Climate Adaptability Analysis of Dwellings in Eastern Hebei Province under Building Energy Efficiency Context

Zheng Li¹, Sijia Wang¹,*, Cuiping Dong¹ and Qi Zhang²

¹ Hebei Normal University of Science & Technology, Qin Huangdao, P.R.China
² The Planning and Construction Bureau of Beidaihe New District Qin Huangdao City, P.R. China

*Corresponding author email: 441017115@qq.com

Abstract. Building energy efficiency plays a vital role in solving conflicts between energy resource supply and social economic development and accelerating the development of circular economy. On the basis of "Regulations for Energy Efficiency of Civil Buildings in Hebei Province", combined with Climate Consultant, the paper analyzes the meteorological data of dwellings in Eastern Hebei Province, obtains suitable for dwellings climate policy and valid time in the region. Through above analysis, the paper concludes the passive strategy suitable for dwelling construction so as to provide viable architectural design and energy-saving strategies for the application of energy-saving technologies, planning and construction in Eastern Hebei Province.

Keywords: Building energy efficiency; Eastern Hebei Province; Dwellings; Climate analysis; Passive strategy.

1. Introduction
Dwellings is the earliest form of architecture built by human beings to shelter from the weather. In the period of spontaneous construction of vernacular architecture, various climate adaptability strategies in residential spatial forms, structure styles and construction methods were taken by human beings in order to adopt to different weather conditions and form indoor microclimate suitable for human settlement. Dwellings were presented in rich architectural forms. With the development of technology, it is possible to rely on construction equipment to create a comfortable indoor environment, and the connection between climate and architecture is gradually separated. This led to serious homogenization of cities and buildings, loss of their own characteristics, great energy waste and heavy environmental pollution [1]. In developed countries, approximated 40% of energy is consumed on buildings. Estimate from experts, 2/3 to 3/4 resources can be saved via effective climate adaptation measures [2]. Mature traditional architectural forms must have their adaptability to the environment. Research on the climate adaptability of traditional dwellings will help us to inherit their valuable experience and improve their deficiencies so that modern dwellings will be developed in the direction of energy efficiency and ecology. On the basis of the analysis of the local climate conditions by Climate Consultant software, including temperature, humidity, rainfall and total solar radiation, etc. The paper combines with building layout, materials, building construction and living habits in Eastern Hebei Province, concludes the corresponding passive climate regulation strategies, for example, improving air tightness of the doors and windows, increasing the thermal mass of the walls. It explores the experience and deficiencies of climate adaptability of dwellings in Eastern Hebei Province in order to provide a scientific basis for improvement of modern dwelling construction and new rural planning design.
2. Selection of Analysis Software and Comfort Model

2.1. Selection of Analysis Software
During building thermal environment analysis, natural climate, indoor thermal comfort and architectural design measure should be comprehensively considered to analyze climate data of designated region and generate building climate analysis chart. The commonly used softwares for climate adaptability analysis are Climate Consultant and Weather Tool, the subsystem of Autodesk Ecotect. Climate Consultant is a software developed by University of California at Los Angeles (UCLA) for climate research and effectiveness analysis of passive strategy. It can effectively load two types of weather data published from official website of U.S. Department of Energy: CSWDEPW and SWERAEP. The SWERAEP data includes the "Dedicated Meteorological Data Set for Analysis of China's Building Thermal Environment" researched and developed jointly by the Meteorological Information Center of China Meteorological Administration and Tsinghua University in 2005, covering the typical TML comprehensive data of 270 meteorological stations across the country over the past 10 years [3]. SWERAEPW data is a database developed based on the evaluation of solar and wind energy resources. Climate adaptability analysis software provides abundant climate data analysis charts. Psychrometric charts in the Climate Consultant are relatively simpler than that in the Weather Tool, with less comparisons between years or typical months, but Climate Consultant software can use psychrometric charts to analyze applicability of passive strategy and calculate the effectiveness of each measure after evaluation on climate conditions of specific regions, and the psychrometric chart of the Climate Consultant can be used to show subtle climatic attribute and its impact on the architectural form [4]. Therefore, Climate Consultant is used to analyze the meteorological data in Eastern Hebei Province and climate adaptability of local traditional dwellings.

