Energy Consumption Building Design in Tianjin, China

Sun Zhong, Yun Yingxia, Li Na, and Xu Zhonghua

***Abstract*—Starting from the basic theory of the energy consumption building design, with the actual conditions of Tianjin, the key technical problems on design of low energy consumption building are researched and using multi-disciplinary building theories on the climate and the environmental engineering and others, the paper systematically studies the rule of the correlation on the thermal comfort demand indoor and the typical climate outdoor and then put forward the analysis technique of low energy building design and the way of the climate partition and the calculation method of the passive-solar heating and regenerative thermal design of ventilation and cooling, to provide theoretical support and solutions for the sustainable development of the regional architecture.**

***Index Terms*—Passive ultra-low energy consumption building, building energy conservation, body feeling comfort.**

I. Introduction

The United Nations Framework Convention on Climate Change conference was held in Denmark, 2009 and the conference assigned the task of the greenhouse gas emission reductions all over the world. The goal is the same, although there are many differences on emission reductions every nation. By 2020, Chinese government promised to reduce carbon dioxide emissions by 40% - 45% of gross domestic product (GDP). Three major energy-consuming section are construction, industrial and transportation and the construction is on the top of the three section, so passive low energy building design in China is beneficial to energy conservation and emissions reduction. Germany has already proposed the criteria for recognition of the low energy consumption building in the 1980s; the definition of passive low energy consumption building was put forward at first by professor Ada, Lund University Sweden and Dr. Fuster, Germany. However, the design standards of passive low energy consumption residential buildings were introduced in China until 2015. Because China has different climate conditions and the unified design standards of China are not quite suitable for Tianjin, so calculation method of the low energy buildings in Tianjin is put forward.

II. The Standards of the Passive Low Consumption Building

A. The Standards of the Passive Ultra-low Energy Consumption Building in Germany

The biggest characteristic is the passive design and fine construction and scientific operation management on the passive low energy consumption building, to reach minimize energy demand for heating, ventilation and air conditioning in winter and summer.

Germany's certification has the six requirements to the passive buildings.

(1) The structure of the heating energy consumption$\leq$15kwh/(m^2.a).

(2) Total energy consumption (heating, air conditioning, ventilation, hot water, lighting and electrical appliances, etc.)$\leq$120kwh/(m^2.a).

(3) Heat transfer coefficient of the external windows$\leq$0.8 W/($m^2 \cdot$K).

(4) Exterior wall, roof heat transfer coefficient$\leq$ 0.15 W/($m^2 \cdot$K).

(5) Air-tight performance of the building < 50Pa , air changes$\leq$0.6 /h.

(6) The efficiency of the heat recovery fresh air system$\geq$75%.

B. The Standards of the Passive Ultra-Low Energy Consumption Building in China

The passive ultra-low energy consumption building concept has more than 20 years of history, but standards of the passive low energy consumption residential building energy efficiency design were issued in 2015 (Fig. 1).

According to the new standards, the passive low energy consumption residential buildings must meet the following four requirements in China:

(1) The building of the heating demand in unit area, $Qh\leq$15 kWh/($m^2 \cdot$a).

(2) The building of the heating load in unit area, $qh\leq$10 W/m^2.

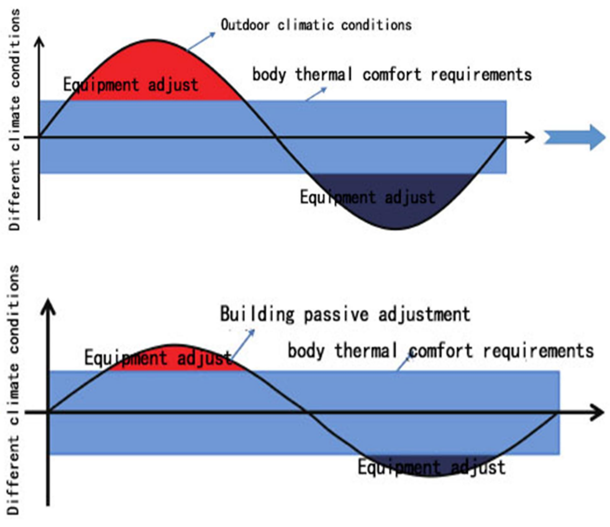

Fig. 1. Passive climate control principle.
Image: passive ultra-low power consumption basis and application of architectural design.

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(3) Housing refrigeration requirements in unit area, $Qc \leq 15$ kWh/(m²·a).
(4) Housing refrigeration load, qc, max≤20W/m².

