Building Simulation

Seventh International IBPSA Conference
Rio de Janeiro, Brazil
August 13-15, 2001

REGIONAL CHARACTERISTICS OF AIR-CONDITIONING LOADS FOR RESIDENCES IN CHINA

Qingyuan Zhang , Kenji Asano, and Hajime Imai, Tsukuba College of Technology
4-3 Amakubo, Tsukuba 305-0005, Japan

Joe Huang, Lawrence Berkeley National Laboratory, Berkeley, 94720, USA

Hongxing Yang, Polytechnic University, Hong Kong, China

Tetsuo Hayashi, Kyushu University, Kasuga, 816-8580, Japan

You Shijun, Tianjin University, Tianjin, China

ABSTRACT

In this study, the Typical Weather Year data for the simulations of buildings were developed following the previous study. Using these data, the annual heating and cooling loads of model houses in 69 Chinese cities were calculated. Regression equations were made to estimate the annual heating and cooling loads using the simulation results. The regional characteristics of the annual heating and cooling loads were clarified.

INTRODUCTION

The energy consumption in the residential sector in China grows rapidly with the improvement of living standards in recent years. The energy consumption for air-conditioning is the main part of the total consumption. However the annual energy consumption for the residential sector and its regional characteristics are not clear, mainly because the weather data for simulations have not been developed until recently.

The authors developed the Typical Weather Year (TWY) data for the main Chinese cities using a database with observed weather data, which lays a foundation for the building simulations in China [Zhang et al.]. In this paper, the development of TWY data was continued following the previous studies. Two model houses were supposed for the simulations. Annual air-conditioning loads of model houses in 69 main Chinese cities were calculated hourly with the TWY data mentioned above.

Simplified models are established to calculate the heating and cooling loads with the parameters such as degree-days, solar heat gain, heat loss coefficient of a house etc. by comparing the results from the hourly simulations and the simplified models. The heating/cooling loads of a region can be predicted with the model with minor errors.

THE TYPICAL WEATHER YEAR DATA

So far, there have been very few reports on the typical hourly weather data for the Chinese locations mainly because the observed data are not easily available and not digitalized. In former studies, the authors developed the typical weather year data for some main Chinese cities. In this paper, we extended the locations to 69 (see Fig.1) using the database from the U.S. National Climate Center with three-hour intervals.

Because there is no observed data on solar radiation in this database, it is necessary to produce the data of solar radiation. Using the total cloud cover, dry bulb temperature, relative humidity and wind speed, and the global solar radiation on the horizontal surface of Beijing and Guangzhou in 1993 from other source, the following model can be established.

$$I = [I_0 \bullet 3600 \bullet \sin(h) \bullet \{c_0 + c_1(\frac{CC}{10}) + c_2(\frac{CC}{10})^2$$
$$+c_3(T_n - T_{n-3}) + c_4\varphi + c_5 V_W\} - d]/k \qquad (1)$$

Here, I is the predicted solar radiation in J/(m^{2}h); I_0 is solar constant in W/m^2; $c_0 \ldots c_5$, d, k are constants determined by regression; h means solar angle, the angle between sunlight and the horizon; *CC* means cloud cover; φ means relative humidity in %; T_n and T_{n-3} are the dry bulb temperature ($°C$) of *n* o'clock and *n-3* o'clock respectively; *Vw* is the wind speed in m/s. The constants can be calculated with multi-parametric analyses, the values of which are as follows:

c_0=0.5598, c_1=0.4982, c_2=-0.6762, c_3=0.02842, c_4=-0.00317, c_5=0.014, d=-17.853, k=0.843.

The Typical Weather Year contains the measured data of 12 calendar months, between which the variables were smoothed to avoid abrupt changes. Some methods have been developed to select the typical months (TMMs) like the method of National Climate Center, and the method of Matsuo et al. (Matsuo, et al, 1974). The former has the problem of being subjective, while the latter depends on the air-conditioning loads of the model building at the last stage of the selection, where the model of the house to be supposed will effect the selection of the TMMs. In this study, we adopted a method combining these two. The procedure is described as follows:

