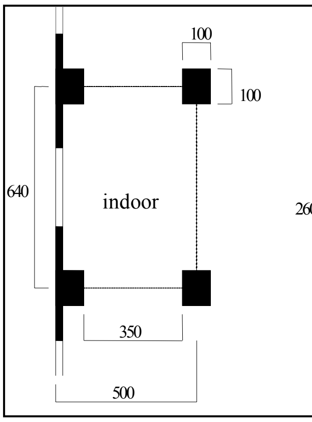

Fig 1. Plan

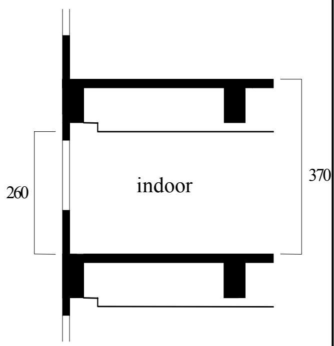

Fig 2. Section

3. Building variables

The research assumed lots of building variables that are common used in Taiwan, including sunshade variables and construction variables. The former include the opening rate of the building envelope, the performance of the sunshade plates over the windows, and the shading coefficient of the window glasses. The latter variables include different heat transmittance (U value) of building construction components (walls, roofs and floors). They are described in Table 1.

4. The air-conditioning condition and its zoning

The research focuses on 4 types of buildings, including Office, Hospital, Hotel and Commercial Buildings. There are different air-conditioning requirements between them. Thus, the spaces with similar air-conditioning using are generalized. The description is in Table 2 and Table 3.

5. The illumination density and its time schedule

There are many kinds of spaces with different illumination modes in this research. Although there are some extreme modes in special cases, it is very hard to take all illumination modes into consideration. For this reason, an identical illumination density assumption range value was adopted by this research. That means there is only one range value for the average illumination density in a space of a single zone. The detail is in Table 4. As for the illumination time schedule which also influences the cooling load, 16 day schedule configuration types (which are 8 air-conditioning requirements each with weekdays and weekend setting) were assumed to meet every special requirement. Fig 3 is a case out of the 16 time schedules.

6. The human density and its time schedule

The setting of human density and its time schedule is similar to illumination. The range value of the average human density is in Table 5. The relation between time schedule and human density load is shown in Fig 4. Fig 4 is also a case out of the 16 modes (8 air-conditioning requirements each with 2 kinds of time schedule).

Table 1

The Assumed Building Variables

Item	Description	Condition or Performance		
		Unit	Min	Max
Sunshading Factor	Opening Rate of Building Envelope	%	25%	60%
	Sunshade Plate on the Windows	%(No.1)	18%	100%
	Glasses (Sunshading Coefficent)	%	57%	97%
Construction Factor	Roof	W/㎡°K	0.75	2.83
	Exterior Wall	W/㎡°K	0.71	3.82
	Interior Wall	W/㎡°K	1.25	3.78
	Floor	W/㎡°K	----	----
	Glasses (U value)	W/㎡°K	1.83	6.31

Note 1:

The performance of sunshade plate. The factor presents how much rate of the outdoor annual total sunshine outside the window is allowed to come through inside.

Table 2
The Air-con Zoning

Item	Air-con Zoning	Contents
Office Buildings	10 hours air-con requirement	all spaces
Hospital Buildings	10 hours air-con requirement	clinic, pharmacy, inspection, restaurant…etc
	24 hours air-con requirement	emergency, ICU, surgery, sickroom…etc
HotelBuildings	6 hours air-con requirement	saloon, dance hall…etc
	10 hours air-con requirement	executive branch
	12 hours air-con requirement	restaurant, shopping places, banquet hall…etc
	24 hours air-con requirement	quest rooms, lobby…etc
Commerce Buildings	12 hours air-con requirement	all spaces

Table 3
The Air-con Condition

Item	Temperature setting			Humidity setting	Fresh Air
	Summer	Winter	Spr. & Atn.	Annual	Annual
Office Buildings	24~26℃	20~22℃	22~24℃	40~70%	10(m3/m2hr)
Hospital Buildings		Note 1		40~70%	10(m3/m2hr)
Hotel Buildings	24~26℃	20~22℃	22~24℃	40~70%	10(m3/m2hr)
Commercial Buildings	25~27℃	21~23℃	23~25℃	40~70%	10(m3/m2hr)

Note 1:
The temperature setting of surgery room is 15~17℃ annual. The ICU is set as 18~20℃ in summer, 16~18℃ in Winter. The emergency is set to +2℃ than ICU. The other spaces are set to -1℃ than the Office Buildings.