The rule make apart from the low-energy building with the heating and cooling energy consumption building. For example, many zero energy buildings and low energy consumption buildings that demand energy is very high , to meet the building energy consumption only use solar photovoltaic and thermal energy consumption of the building [1].

The passive low energy consumption residential building must meet the following seven aspects of living environmental indicators:

(1) Room temperature:200°C ~ 260°C.
(2) Over temperature frequency≤10%.
(3) CO_2 in the room≤1000ppm.
(4) Retaining structure is less than 30°C the inner surface of the transparent part, the internal surface temperature is not lower than 30 ℃ indoor temperature of the retaining structure.
(5) Doors and windows no condensation phenomenon of the indoor side.
(6) The relative humidity at 35% ~ 65% indoor all the year.
(7) Through the network and of the auxiliary channel transmission the voice should comply with the room≤35dB, function room, bedroom and living room≤30dB.

III. Passive Ultra-Low Power Consumption Needs to Solve the Problem of the Architectural Design

The passive-low energy consumption building design needs to solve two key problems and a design goal. Firstly, consider the local climate resources available. Secondly, the method of architectural design.

Achieve the aim: narrow the difference of body thermal comfort requirements and the outdoor climate, expand the construction of passive technology can adjust and control the climate range, minimize the demand of the construction of artificial environment equipment [2].

A. Building of the External Conditions

The passive technology is interaction that the micro climate indoor and the climate outdoor, and with the outdoor climate fluctuation and regular change accordingly, presents a significant "free running state". Air as the main part in the connection of three systems, use the "air enthalpy wet figure" as building climate analysis reproduction tools (Fig. 2).

From the thermal environment design goal, the body thermal comfort is index that can be described through the air quality and thermal comfort state, the effective temperature becomes best indicator system parameters to the "man - construction - climate" of the combined from temperature and humidity. We use the figure as the reproduction; temperature is variable, build climate analysis tools - climate analysis diagram (Fig. 3). The vertical and horizontal lines represent the climatic conditions, the orange line representative the monthly climate for a particular region, the grey area is the heat comfort zone. The figure shows the outdoor climate can get comfortable with the passive technology and the zero energy consumption in the line area.

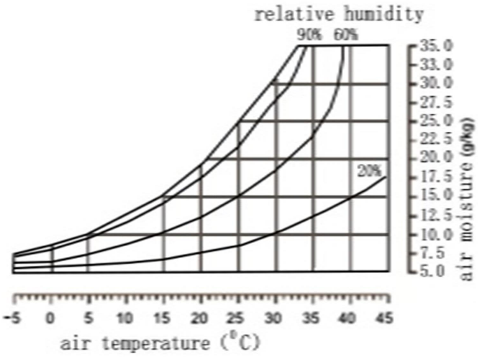

Fig. 2. The climate analysis for reproduction.
Image: author drawing.

The calculation method and the spatial interpolation method used to calculate the total radiation. The model and calculation method estimate the solar total radiation values through sunshine, cloud cover and other related to solar radiation meteorological elements. For example, the" Angstrom – Prescott" model with the day sunshine radiation, the speculation of "Zhang qing-yuan" model use the cloud cover and dry bulb temperature, the spatial interpolation use a certain number of samples to the existing space that reflect the features of the radiation data, and then predict the unknown radiation characteristics of the geographic space. Through the cross validation method analysis, we found use the Angstrom Prescott model is superior to the spatial interpolation method the radiation observation data in china presently [3].

B. Building Micro Climate Indoor

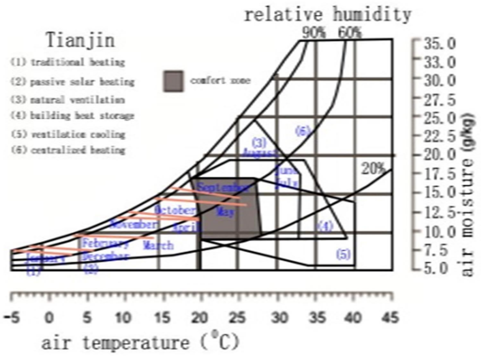

Fig. 3. Building climate analysis.
Image: author drawing.