2.2. Selection of Thermal Comfort Model
There are two general types of models for assessing the thermal comfort of people in the building environment: static model and adaptive model. Four thermal comfort models are provided by Climate Consultant 6.0, which are ① California Energy code comfort Model, 2013, ② Adaptive comfort model in ASHRAE Standard 55-2010, ③ ASHRAE Standard 55 and Current Handbook of Fundamentals Model, ④ ASHRAE Handbook of Fundamentals Comfort Model up through 2005 [9]. The first two belong to static model, Model ① is suitable for closed central air conditioning environment, Model ② is suitable for open natural ventilation environment [6]. PMV comfort model in Model ③ sets the upper limit of humidity, but no lower limit, assuming that the moisture content has nothing to do with the thermal sensation [7]. When thermal comfort model in Model ④ sets the relative humidity of 50%, the effective temperature (ET) is 20.0 to 23.3 °C, the maximum wet bulb temperature is 17.8 °C, the minimum dew point temperature is 2.2 °C, the clothing thermal resistance is (0.5 clo in summer and 0.9 clo in winter), the metabolic activity of the body is (M ≤ 1.2met), the air velocity is (summer ≤ 0.8m/s, winter ≤ 0.15m/s), which are in line with the comprehensive and complex characteristics of human thermal and humid sensation [8]. Based on views mentioned above, the paper selects the analysis model of ASHRAE Handbook of Fundamentals Comfort Model up through 2005.

3. Climate Adaptability Analysis of Dwellings in Eastern Hebei Province

3.1. Climate Classification in Eastern Hebei Province
Eastern Hebei Province is located in the eastern part of the north China plain. This region belongs to the typical Temperate Continental Monsoon Climate. It has the abundant solar energy, solar radiation 5400-6700MJ/(m²•a). The weather is humid with clear four seasons and abundant in rainfall concentrating on the period from June to August. Due to the limitation of EPW data collection, the final location is approximately at 39.43 degrees north latitude and 118.88 degrees east longitude, which is located at the junction of Qinhuangdao and Tangshan.
3.2. Analysis of Climate Psychrometric Chart in Eastern Hebei Province

The use of Psychrometric Chart is developed from Olgyay's “Bioclimatic Analysis Chart” and Givoni's “Building Climate Design Analysis Chart”, integrated with the concept of human comfort and comfort range. It's a graphical analysis designed for building environment comprehensive meteorological parameter and primary basis for Climate Consultant to proceed passive strategy analysis. The climate psychrometric chart of Eastern Hebei Province is shown in Figure 1, the horizontal axis shows the dry-bulb temperature, the vertical shows the absolute humidity and the dew-point temperature, the oblique curve shows the relative humidity and the oblique line shows the wet-bulb temperature. The quadrangular area in dark blue indicates the range or status of indoor thermal comfort that can be achieved without any technical measures or under natural climatic conditions. The combination of psychrometric chart and comfort zone can indicate the degree of discomfort and climate characteristics of the outdoor climate. On the left side of the comfort zone is a subcooled climate zone, the right is the overheated zone, the top is overwet zone, and the bottom is overdried zone.

“Show Best Set of Design Strategies” is selected and the passive building strategy that best suits the climatic conditions in Eastern Hebei Province will be concluded after removing conflicts and redundant options. Under the premise without traditional heating or cooling system, the maximum comfort time can be achieved by these strategies with least measure combinations. The results are shown in Table 1.

![Figure 1. Psychrometric chart of climate data in eastern Hebei Province.](image)

From the chart analysis, it’s known that only 8.4% throughout the year is in comfort in Eastern Hebei Province, mainly in spring and autumn. 43.9% throughout the year requires heating, adds humidification if needed. 20.6% is internal heat gain. 10.8% requires passive solar direct gain high mass. 9.2% requires sun shading of windows. Other applicable passive building strategies are arranged in order of fan-forced ventilation cooling (8.4%), cooling, add dehumidification if needed (8.3%), dehumidification only (7.9%), two-stage evaporative cooling (2.6%), wind protection of outdoor spaces (0.5%), humidification only (0.4%) based on the effectiveness duration.
Table 1. Effective timeline of passive strategies of Dwellings in eastern Hebei Province.

| Control Mode                        | Jan   | Feb   | Mar   | Apr   | May   | Jun   | Jul   | Aug   | Sep   | Oct   | Nov   | Dec   |
|-------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Thermal Comfort                     | 0.4%  | 2.6%  | 25.3% | 31.3% | 1.2%  | 9.8%  | 25.7% | 4.7%  |
| Sun Shading of Window               | 1.4%  | 12.4% | 24.3% | 26.1% | 26.1% | 19.6% | 0.4%  |
| Fan-forced Ventilation Cooling      |       |       | 26.1% | 21.6% | 31.7% |
| Internal Heat Gain                  | 8.2%  | 39.7% | 59.9% | 31%   |       | 6.5%  | 47.8% | 42.2% | 11%   |
| Passive Solar Direct Gain High Mass | 19.4% | 22%   | 12.2% |       | 2.6%  | 20.1% | 17.6% | 11%   |
| Wind Protection of Outdoor Spaces   | 0.7%  | 1.2%  | 0.8%  |       |       |       | 1.6%  | 1.5%  |
| Dehumidification Only               | 2.1%  | 0.3%  | 20%   | 30.1% | 30.1% | 1.3%  | 0.8%  |
| Heating, add Humidification if needed | 93.4% | 86.6% | 75%   | 41.1% | 4.4%  | 1.8%  | 38%   | 78.1% | 89.4% |

