

Calculation of solar radiation load through glass windows in BIN building energy analysis

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Abstract: The load through glass windows has higher proportion in the whole building load. It's too rough for the BIN method to regard that the load through glass windows has linear relationship with the temperature. Get detailed statistical relationship between hourly temperature and the load through glass windows with much statistical data, which can make higher precision in calculating the load and energy consumption. Usage of the statistical data has been introduced.

Key words: BIN method; energy consumption analysis; load; solar radiation

1. Introduction

Building energy analysis is very important to building energy saving. There are detailed methods and simplified methods to calculate building energy consumption. Although detailed methods have detailed description to the building, the programs are so complex, that they are not suitable for the designers to use. Simplified methods are more often used because of their simplicity, easy for use and reliability.

BIN method is also called frequency method. The relationship between all kinds of load and outside temperature is established. Divide the outside temperature into equal intervals, and number of hours of each temperature interval is figured out, get the mean value of humidity. The energy consumed for each temperature are calculated with represented load and corresponding frequency, and the energy consumed for a whole year can be solved by summing the energy consumption of each interval.

BIN method has better way of thinking, and it's convenient to use. But it's too rough to calculate the solar radiation load through glass windows, which takes high proportion in the whole load. It regards the relationship of solar radiation load through glass windows and the outside temperature as linear relationship. Get mean value of solar radiation for summer and winter respectively, at the same time, get the representative temperature of summer and winter, in this way, two points are obtained, and linear relationship could be obtained according to the two points, with the linear relationship load can be

calculated to each temperature. It's too rough to calculate load in this way, because linear relationship does not exist between solar radiation load and temperature, and the selection of representative temperature to summer or winter load is lack of impersonality criterion.

2. Calculation of solar radiation load through glass windows

2.1 Cooling load coefficient [2]

Because the air is mainly made of two-atom gases, the solar radiation heat is firstly absorbed and deposited in various object surface when solar radiation enter into the room. When the surface temperature getting higher than the inside temperature, the deposited heat is transferred to the inside air with convection, and the inside temperature become higher which turns into cooling load. So heat gain is not equal to cooling load. Because of the lag of heat scattering, solar radiation is still operate at night. In order to calculate hourly solar radiation load through glass windows, cooling load coefficient method is put forward and cooling load coefficient to different direction are given respectively.

Solar cooling load coefficient is used to get summer or winter solar radiation load initially. Having the maximum solar radiation heat gain factor DJ_{max} of summer and winter, multiplied by hourly cooling load coefficient, hourly load of solar radiation through glass windows could be obtained.

The former BIN method got the relationship of load and temperature, but it had only two points with which

linear relationship was made. On the base of acknowledging the thinking of former BIN method, get more hourly relationship of load and temperature with which get the more detailed statistical relationship of load and temperature.

Determine the maximum solar radiation heat gain factor D_{Jmax} firstly.

2.2 Determination of the daily maximum solar heat gain factor D_{Jmax}

2.2.1 Determination of hourly solar azimuth angle A

Solar azimuth angle A is the angle between solar projection on the earth and the south.

According to Ref. [3], angle A can be figured out by formula (1),

$$\sin A = \frac{\sinh \cos d}{\cos \beta} \quad (1)$$

where h is solar hour angle; d is solar obliquity; and β is solar altitude angle. All the three are hourly parameters, solar hour angle h represents distance departure from transit of solar, it is set as zero when at noon and it's positive in the morning while negative in the afternoon. The time indicated by the solar hour is not the same as clock time. The difference between them is called time difference. Otherwise, Beijing time is Chinese standard time. There is time difference between Beijing time and local time because of longitude difference. And their relation is

$\frac{1}{15} \times (l - l_s)$, l is local longitude and l_s is Beijing longitude. Therefore

$$h = \left(t_s \pm \frac{l - l_s}{15} + \frac{e}{60} - 12 \right) \times 15$$

Solar obliquity d is the angle between the solar ray and the earth equator. The mean value of d can be figured out by formula (2), n is date number

$$\begin{aligned} d(n) = & 0.0063218 - 0.4057476 \cos\left(\frac{2\pi n}{366} + 0.1532310\right) \\ & - 0.0058798 \cos\left(\frac{4\pi n}{366} + 0.2070988\right) \\ & - 0.0032334 \cos\left(\frac{6\pi n}{366} + 0.6201293\right) (\text{rad}) \end{aligned} \quad (2)$$

Solar altitude angle β is the angle between the solar ray and the horizon. β can be figured out by

$$\sin \beta = \sin d \sin \varphi + \cos d \cos \varphi \cos h \quad (3)$$

φ is latitude of certain point on the earth.

2.2.2 Determination of θ (the angle between solar ray and the wall).

θ is the angle between horizontal projection of solar ray and that of normal of the wall. θ can be figured out by formula (4),

$$\theta = \text{abs}(A - \alpha) \quad (4)$$

where α is azimuth of the wall. It is the angle between the normal projection of the wall on the earth and the south. It is thought as positive in the morning and negative in the afternoon.