Table 4
The Average Illumination Density

Item	Air-con Zoning	Illumination Density
Office	10 hours air-con	20~30 (W/m^2)
Hospital	10 hours air-con	25~35 (W/m^2)
	24 hours air-con	20~50* (W/m^2)
Hotel	6 hours air-con	15~25 (W/m^2)
	10 hours air-con	20~30 (W/m^2)
	12 hours air-con	35~45 (W/m^2)
	24 hours air-con	15~25 (W/m^2)
Commerce	10 hours air-con	35~70** (W/m^2)

* 40~50 for surgery, 30~40 for ICU and emergency, 20~30 for the other space.
** A wider spread to fit the unique requiremen of display.

Table 5
The Average Human Density

Item	Air-con Zoning	Human Density (person/m^2)
Office	10 hours air-con	0.12~0.18
Hospital	10 hours air-con	0.12~0.50*
	24 hours air-con	0.04~0.18**
Hotel	6 hours air-con	0.20~0.30
	10 hours air-con	0.12~0.18
	12 hours air-con	0.40~0.50
	24 hours air-con	0.04~0.10
Commerce	12 hours air-con	0.40~0.50

* 0.40~0.50 for restaurant, 0.30~0.40 for clinic & pharmacy, 0.12~0.18 for the other space.
** 0.04~0.10 for sickroom, 0.12~0.18 for the other space.

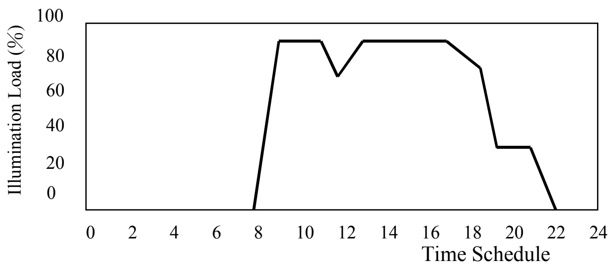

Fig 3. Illumination Load Time Schedule
(Hospital Buildings, 10hr air-con, weekdays)

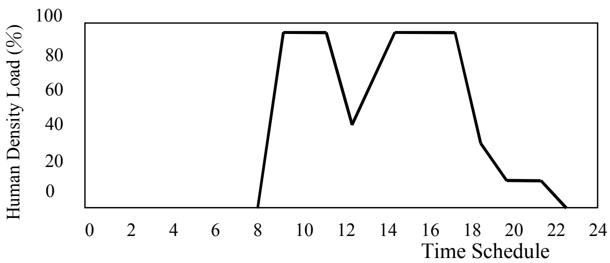

Fig 4. Human density Load Time Schedule
(Hospital Buildings, 10hr air-con, weekdays)

7. The resources of the assumed input data

It is very important to verify the correctness of the input data. This research investigated real cases of buildings, including 26 office buildings, 22 hospital buildings, 11 hotel buildings and 8 commercial buildings. All the building variables, air-conditioning settings, illumination configurations, and human density were manipulated from the investigated cases.

METHODOLOGY

1. Generate Imitation cases for Experimental Design Method Analysis

To generalize the input data and create the imitation cases efficiently, the Experimental Design Method (Taguchi robust design experiment's orthogonal arrays) was adopted by this research with 27 runs for each simulation work to decrease the total possible combinations with the variables describe above. Each variable has 3 levels. First level presents the maximum value, the second is the average value and the third is the minimum. For the use of Experimental Design Method, each air-conditioning zone will have to generate 1512 imitation cases for simulation works (27 cases × 7 weather areas (located in Taiwan) data × 8 building orientation). Theoretically, the 1512 cases could also present 89,282,088 cases (1512 × 3^3(sunshade factors) × 3^5(construction factors) × 3^2(illumination & human density)) which are impossible to do such numerous runs, and that's why the Experimental Design Method is hence used here.