3.3. Climate Adaptability Analysis of Dwellings in Eastern Hebei Province

The gross solar radiation in Eastern Hebei Province is 5040 MJ / (m² • a) to 6300 MJ / (m² • a), which belongs to the region with abundant solar energy resources. The effective annual sunshine duration is 2500h to 3000h. On the basis of the climate characteristics of the Eastern Hebei Province, the solar energy that can be utilized in winter is quite impressive, the average relative humidity of air in summer (June, July and August) is about 80%, and the outdoor temperature is near dew point in early morning (before sunrise), therefore the climate design strategy suitable for the region can be acquired. The design strategy in winter, mainly in insulation and winter protection, makes the maximum use of solar energy and combines solar energy of both active and passive. In addition, pay attention to wind and freeze protection. The design strategy in summer, mainly in natural ventilation, pays attention to thermal insulation and shade design so as to effectively prevent solar radiation, and protects the external structure from moisture and setting sun.

Layout plan of typical dwellings in Eastern Hebei Province, as shown in Figure 2, the window area in south is relatively large, the window area in north is relatively small and the position is relatively high, only lighting needs satisfied, both east and west in the building layout have no conditions for window. The living room is set in the middle, where stove and other facilities located, heated brick bed in the room on south side, and furniture in the room on north side. Natural ventilation is favorable in summer, the effectiveness of internal heat gain is relied in spring and autumn, but due to the low outdoor temperature in winter, it is completely unable to meet indoor thermal comfort dependent on internal heat gain alone, the heated brick bed should also be used for heating. "Shallow Vaulted Roof" is the main roof type of dwellings in Eastern Hebei Province. On the one hand, the air volume at the top of the building is properly reduced which can preserve heat and save building materials at the same time. On the other hand, the roof is relatively flat and the terrace area for food drying is increased. But, in comparison with cornice of Pitched Roof, the cornice size of "Shallow Vaulted Roof" is relatively small.
Figure 2. Plan layout of Dwellings in eastern Hebei Province.

The dwelling architectural form in Eastern Hebei Province can make the maximum use of winter sunlight, and a typical high mass material - adobe is used to build heated brick bed for heating. But there is inadequate consideration of wind protection of outdoor spaces, and measures as window seal plus curtains are usually taken to make up in winter; and there is inadequate consideration of shading design in summer, the feature of sun shading of windows gradually disappears as the traditional top-hung window gradually changed to side-hung windows and sliding windows, therefore it's required to redesign the shading of windows.

4. Transformation Strategy for Energy Efficiency of Dwellings in Eastern Hebei Province

4.1. Sun Shading and Seal Design of Openings

More solar radiation can be acquired via optimizing transparent envelope structure of dwellings in Eastern Hebei Province. Survey data shows that aluminum alloy or plastic steel frame with a single layer of ordinary glass is mostly adopted to the current dwellings. The sealing quality among window frames decreases after long-term use, which led to cold air infiltration and serious "Heat Bridge" effect. In selection of window materials, it’s proposed to adopt broken bridge aluminum window frame with double-layer Low-E glass, the window opening method is changed from the general sliding window to side-hung window. The wall on both sides of window openings is proposed to change from parallel structure to splayed structure so as to acquire more solar radiation without enlarging window size.

Sun shading design for the summer should mainly focus on cornice design, as shown in Figure 3. The design should achieve the actual result of sun shading of window in summer and full sunlight of window in winter, reducing solar gain in summer and increasing solar gain in winter. Tall deciduous trees can also be adopted to green, but not in the front direction, 45° angle should be formed between the green plants layout and widows / doors so as to avoid impact on ventilation. In order to enhance the effect of natural ventilation in summer, air inlet of lower position and air outlet of higher position can be set.
4.2. Heat Preservation and Thermal Mass of Wall

Based on analysis of psychrometric chart, the effect of Passive Solar Direct Gain High Mass strategy is obvious, but there is no thermal insulation layer in the traditional dwelling design. In the passive design strategies, the high heat resistance materials can be used as insulation, such as polystyrene, rock-wool panel. Insulation should be set in the outer layers of the walls and roof; the thickness is greater than 80 mm. The outdoor temperature is not too low in spring and autumn, mechanical heat source can be relied to achieve ideal thermal comfort. The passive residential buildings in Eastern Hebei Province always use the air source heat pump to be the HVAC system, to achieve the purpose of indoor thermal comfort and energy saving. In the specific design scheme, by improving the palisade structure thermal insulation properties, reduce the heat loss in winter heating and power consumption of air conditioning refrigeration in summer. The sealing between components of wall should be cared so as to minimize air infiltration and discharge. In the design of core layer separating the wall, the uninsulated metal support should be increased from 40mm to 60mm for every separation so as to reduce thermal bridge effect and heat loss.