2.2.3 Determination of direct radiation density in perpendicular to the solar ray

The original data obtained are all direct radiation density I on horizon, because

$$I_n = \frac{I \times F}{F \sin \beta}$$

we have

$$I_n = \frac{I}{\sin \beta}.$$

2.2.4 Direct radiation density on vertical surface

Hourly angle have been determined, direct radiation density can be figured out by

$$I_{cz} = I_n \times \cos \beta \times \cos \theta \quad (5)$$

2.2.5 Calculation of the incidence angle

In order to get hourly incidence rate using the successional relationship between the incidence rate and the incidence angle, hourly incidence angle need to be calculated. Incidence angle Ω can be figured out by formula (6),

$$\Omega = \arccos(\cos \theta \cos \beta) \quad (6)$$

2.2.6 Get the successional relationship between the incidence rate and the incidence angle

We can get direct radiation incidence rate on some angle according to reference [2], incidence rate on any incidence angle is needed. So polynomial regression has been made using the data obtained, in this way the successional relationship between the incidence rate and the incidence angle could be found. Diffused incidence rate is set as that of 45° of direct radiation.

2.2.7 Calculation of hourly solar radiation heat gain factor D_J

D_J can be figured out by

$$D_J = \tau_N I_{cz} + \tau_D + N(\alpha_N J_N + \alpha_D J_D) = (\tau_N + N\alpha_N) I_{cz} + (\tau_D + N\alpha_D) J_D \\ = \lambda I_{cz} + (\tau_D + N\alpha_D) J_D \quad (7)$$

where τ_D is diffused radiation permeation rate; α_D is diffused radiation absorptivity; $\tau_D + N\alpha_D$ is the entrance proportion to the room of the diffused radiation, it is figured out through multiplying $\tau_D + N\alpha_D$ of standard glass by overshadow factor C_z ; J_D is diffused radiation density in W/m^2 ; τ_N is direct radiation permeation rate; α_N is direct radiation absorptivity; N is the entrance proportion to the inside of the heat absorbed by glass; $\lambda, \tau_N + N\alpha_N$ is the entrance proportion to the inside of the direct radiation (incidence rate); I_{cz} is the direct radiation density on the normal of the glass, $I_{cz} = I_n \times \cos\theta \cos\beta$, so direct radiation load can be regarded as linear relationship of the direct radiation density.

2.2.8 Determination of daily maximum solar heat gain factor D_{Jmax}

The biggest solar heat gain factor D_{Jmax} is selected after hourly factors D_J are figured out for each day.

2.3 Calculation of hourly solar radiation load

We have obtained daily maximum solar radiation heat gain factor in 1.1. For a certain direction, hourly solar load factor C_f through glass is figured out through multiplying D_{Jmax} by hourly cooling load coefficient of that direction. C_f represents the solar load of unit glass net area in normal glass. Having hourly temperature, hourly temperature is corresponding to hourly solar load. So we can get the relationship of hourly temperature and the solar radiation load factor through glass windows

In order to get the relationship of temperature and the solar radiation load factor through glass, which is practicable in the calculation, get mean value of solar radiation load factor for a certain temperature, get the middle temperature corresponding to the mean value.

We get the temperature, humidity and radiation frequencies which can be used to calculate energy consumption of whole day running system, day time running system and ice cooling system using Chongqing, Chengdu, Kunming and Guiyang original data, at the same time, monthly and quarterly frequencies are also given. Frequency data for other cities would be given in the succedent works. In this paper, only the relationship of temperature and C_f for whole day running system without inside overshadows, Chengdu is given in table 1.

Table 1 Relationship of temperature and C_f , Chengdu

T/ °C	n/ h	solar radiation load factor C_f /(W/m^2 window area)								
		E	SE	S	SW	W	NW	N	NE	H
-3	2	77	86	56	44	29	29	97	83	61
-1	9	43	57	53	44	30	29	60	42	63
0	15	46	54	43	35	24	23	59	47	50
1	55	34	40	36	32	24	23	42	33	42
2	71	39	46	41	36	28	27	49	38	46
3	100	39	47	43	36	26	26	51	38	50
4	148	45	51	47	40	31	30	60	45	54
5	199	50	63	62	53	41	40	67	49	72
6	319	40	46	44	37	31	31	55	40	51
7	367	42	49	49	41	34	34	59	42	57
8	393	43	52	56	47	39	38	65	43	64
9	378	44	54	61	51	42	41	69	44	71
10	340	48	65	78	65	50	47	80	48	92
11	306	52	67	80	66	53	51	86	52	93
12	272	52	66	90	76	57	55	92	52	106
13	288	53	62	76	70	57	54	90	54	89
14	292	54	60	62	59	51	49	84	54	78
15	348	54	59	60	55	47	46	81	54	76
16	392	63	67	63	60	53	50	85	59	89
17	357	69	78	74	66	59	55	92	65	105
18	352	77	87	87	78	68	65	109	72	126
19	342	74	86	93	82	71	66	116	72	135
20	349	74	85	89	80	71	66	116	71	132
21	396	80	90	100	95	82	74	122	76	149
22	404	83	91	97	89	79	74	124	81	142
23	460	73	81	87	83	74	68	115	70	134
24	375	80	89	94	84	76	72	120	79	138
25	333	89	100	111	105	94	87	137	86	167
26	269	82	92	100	88	78	74	128	79	149
27	211	74	89	101	84	76	74	132	74	146
28	182	66	81	106	101	94	89	141	67	149
29	159	79	98	135	129	114	105	169	79	206
30	123	71	88	131	130	113	103	162	71	192
31	81	78	93	146	150	131	114	179	77	229
32	43	83	100	154	155	134	120	191	82	241
33	21	70	85	135	143	120	110	169	72	196
34	7	62	75	126	119	97	83	145	64	194
35	2	44	52	87	84	71	62	106	47	100