2. Multiple Regression Formula as simplified estimation method for cooling load is derived from the Experimental Design Method

The purpose of this research is to pursue a simplified method to estimate the building's total annual cooling load in Taiwan. However, the accurate estimation procedure is often difficult to put into practice for its complexity. On the other hand, existing easily applicative method is often inexact itself. It is hesitant to make a decision on what kinds of combined variables and formula structure will be better to predict the cooling load exactly and easily. After series of experiments and discussions, the prototype formula model is as following:

ENVELOPE LOAD ("ENVLOAD" in short)
$$= a_0 + a_1\times \underline{G} + a_2\times \underline{L}\times \underline{DH} + a_3\times \Sigma \underline{Mk}\times \underline{IHk}$$

Nomenclature

ENVLOAD = annual cooling sensible heat load (KWh/m^2-fl-area・yr)

G = annual internal loads (Wh/m^2-fl-area・yr)

L = coefficient of heat loss of the envelope (Wh/m^2・℃)

DH =Degree-hours based on monthly temperature averages (℃・h/yr)

Mk=coefficient of solar heat gain at k orientation of the envelope, dimensionless

Ihk=Isolation-hours based on monthly weather averages on k orientation (W・h/yr)

a_0 , a_1 , a_2 , a_3 = regression constant, dimensionless

Among the above formula

1. The G value

This value includes all the dispersing heat from human, illumination, and the other equipments. The G value was set to an invariable constant for the reason that to reduce some calculation works for the building designers. The constant value is derived from the statistical analysis on the common use of the investigated cases. This decision was made for the reason that most of the building designers usually think it troublesome to calculate the data. With regard to the load contributed from outdoor fresh air, it is also contained in this value by a group of following related sub-formulas.

G = Gi×Ac (KWh/m^2-fl-area・yr)

where

Gi = annual average internal loads, constant value (KWh/m^2-fl-area・yr)

$Ac = a_0+a_1\times Tu+a_2\times Tu^2$ (h/yr)

Ac = cooling apparatus operation hours (h/yr)

Tu = average indoor temperature increment (K)

a_0 , a_1 , a_2 = regression constant, dimensionless

Tu = Gi/L (K)

2. The product of L×DH

This combination item presents the heat loss or gain from the building construction material variables. The L means the performance of heat transmittance of building envelope and it takes the average U value of the envelope as its value. Therefore, the transmittance ability would be directly connected with the outdoor temperature.

3. The product of ΣMk×IHk

This combination means the heat gain from the sunshade factors. The Mk presents the average ability of the building envelope at k orientation. Consequently, it should be multiplied together with the solar gain in the same direction (that is the isolation-hours IHk).

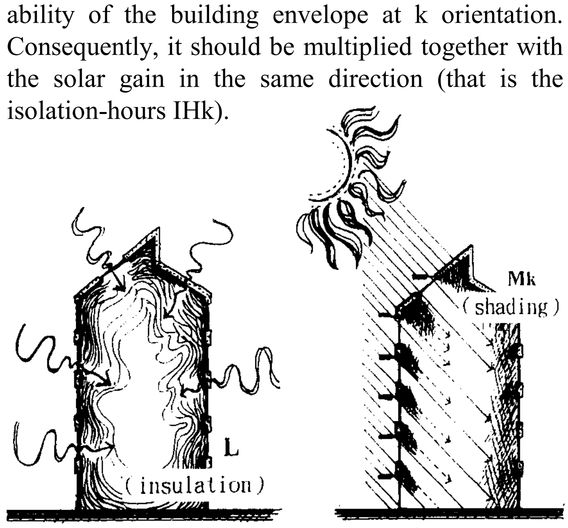

Fig 5. Diagram for L×DH and Mk×IHk

4. The ENVLOAD value

According to the subtropical climate in Taiwan, predicting the cooling load is far more important than predicting the heating load. Thus, the ENVLOAD is used to estimate the air-conditioning cooling load only. Furthermore, this estimation method is limited to calculate the total air-conditioning floor area of the "perimeter zone" of the building. We defined the scope of "perimeter zone" as an area at a distance 5 meter away from the building's boundary directed to the center of interior (named "Afp" in short). Although it is unable to predict the total air-conditioning loads of a whole building, it does reflect the actual air-conditioning load within the "Afp area" of a building. It becomes a method to estimate cooling load of a building's envelope and it is a better way we can adopt in Taiwan.