1. Select the months whose monthly average dry bulb temperature, dew point temperature, solar radiation and wind speed are within the range of 0.6 times standard derivation. If there is only one candidate left after Step 1, the only candidate is selected as the TMM. If there is no candidate left, go forwards to Step 2. If there is more than one candidate after step 1, jump to Step 4.
2. Select the months whose monthly average dry bulb temperature, dew point temperature, solar radiation and wind speed are within the range of 0.8 times standard derivation. If there is only one candidate left after Step 2, the only candidate is selected as the TMM. If there is no candidate left, go forwards to Step 3. If there is more than one candidate after step 2, jump to Step 4.
3. Select the months whose monthly average dry bulb temperature, dew point temperature, solar radiation and wind speed are within the range of standard derivation. If there is only one candidate left after Step 3, the only candidate is selected as the TMM. If there is more than one candidate left after step 3, go forwards to Step 4.
4. Compare the *WS* values of the left months, select the month whose *WS* is the smallest as the TMM.

The value of WS can be calculated as follows:

$$WS = \sum w_i \bullet FS_i \qquad (2)$$

where FS_i is Finkelstein-Schafer (*FS*) statistic. The smaller the *FS* is, the closer the structure of a variable will be to the average year. The values of w_i mean the weights of element i like dry-bulb temperature, dew point, solar radiation, or wind velocity. In this paper, the values of w_i by the National Climate Center [National Climate Center, 1981] were adopted as follows:

Term			w_i
Temperature	Dry Bulb	Max	1/24
		Min	1/24
		Mean	2/24
	Dew Point	Max	1/24
		Min	1/24
		Mean	2/24
Wind Speed		Max	2/24
		Mean	2/24
Solar Radiation			12/24

MODEL HOUSES FOR SIMULATIONS

To simulate the air-conditioning loads for different locations in China, two models of apartment houses are supposed in this study as shown in Fig.2. The floor area of these two houses is 50.1 m^2 and 86.8 m^2 respectively. The houses are made of bricks, with the external wall of 0.36 m and internal wall of 0.24 m thick. Considering the real residences in China, insulation materials are not used in all the walls and floors. The air change rate is supposed to be 0.5 times each hour. The houses are air-conditioned throughout a day during the cooling or heating seasons. Double glass windows are adopted throughout the country regardless of the climate. The residents are supposed to be a family with a couple and a child. Both the adults are working during the day but only one adult cooks and has lunch at home with the child. The room temperature is set at 20 °C and 26 °C respectively for heating and cooling seasons. The heat loss coefficient is 1.36W/m^{2}K and 1.13 W/m^{2}K respectively for Models A and B. The relative humidity is supposed at 60% in cooling season and uncontrolled in heating season.

REGIONAL CHARACTERISTICS OF HEATING LOADS

The heating loads of the model houses are simulated with the typical weather year data for the 69 cities mentioned above using a program call PSSP [Hayashi et al., 1988], by which the thermal performance and air-conditioning loads of a multi-room system can be simulated. The city where the heating load is the biggest among all the 69 cities is Qiqihar, while the city without any heating load is Yaxian in Hainan Island.

To make clear the regional characteristics of the heating loads of residences, the heating loads of more locations are needed. Because only the Typical Weather Year data of 69 locations have been developed up to now, some other methods are necessary to estimate the annual heating loads for other locations. In this paper, we tried to find some regression equations to estimate the annual heating loads.

When analyzing the heating or cooling loads of a house, two kinds of factors have to be considered: building-related factors and human activities-related factors. The level of thermal insulation, ventilation rate, and solar gain belong to the former, while the heat generations from lighting, from building equipment and from human bodies belong to the latter. Using the Least Square Method, the following regression equation was established to estimate the annual heating loads of the model houses.

$$L_H = 1.01 + 1.1696 \bullet Q \bullet 0.00876 \bullet HDD_{20} - 0.351 \bullet \mu \bullet I_D \bullet HD$$
$$-0.227 \bullet (H_B + H_E + H_L) \bullet HD / S \qquad (3)$$

where L_H is the annual heating loads for per m^2 (MJ/m^2); Q is the heating loss coefficient(W/m^{2}K); μ is solar gain index; I_D is the daily insolation (MJ/day/m^2); HDD_{20} is the heating degree-day with the basic temperature of 20 °C; HD is the heating days; H_B is the sensible heat production by human bodies per day(MJ/day); H_E is the sensible heat production from equipment (MJ/day); H_L is sensible heat from lighting per day (MJ/day); S is the total floor area(m^2).