3. Comparison to the load of the original linear relationship

Comparing conditions: certain air conditioning room in Chengdu. Air conditioning area, $900m^2$; monolayer steel glass window, 5mm brown glass, overshadow with light blue drape; east, south, west, north window area are all $60m^2$.

In order to see the difference, the load graphs to different directions are given in Fig. 1.

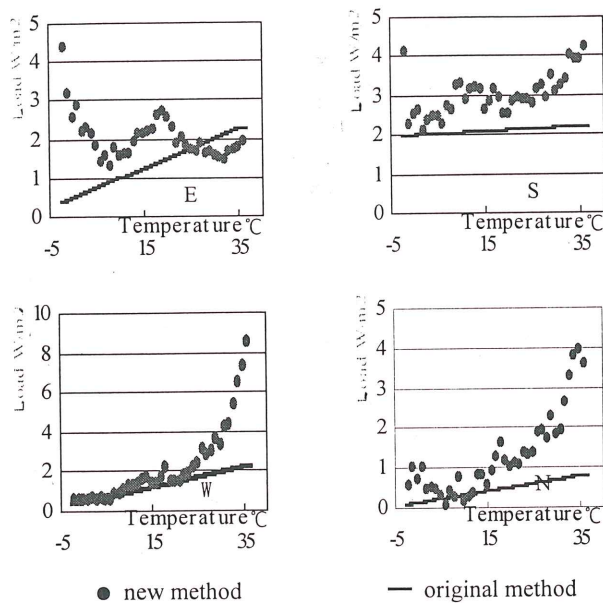


Fig.1 Comparison of load using two methods

Above all, there are obvious differences between new method and the old method. It's shown through quantity data in this paper that there isn't linear relationship between solar radiation load and temperature. Detailed relationship between solar radiation load and temperature has been obtained in this paper. The new relationship has preciseness theory and reliable data, so it has obvious advantages. The old method should be replaced by the new one to calculate solar radiation load and energy consumption.

4. Usage of statistical data in table 1

The method for calculating load and energy can be illustrated with south glass window in Chengdu. Calculation condition is the same as the last paragraph: air conditioning area, 900 m²; monolayer steel glass window, 5mm brown glass, overshadow with light blue drape.

- (1) According to reference [1], the covering factor is 0.75 considering the glass style, inside shadows and the efficiency area of the windows. The solar radiation load for unit air conditioning area is $CL(T_i) = F \times C_z \times C_f(T_i) / A_r = 60 \times 0.75 \times C_f(T_i) / 900 = 0.05 C_f(T_i)$ (W/m² air conditioning area). Solar

radiation load to different temperature could be figured out by multiplying C_f .

- (2) Having calculated the solar radiation load to different temperature, multiplied by corresponding frequency, energy consumption to this temperature could be figured out by formula $CL(T_i) \times n_i$ (W.h/m² air conditioning area).
- (3) Summing up the energy consumption to different temperature, the total energy consumption could be figured out by formula $Q = \sum CL(T_i) \times n_i$ (W.h/m² air conditioning area). The results are listed at table 2, from 22°C to maximum 35°C.
- (4) The energy consumption to unit air conditioning area is 50.191 MJ/m², and the total energy consumption to the air conditioning room is 45 172 MJ.

Table 2. Calculation of radiation load and energy consumption

Temperature <i>t</i> /°C	Frequency <i>n</i>	Factor <i>C_f</i>	0.05 <i>C_f</i>	Energy <i>Q</i> /(kJ/m ²)	Energy <i>Q</i> /(W.h/m ²)
22	404	97	4.9	7053.8	1959
23	460	87	4.4	7203.6	2001
24	375	94	4.7	6345.0	1763
25	333	111	5.6	6653.3	1848
26	269	100	5.0	4842.0	1345
27	211	101	5.1	3836.0	1066
28	182	106	5.3	3472.6	965
29	159	135	6.8	3863.7	1073
30	123	131	6.6	2900.3	806
31	81	146	7.3	2128.7	591
32	43	154	7.7	1192.0	331
33	21	135	6.8	510.3	142
34	7	126	6.3	158.8	44
35	2	87	4.4	31.3	9

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