CONCLUSIONS

The Multiple Regression Formulas

The formulas are shown in Table 6. They are mainly organized by air-conditioning time zones. For example, the Office buildings are only suitable for the 10 hours air-conditioning formula. Moreover, the Hospital buildings should be divided into 24 hours and 10 hours air-conditioning time zones. It means that there are 2 formulas for the Hospital buildings, and should be estimated twice, individually. With these predicting models, the building designers can predict their cases on the performance of energy consumption of the building's envelope design in the design phase as they want and can easily take advantage on these formulas instantly.

APPLICATIONS

1. **The Government Policies named "Energy Conservation Design of Buildings Regulation" in Taiwan**

Taiwan lacks sufficient domestic energy source, and almost depends on energy imports totally. We have experienced rapid growth in energy consumption in recent years. The annual electricity consumption in 2000 is nearly twice than that in 1990. Furthermore, the peak load of Taiwan's electric system occurred in summer time is much higher than that in winter, which indicates a special phenomenon in subtropical or tropical zone. Obviously, one of the most important reasons is caused by the air-conditioning electricity consumption in summer. It's not necessary for us to use air-conditioning in winter. Therefore, restricting the building's envelope design to save the air-conditioning electricity not only saves the annual electricity consumption but also reduces the peak load.

In order to improve this situation, the Government legislated "Energy Conservation Design of Buildings Regulation" in 1995 against the huge electricity consumption of buildings.

At the initial period, the regulation was purposed to stipulate for Office Buildings only. The Hotel Buildings, Commercial Buildings, Hospital Buildings and Residential Buildings were added in this Regulation in 1998 afterward. At the end of 2002, there were momentous emendations in this Regulation. Table 7 is the norm's content. In addition to add School Building type, the standards were divided into 3 climate zones as shown in Fig 6 (North, Middle and South). They have different levels of standards according to the different weather data and administrative divisions. Although Taiwan is a long and narrow island, the climate in the southern island is quite different from the northern island.

As the table 7 shows, the former 4 building types are exactly the same with the result of this research. The main theories of the latter 3 types are also based on this research, too. Among them, the "Req" index in

Table 6

The Simplified Estimation Method in Multiple Regression Formula

ENVELOPE LOAD ("ENVLOAD" in short) = $a_0 + a_1 \times \underline{G} + a_2 \times \underline{L \times DH} + a_3 \times \Sigma \underline{Mk \times Ihk}$

Building Type	Air-Con Zoning	a_0	a_1	a_2	a_3	R^2
quest rooms of Hotel Buildings & emergency, ICU, surgery, sickroom of Hospital Buildings	**24 hours system** / **00:00~24:00**	-20947	0.25	-0.054	1.127	0.86
restaurant, banquet hall of Hotel Buildings & Commercial Buildings	**12 hours sysytem** / **10:00~22:00**	-10070	1.713	0.413	1.457	0.91
executive branch of Hotel Buildings & clinic, pharmacy, inspection of Hospital Buildings & Office Buildings	**10 hours system** / **08:00~18:00**	-20370	2.512	-0.326	1.079	0.88
saloon, dance hall of Hotel Buildings	**6 hours system** / **18:00~24:00**	-21093	1.523	0.309	0.911	0.89

Residential Buildings and the "AWSG" index in School Buildings have the same significance. The "Req" is a simplified index of the average opening ratio of the building's envelope. The "AWSG" presents the average shading factor for the openings of building's envelope. The two indexes emphasized the blocking of the sunshine from coming through the windows. In terms of the vernacular architecture and energy saving in subtropical or tropical climate, these factors are more important than the others. The Other Buildings Type stipulates for buildings that are excepted from the former types and uses the average U value of roof ("Uar" in short) as the index in this type.

This Regulation was published with a series of Technical Codes complied with 9 books. As long as the designers follow the guidelines of the books, there are many data tables in it that can help them through the calculation works. It is expected that there are 20% of building energy, 5% of nation-wide annual electricity, and 7% of electricity system peak load will be saved after 20 years' enforcement of the regulation .