The micro climate indoor was caused by the air temperature, the humidity, the wind speed and the surface radiation of the surrounding. The environment comfort by indoor micro climate and on the surface of body in thermal equilibrium, when the micro climate indoor created by building that the closer comfort requirements the body thermal, the most energy saving. In the late of the 1970s, Humphrey put forward the theory of "heat acclimation, he think the body active adaptability that the environment changes and produces heat to accommodate environment through the behavioral, the psychological and the physiological [4], It make the actual thermal comfort range than the predicted results of the current standard. The building thermal environment design from the "stable, uniform, control, energy dissipation" design that make the building should respect the natural ventilation design direction, and further support the theory of passive-low energy consumption building design from the theory of thermal comfort level.

IV. The Calculation of the Use Energy and Feeling Comfortable Time in Tianjin

To calculate the body feeling comfort in Tianjin, analyze the energy use of the passive-low energy consumption building period and residential.

A. Calculate the Body Feeling Comfort in Tianjin

The China have diverse climate, people's social and economic background and living habits have huge differences, the crowd thermal comfort demand is different from international and other region, so the thermal comfort standard can't use the international standards, also cannot use the unified national standards of the temperature index [5].

TABLE I: Thermal Comfort Models and Comfortable Temperature Range in Eastern China

Climate Region	Typical city	The adaptation model	Comfort temperature （℃）
Severe cold region	Harbin	T_n=0.12T_0+21.49	16.3 < T_n < 26.2
cold region	Beijing	T_n=0.27T_0+20.01	15.8 < T_n < 29.1
Hot-summer and cold-winter region	Shanghai	T_n=0.33T_0+16.86	16.5 < T_n < 27.8
Hot summer and warm winter region	Guangzhou	T_n=0.55T_0+10.58	16.2 < T_n < 28.3

TABLE II: Thermal Comfort Models and Comfortable Temperature Range in Western China

Region Climate	Typical city	Double variable adapt to climate model	Comfort temperature range（℃）
Moderate the year	Kunming	T_n=0.12T_0+21.49	15.8 < T_n < 23.6
Plateau climate	Lhasa	T_n=0.27T_0+20.01	16.3 < T_n < 22.9
Dry and hot	Turpan	T_n=0.33T_0+16.86	21.7 < T_n < 31.5

Table source: passive ultra-low power consumption basis and application of architectural design

TABLE III: Comfort Index and the Corresponding Human Feeling

rank	Comfort index	Body feeling
1	< 0	Sever cold, bare skin frostbite
2	0-25	Very cold, very uncomfortableness
3	26-38	Cold, uncomfortableness
4	39-50	Very cool, most people don't feel comfortable
5	51-58	Cool, a few people don't feel comfortable
6	59-70	feel comfortable
7	71-75	Warm, a few people don't feel comfortable
8	76-80	Hot, most people don't feel comfortable
9	81-85	Very hot, uncomfortable
10	86-88	sever heat, extremely uncomfortable
11	≥89	Extremely heat, have a heat stroke

There are 20000 effective samples analysis through 25 indoor micro climate environment, human subjective thermal sensation and thermal comfort index test and investigation all the climate zones in China town, then get the rule that the comfortable temperature in china with the geographical, seasonal changing, and set up a model that the different parts of the human body thermal adaptation and a comfortable temperature range (Table I-Table II) [6].

$$I = 1.8Ta - 0.55(1 - RH) + 32 - 3.2\sqrt{V} \qquad (1)$$

Ta: air temperature (℃)
RH:relative humidity(%)
V :wind speed (m/s)

Source: passive ultra-low power consumption basis and application of architectural design

From the Table III, Comfort index between 51 ~ 58, the body feels cool and have a few people don't feel comfortable; The body feel comfortable between 59 - 70; the body feeling warm and a few uncomfortable between 71- 75. According to the conclusion that the body thermal comfort index interval between 51-75 in Tianjin.

B. Energy Use Time Division in Tianjin

The use energy time division standards of the zero energy house that based on "comfort and health" in Tianjin, that can be divided into heating, cooling, ventilation, humidification and dehumidification, etc. Set up a two-stage evaluation parameters, the first level was meet the human body comfort, contain the heating, the cooling and the ventilation seasonal, the second level control range for a healthy living environment humidity ,contain the humidification and the dehumidification season.

According to the special meteorological data set "China building thermal environment "analysis of the typical meteorological year data of the meteorological parameters in Tianjin, the required parameters calculation model in the human body comfort index, obtained as shown zero residential energy consumption use energy period of time in Tianjin in Table IV.