Because the term of solar gain $\mu \bullet I_D \bullet HD$ and heat production from human activities $(H_B + H_E + H_L) \bullet HD / S$ decrease the heating loads of the house, the signs of the coefficients are negative.

The correlations between the heating loads of Models A and B from Equation (3) and simulations are shown in Fig.3. The root square mean errors (RSME) of Models A and B are 11.0 MJ/m^2 and 11.4 MJ/m^2 respectively, which shows that the annual heating loads can be estimated by Equation (3) with only small errors.

The Heating degree-days HDD_{20} are necessary to calculate the annual heating loads with Equation (3). The HDD_{20} is estimated by Equation (4), which is established by the Least Square Method.

$$HDD_{20} = 2609.0 - 168.36 \bullet \theta_1 + 0.2330 \bullet h \qquad (4)$$

where θ_1 is the average temperature of January in °C; h is the attitude from the sea level in m.

The heating days HD in Equation (3) are calculated by the following equation:

$$HD = 7.593 + 0.5712 \bullet \frac{HDD_{20}}{20-\theta_1} + 0.006111 \bullet \left(\frac{HDD_{20}}{20-\theta_1}\right)^2 - 0.00355 \bullet h$$

(5)

The RMSE of Equation (5) is 11 days, which implies that heating days can be estimated accurately with Equation (5).

The monthly average of solar radiation in Equation (3) can be downloaded from the web page of National Aeronautics and Space Administration [NASA Atmospheric Sciences Data Center].

Using Equation (1), the annual heating loads of

Models A and B for 530 locations are calculated. Fig.4 is a map with isometric lines of heating loads from the average of Models A and B. According to the map, the heating loads per m^2 range from 0 to 1100 MJ. The heating load in Hainan Island is zero, and the largest load appears in Mohe, Heilongjiang Province. In the east part of China, the heating load increase with the increase of latitude, but in the west, the heating load is affected significantly by the elevation. For example, the heating load in the Chaidamu Basin is much smaller than the heating load in the higher area like Tibet Highlands.

REGIONAL CHARACTERISTICS OF COOLING LOADS

The annual cooling loads of Model A and B are also calculated with PSSP with the TWY data for the 69 locations. In order to clarify the regional characteristics of cooling loads, a regression equation was established as follows:

$$L_C = -5.5849 + 4.515 \bullet Q \bullet CDH_{26} \bullet 0.0036 - 5.9127 \bullet \mu \bullet I_D \bullet CD$$
$$+1.8652 \bullet (H_B + H_E + H_L) \bullet CD / S$$

(6)

where L_C is the annual cooing load per m^2 floor area; CDH_{26} is the cooling degree-hours with the basic temperature of $26\,°C$, which is from the research of Huang.

The correlation between the cooling loads from Equation (6) and simulations is shown in Fig.5. The RSMEs for Models A and B are 13.5 MJ/m^2 and 10.0 MJ/m^2, which imply that the annual cooling loads can be estimated accurately with Equation (6) like the estimation of heating load calculation with Equation (3).

Using Equation (6), the annual cooling loads are calculated for 530 locations. Figure 6 shows a map with isometric lines of cooling loads from the average of Models A and B. The annual cooling loads range from zero to 320 MJ/m^2. In about 60% of the whole China, the annual load is smaller than 50 MJ/m^2. The largest value of cooling load occurs in Hainan Island. The cooling load is affected significantly by the elevation of the locations. The value of cooling load is larger than 150 MJ/m^2 in the southeast part of China, where the elevation is low.

CONCLUSIONS

In this paper, the Typical Weather Year data are developed following the previous studies, which are used to simulate the heating and cooling loads. The regression equations are established to predict the heating and cooling loads for 530 locations in China. The main conclusions from this study are:

a. The regression equations to predict the heating and cooling loads agree well with the simulations.
b. Maps with isometric lines of annual heating and cooling loads are developed.
c. The heating and cooling loads are affected by the elevation of the locations.
d. The heating and cooling loads of the proposed model apartment houses range from 0-1100 MJ/m^2 and 0-320 MJ/m^2 respectively in China.