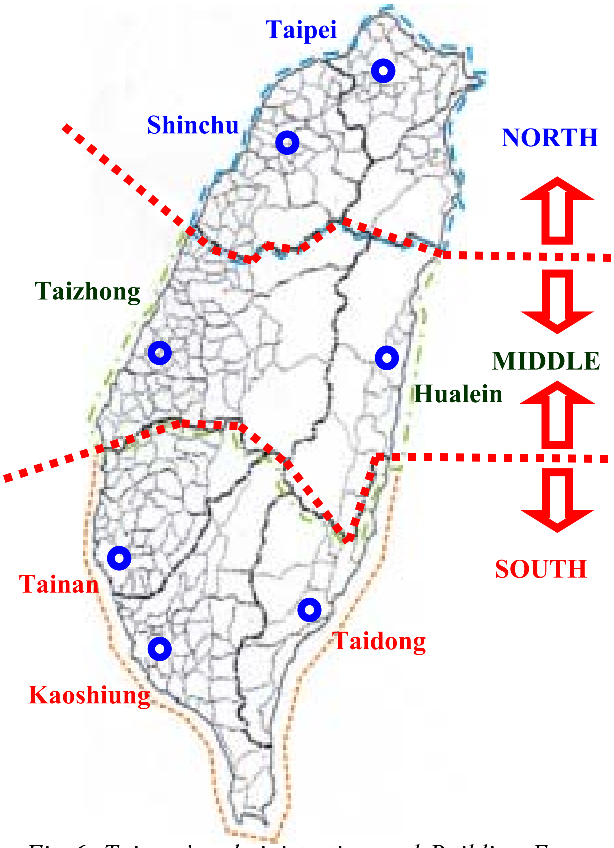

Fig 6. Taiwan's administration and Building Energy Regulation zoing

Table 7
The Outline of Taiwan's "Energy Conservation Design of Buildings Regulation"

Building Type	Energy Saving Standard	Climate Zone	Standard Value
Office Buildings	**ENVLOAD**	North	< 80 kWh/(m^2 • yr)
		Middle	< 90 kWh/(m^2 • yr)
		South	< 115 kWh/(m^2 • yr)
Commercial Buildings	**ENVLOAD**	North	< 240 kWh/(m^2 • yr)
		Middle	< 270 kWh/(m^2 • yr)
		South	< 315 kWh/(m^2 • yr)
Hotel Buildings	**ENVLOAD**	North	< 100 kWh/(m^2 • yr)
		Middle	< 120 kWh/(m^2 • yr)
		South	< 135 kWh/(m^2 • yr)
Hospital Buildings	**ENVLOAD**	North	< 140 kWh/(m^2 • yr)
		Middle	< 155 kWh/(m^2 • yr)
		South	< 190 kWh/(m^2 • yr)
Residential Buildings	Average U value of Roof ("**Uar**")	Nation-Wide	< 1.2 W/(m^2 • K)
	Average U value of External Walls("**Uaw**")	Nation-Wide	< 3.5 W/(m^2 • K)
	Ratio of Equivalent Transparency ("**Req**")	North	<13%
		Middle	<15%
		South	<18%
School Buildings	Average U value of Roof ("**Uar**")	Nation-Wide	< 1.2 W/(m^2 • K)
	Average Window Solar Gain ("**AWSG**")	North	< 160 kWh/(m^2 • yr)
		Middle	< 200 kWh/(m^2 • yr)
		South	< 230 kWh/(m^2 • yr)
The others	Average U value of Roof ("**Uar**")	Nation-Wide	< 1.5 W/(m^2 • K)

PS : North means the northern part of Taiwan, be the same ways with the Middle and South.

2. The Estimation Computer Program BEEPⅡ

The full name of BEEPⅡ is "Building Energy Evaluation Program-Second Edition". This software is a by-product of this research and published by the Government. It was developed by computer program language Visual Fox Pro. The main purpose of this software is to help the designers estimate their building design efficiently to meet the standards in **"Energy Conservation Design of Buildings Regulation"**. In addition, it also performs 2 important functions. The first one is the "Energy Expert Diagnosis System". The function provides the designers with energy diagnosis according to the building design data they input. The diagnosis will show the designers "the energy saving capability of their building design". The other function is "energy saving prescription". That is to provide some energy saving advices when their design can't pass the regulation's standards. For example, if the designer changes the SC factor of the window glasses or cancels some windows, the program can immediately shows how much amount of energy can be saved. It is interactive and has friendly interface. Beginners can use it conveniently. The software is developed and maintained by our studio and free to everyone. But it is just suitable in Taiwan and written in Chinese language only.