The result of the division to the zero energy house use energy time in Tianjin: the heating time from 1.1-4.6 and 10.29-12.31, the total number of days to 160 days; the cooling time from 6.18-8.22, the total number of days to 66days; natural ventilation time is4.7-6.17and 9.3-10.28, the total number of days to 128 days; Without humidification season; dehumidification season from 8.23-9.2, the total number of days to 11 days. From the result to the statistics of Fig. 3, it can be seen from the figure in the heating season and time accounts for 44% of the proportion of the number of days all the year round, the cooling season account for 18% of the annual, ventilation time accounts for 35%, the dehumidifying time accounts for 3%.

C. Building Use Energy Analyzed in Tianjin Residential

TABLE IV: ZERO ENERGY HOUSE CAN USE PERIOD OF TIME IN TIANJIN

		HEATING	REFRIGERATION	VENTILATION	HUMIDIFICATION	XERANSIS
CLASSIFICATION STANDARD	I	I≤50	I≥76	51≤I≤75	51≤I≤75	51≤I≤75
	II			d≤14g/kg Ø≥30%	Ø≤30%	d≥14 g/kg
COMMENCEMENT DATE		1.1-4.6 10.29-12.31	6.18-8.22	4.7-6.17 9.3-10.28		8.23-9.2
TOTAL DAYS		160	66	128		11

From the use energy days of the scale, the heating time accounted for 44%, and the refrigeration time accounted for 18%, the refrigeration use energy is far less than in heating use energy. According to "China's building energy conservation annual development report 2009", the residential heating can average of0.3GJ/ m^2·a in the Cold district, (it is GJ/m^2·a in Tianjin), it's about 80kWh/ m^2·a, the air conditioning use energy about 1.6kWh/ m^2·a, the lighting use energy about 5.6kWh/ m^2·a. Using the method of equivalent electrical equivalent standard:

$$\text{Wee} = K * \eta * Q \qquad (2)$$

where Wee: Energy conversion of equivalent electric values(Kwh);

K: The actual transformation index building in the Tianjin area (0.6-0.8)

η: The energy conversion efficiency for the biggest;

Q: The energy of total energy (Kwh);

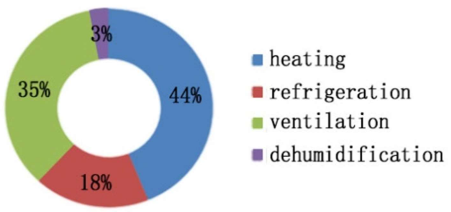

Fig. 4. Use energy with season and time of the year in Tianjin.
Image source: Custom painting.

In the form of the north town municipal central heating hot water to convert, the municipal water supply water temperature of 950°C- 70°C, the Calculation of the outdoor temperature -1.60°C,the work ratio η is 23.6%, Equivalent electricity is 13.22kWh/ m^2·a, the preliminary results of residential energy consumption in Tianjin in Fig. 5.

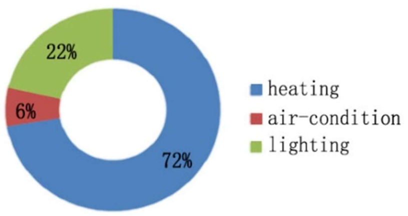

Fig. 5. Residential use can power consumption statistics in Tianjin.
Image: Custom painting.

From the Fig. 4 and Fig. 5, we can see there are the highest percentage whatever on the use energy days or on the power consumption ratio, energy consumption of heating and air conditioning, ventilation, dehumidification, lighting. Therefore, it should be in the first place to reduce heating energy consumption and the "comfortable and healthy" living environment of the residential energy consumption in Tianjin.

V. THE PASSIVE BUILDING ENERGY EFFICIENCY CALCULATION METHOD IN TIANJIN

A. The Passive Solar-Heating Design Method in Tianjin

At present, china has adopted the heat index of the building consumptions for building energy conservation target each region. Namely, it shall not exceed the target value to the energy consumption per unit area of the building equipment. The energy-saving targets should play a leading energy saving of the development of new technologies, and technology, economic is feasible. The current national building energy efficiency design standards focus on saving the artificial environment, radiation is ignored on the worst winter weather, the method is not suitable for passive solar heating buildings.

There are plenty of solar energy, sunshine hours of 2471-2769 hours per year, 80% of the year that the total solar radiation 5.61bj/m^2 in Tianjin. It is the best way to reduce building energy consumption on Use solar energy as the heating energy in Tianjin.