4.3. Heat Insulation and Moisture Protection of Roof and Floor

For the improvement strategy of roof insulation, the software recommends the setting of double-roof with the width of no less than 5cm, which will help the air layer between roofs to form insulation layer and further popularize the application of the ceiling and add a reasonable thickness of insulation between the ceiling and the roof. The vent of insulation air layer should be set and it remains closed in winter and open in summer. Combined with the moisture consideration of the ground and roof in summer, weather stripping should be designed for roof vent and moisture barrier for the floor. It’s encouraged to replace ordinary floor fans with ceiling fans. Although the fan at higher position is not favorable for ventilation in the summer, the software analysis shows that the ceiling fans in good working conditions can reduce above 5 °C of indoor air temperature with windows closed.
5. Conclusion
Design of energy efficiency building is different from the traditional design, architects can quickly and accurately grasp the characteristics of the local climate by means of meteorological analysis software, scientifically provide design basis and improvement methods for creating a comfortable indoor environment. US Green Building Council (USGBC) proposes that the analysis of environment climate can be used at the initial stage of schematic design or the decision-making stage of energy-saving reconstruction on the existing buildings. Architects should have their own judgment on the software analysis result. On the one hand, there is a big difference in climate around the world, but the default setting of Climate Consultant is mainly for general climate conditions. When the analysis object is highly urbanized, architects should pay special attention to the effect of local microclimate and heat island produced on the analysis result. On the other hand, Climate Consultant software is based on modern housing conditions and thermal comfort standards in developed countries and is not entirely applicable to specific conditions in various parts of China. Therefore, the architects are expected to have a certain basic knowledge of construction environment to analyze software analysis result.

Through the analysis described in the paper, we can see that Eastern Hebei Province belongs to the cold region with short natural comfort time. In the course of long-term historical development, local buildings have accumulated living wisdom to deal with local environment. With the vigorous promotion of energy-saving measures for civil architectures in Hebei province, building forms with high energy consumption and materials with heavy pollution are gradually replaced. The application of passive building strategies and new eco-friendly materials can effectively relieve the conflict between heat preservation in winter and ventilation in summer in Eastern Hebei Province so as to further reduce the energy consumption of heating in winter and the energy consumption of cooling in summer and provide users with a comfortable indoor environment.

References
[1] Niu Runping, Chen Qizhen, Zhang Peihong, etc. Status Quo and Prospect of Thermal Comfort Study [J]. HKV, 1999, 10 (1): 38-40
[2] Zhao Jun, Di Yuhui, etc. Status Quo of Building Energy Conservation and Thermal Comfort [J]. Clean and Air Conditioning Technology, 2009, (9): 51-52
[3] He Quan, Wang Wenchao, Liu Jiaping, Yang Liu, etc. Climate Adaptability Analysis of Traditional Dwellings in Lhasa based on Climate Consultant [J]. Building Science, 2017, 33(4): 94-100
[4] China Meteorological Administration, Tsinghua University. Dedicated Meteorological Data Set for Analysis of China's Building Thermal Environment [M]. Beijing: China Building Industry Press, 2005
[5] California Energy Commission. CEC - 400 - 2012 - 004 - CMF- REV2, 2013 Building Energy Efficiency Standard for Residential and Nonresidential Buildings [S]. Sacramento: California Energy Commission, 2012.
[6] de Dear R, Brager G. The Adaptive Model of Thermal Comfort and Energy Conservation in the Built Environment [J]. International Journal of Biometeorology, 2001, (45): 100 - 108
[7] ASHRAE. ASHRAE Standard 55 - 2010, Thermal Environmental Conditions for Human Occupancy[S]. Atlanta: ASHRAE, Inc., 2009
[8] ASHRAE. Chapter 8, Thermal Comfort, ASHRAE Handbook of Fundamentals[S]. Atlanta: ASHRAE, Inc., 2005
[9] Murray Milne, Robin Liggett, Andrew Benson, and Yasmin Bhattacharya. “Climate Consultant 4.0 Develops Design Guidelines for Each Unique Climate”, UCLA Department of Architecture and Urban Design, www.aud.ucla.edu/energy-design-tools.