3. What kind of Building Variables influences the Air-conditioning Load much?

In the light of reducing the cooling load, the climate situation needs to be confirmed first. Every design case has to adapt its climate characteristics. Therefore, this research discusses this question exclusively for Taiwan's climate. Fig 7 shows the same building be situated in different cities in Taiwan, the ENVLOAD value in the southern city（Kaoshiung） appears 50% higher than in the northern city (Taipei).

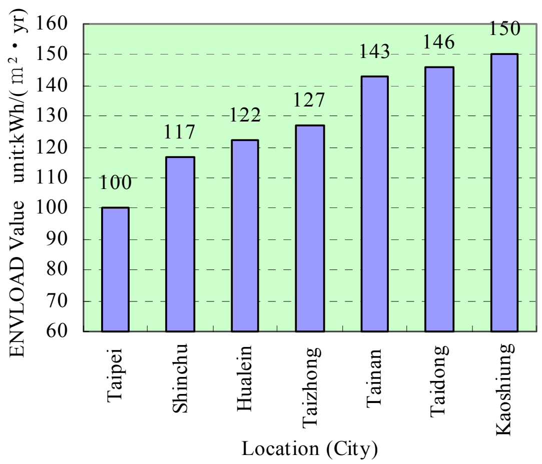

Fig 7. The ENVLOAD variation in different cities in Taiwan

Furthermore, the research assumed a normal office building in Kaoshiung City (located in southern Taiwan). The imitation case is base on the most common design condition and construction in Taiwan. For example, the opening rate of the building's envelope is from 30% up to 60%, the external walls and roofs are mainly made of 15cm reinfored concrete, and the SC factor of the glasses is from 0.5 up to 0.95. From Fig 8 to Fig 10 each describes the fluctuation of ENVLOAD while selected architectural variables be changed gradually within a certain range. The Fig 8 shows the different opening rate of the building envelope results in about 40% cooling load variation [(207.2-122.4)/207.2].

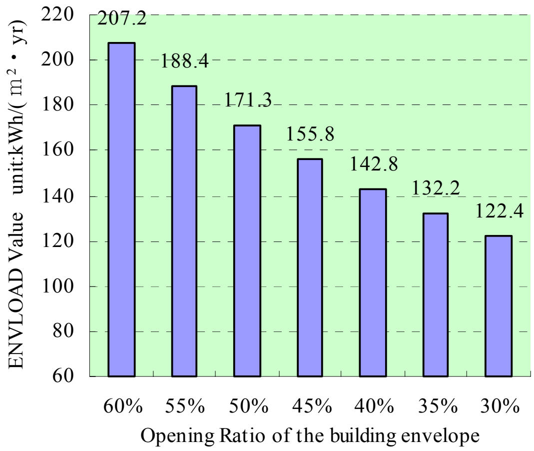

Fig 8. Different opening ratio of the building envelope influences the ENVLOAD value

The Fig 9 shows that the different sunshade plate over the windows can reduce 26% of cooling load [(168.0-124.8)/168.0]. In this figure, the horizontal axis means the bloacking ability of sunshade plate. (0% means there is no sunshade plates over the window, and 10% means there is 90% of the annual solar radiation be letting in.) The average opening ratio of this imitation building envelope is assumed as 35%.

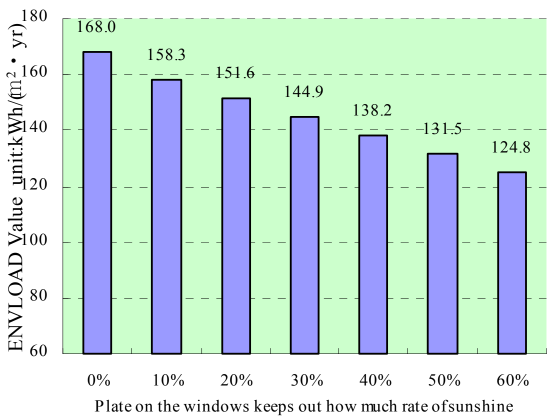

Fig 9. Different plate on the windows influences the ENVLOAD value

The Fig 10 indicates the decrease of cooling load to a maxium amount of 21% while different Shading

Cofficient (SC) of the window glasses is applyed[(168.0-132.7)/168.0]. The average opening ratio of this imitated building envelope is also assumed as 35%.