Through the research to building in Tianjin found the indexes are correlate that the outdoor climatic conditions, physical environment and urban and rural residential building energy consumption, the solar building that the heat consumption is effect on the solar radiation intensity and indoor and outdoor different temperature ,therefore, we use radiation and heating index as the heating consumption index calculation in Tianjin (most of the intensity of solar radiation and heating period I live for the ratio of the Hdd), then puts forward the type:

$$Q = -0.74(\text{I/Hdd})^2 + 0.62(\text{I/Hdd})^2 + 11.5 \qquad (3)$$

Source: passive ultra-low power consumption basis and application of architectural design

The greater heat consumption, the lower energy saving rate. The Solar-heating energy saving rate of the building is closely related to the actual contribution of solar energy. So it introduce "auxiliary heating consumption" as the judgment index of energy-saving rate on the solar-heating building energy efficiency rate calculation in Tianjin [7]. According to the season change of the solar radiation in Tianjin, then put forward to the passive solar heating buildings of auxiliary heat consumption index calculation method of Tianjin, as shown in formula (4). This method can be used as the passive solar-heating buildings to a simplified method of thermal performance evaluation in Tianjin:

$$E_{aux} = K\frac{(1-SES)(t_n-t_e)}{A_0}SG.X_m A_g C \qquad (4)$$

where e_{aux}: the auxiliary heat consumption index to the passive solar building, in addition to the passive solar heating system with heat, provided by the other auxiliary heating unit building area for construction of heat;

A_0: The building construction area;

t_n: Designed indoor temperature; t_e: Heating period the average outdoor temperature, °C;

A_g: The area of the solar heating system cimc hot window;

X_m: The heating system of the effective transmission coefficient;

C: Collection hot glass dirt block coefficient;

K: The heat index in Tianjin, 1-1.5.

B. The Passive Heat Ventilation Cooling Design Method in Tianjin

The Heat ventilation technology involves the thermal environment and wind environment, the influence factors of the cooling efficiency that include the outdoor weather conditions ,the accumulation of heat ventilation, the space layout of the building, the palisade structure heat insulation of the heat storage performance and regenerator and the surrounding air convective heat efficiency. The forecast is very complex of the actual cooling effect, at present the main coupling is used to complete of the fluid mechanics and the heating transfer. Through the analysis of the heat transfer process and fluid dynamics of heat storage of ventilation, it established for cooling ventilation rate and the simplified calculation method of heat storage in Tianjin (type (5) and (6)).

$$G_{req} = K\frac{3.6Q_{MAX}}{cp(T_i - T_0)} \tag{5}$$

$$Q_i = K[T_{massj} - T_{outj}]A_{mass}h_{mass} \tag{6}$$

where G_{req}: The regenerator biggest moment heat storage take away the required ventilation rate;

C: Air specific heat;

T_i: Discharge air temperature;

T_0: Enter the air temperature;

Q_i: i accumulation of heat regenerator, the maximum heat storage :

Q_{max};T_{mass}, i-1:for i-1 regenerator surface temperature;

T_{out}, i: for I outside air temperature;

A_{mass} and h_{mass}: Accumulation of heat surface area and regenerator surface heat transfer coefficient.

K: the heat loss rate of the building in Tianjin (1.2-1.5), the current level of doors and windows, walls and other sealing has some problems.

Combined with the thermal pressure and the wind pressure calculation formula of ventilation, the ventilation cooling effect and determine at night the chimney height and open area such as design parameters for the Tianjin, thus the heat ventilation effectively design.

It is the key to the regenerative ventilation cooling technology in the regenerator design, to obvious of cooling effect on the location, number and arrangement. External regenerator is limited to the influence of the indoor temperature and thermal comfort feeling, while internal regenerator has significant effects on thermal environment indoor; the smaller and smaller indoor temperature reduction, and set up internal regenerator (x) area and the relationship between indoor comfort than (y) in Tianjin:

$$y = 0.0887 \ln x + 0.613 \tag{7}$$

Source: passive ultra-low power consumption basis and application of architectural design

VI. Conclusion

The passive-low energy consumption building of the design theory and method are the science about the interactions about the use of architectural design rather than artificial environment control creates indoor thermal comfort, studies the building and outdoor climate, micro climate indoor. The passive-low energy consumption building of the design is the basis and core according to the climate characteristics of each region which reach a targeted for the design. The passage studies the basis on the passive-low energy consumption building of the Regional design that contain the regional climate analysis technology, the calculation of the body comfort, the division on the energy saving time, the calculation method of the solar heating design and the method of ventilation cooling, to provide a reference for the passive-low energy building design in other areas.

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