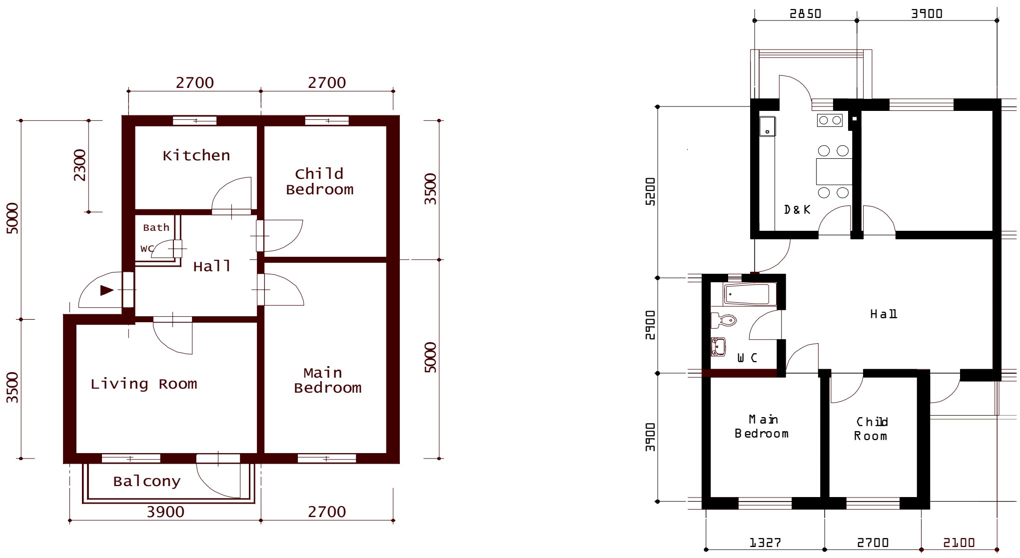
REFERENCES

1) Lin and Matsuo: A Simplified Seasonal Heat Load Index and Its Application to Evaluation of a Building Shelter's Design Condition on a Global Scale, Part 2 Annual Heat Load Distribution Maps in Asia, Transactions of the Society of Heating, Air-conditioning and Sanitary Engineers of Japan, No.27, 1984
2) Qingyuan Zhang and Kenji Asano：Development of the Typical Weather Data for the Main Chinese Cities, Journal of Architecture, Planning and Environmental Engineering, No.543，2001
3) Institute for Building Environment and Energy Conservation: The New Standards of Energy Conservation for Residences
4) Tetsuo .Hayashi, et al.: Prediction of Air Distribution in Multiroom Buildings, Proceedings of Roomvent'87，pp.1-20，1987
5) Kazuaki Bogaki, et al: Study on the Heating and Cooling Pattern and Heating and CoolingPeriod in Residential Buildings on the Basis of National Scale Surveys. Journal of Architecture, Planning and Environmental Engineering, No.509,1998
6) The web page of the Atmospheric Sciences Data Center http://eosweb.larc.nasa.gov/

7) Chinese Map Publisher: Chinese Maps (in Chinese), 1990

8) National Climatic Center: Typical Meteorological Year, User's Manual, 1981

Fig.1 Locations of cities for which the TWY data are developed



a. Model A

b. Model B

Fig.2 House models for simulations

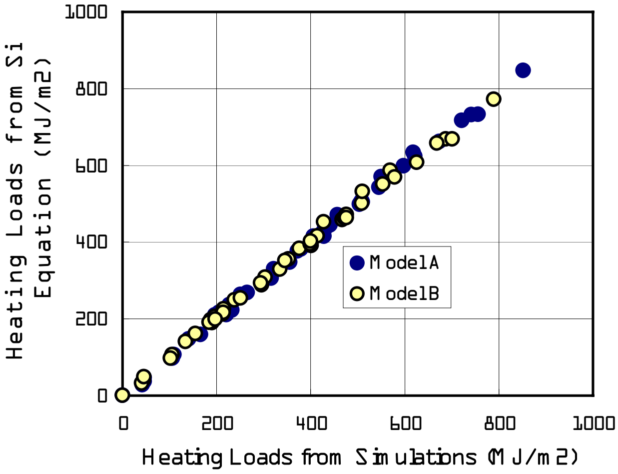


Fig.3 Corelation between Heating Loads from Simplified Equation and Simulation

Fig.4 A map with isometric lines of heating loads

(The numbers in the figure means the heating loads in MJ/m^2)