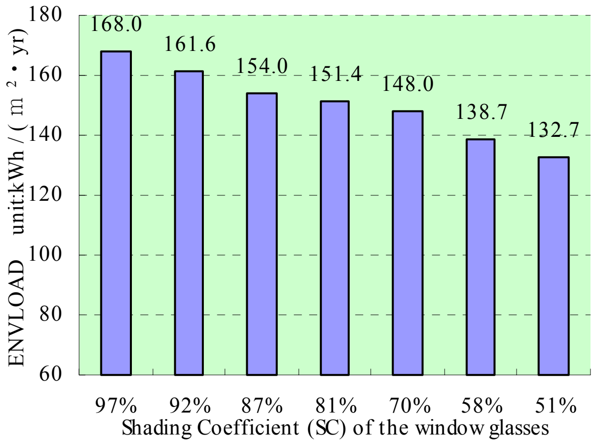

Fig 10. Different Shading Coefficient of the windows glasses influences the ENVLOAD value

In addition, the building orientation also influences the cooling load a lot. However, it is difficult to generalize it to a common conclusion. Because the different building form or type results in a lot of differences. In fact, all of the building variables interwork eath other. They exert complex reciprocal effects. For example, if we arise the average opening rate of the building's envelope, the SC fator of the glasses will influence the air-conditioning load more than 21%. While doing building envelope design, the factors from Fig 8 to Fig 10 are the most potential variables that can save the electicity bill enormously in Taiwan.

Lastly, how much does the U value influence the air-conditioning load? We set a single story building to simulate it. The Fig 11 shows that if the U value of the roof is made of iron (U=5.37), it really influences the cooling load a lot. But most of the U value of common roof's construction lies between 0.75~2.83. Obviously, it influences the cooling load about 10% only. Therefore, it is unworthy for the building owners to pay additional money to improve the U value of building's envelope.

In addition, Fig 11 also implies two important concepts. One is that if there is 40% of total roof area constructed of reflection glasses, the cooling load almost doubles the one with no openings or glasses on the roof. The other is that different climates in Taiwan really cause a lot of differences of cooling load. As curve 1 vs. curve 2 and curve 3 vs. curve 4 shown in Fig11, each pairs present the same building but be situated in different climates. It appears that the ENVLOAD value in Kaoshiung is 50% higher than in Taipei. It has the same conclusion in Fig 7, similarly.

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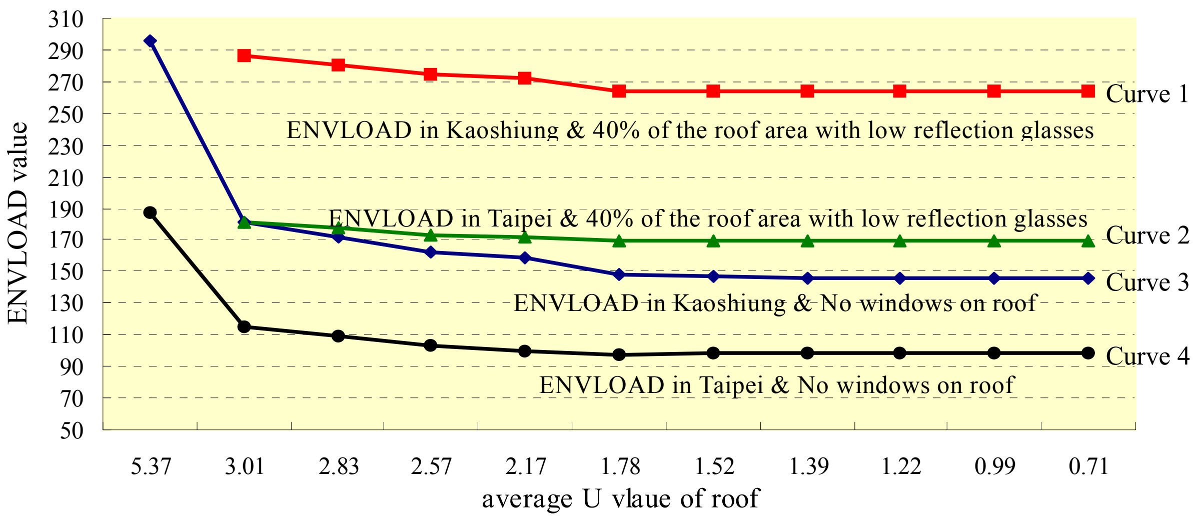

Fig 11. Different U value influences the ENVLOAD value