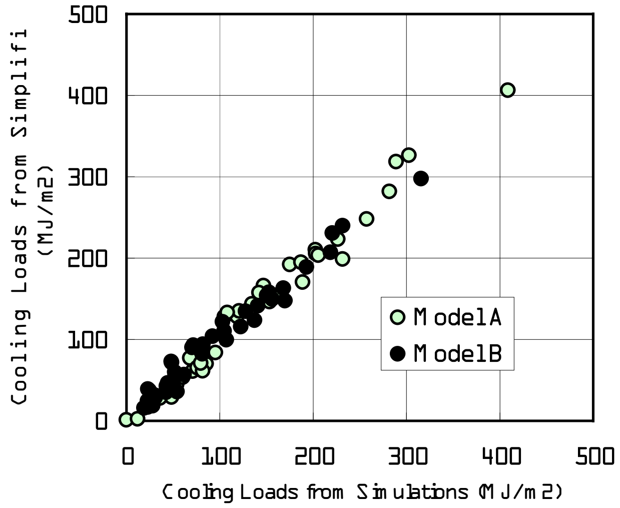


Fig.5 Corelations between Cooling Loads from the
Simplified Equation and Simulations

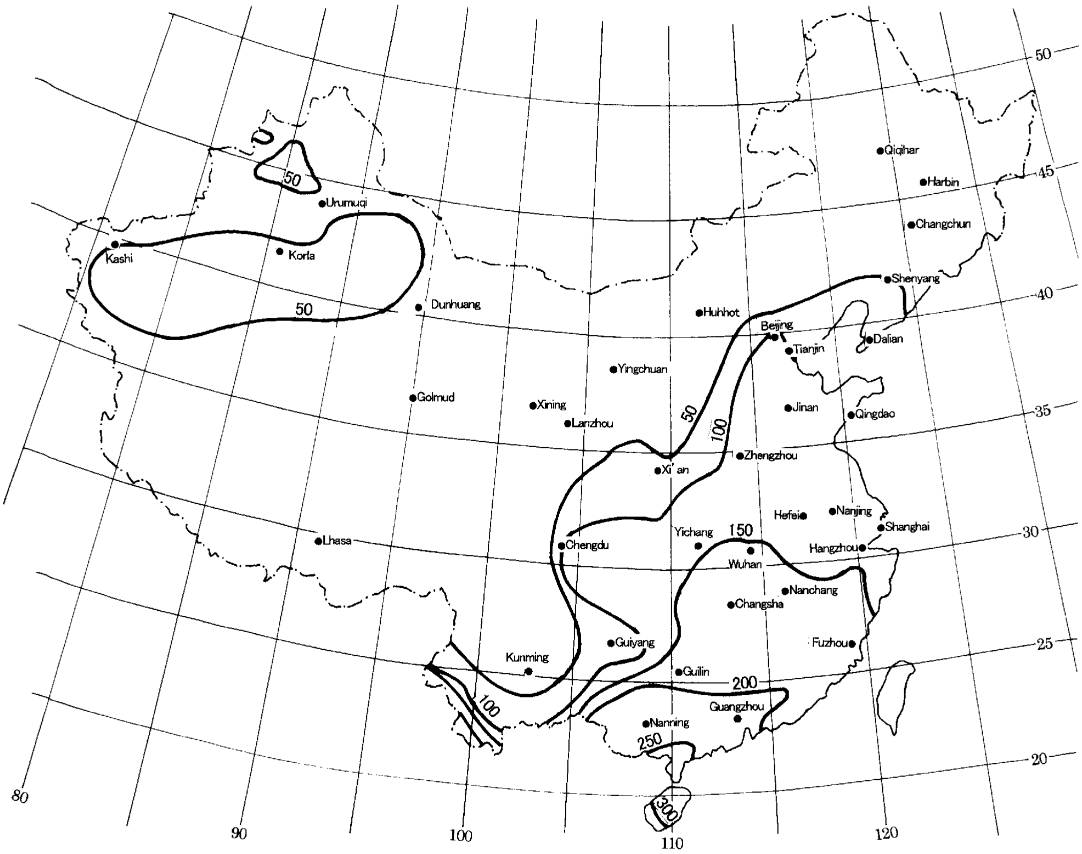


Fig.6 A map with isometric lines of cooling loads