Application and Design of Residential Building Energy Saving in Cold Climates

Zhi-sheng Li, Dong-Mei Li, Sheng Mei
Faculty of Construction, Guangdong University of Technology
Guangzhou, China, 510643
Chinaheat@163.com

Guang-qiang Zhang
College of Civil Engineering, Hunan University
Changsha, China, 410082
Gqzhang@sina.com

Jian-long Liu
Hunan University of Technology
Zhuzhou, China
jlliu7887@126.com

Abstract: Climate is the one of main considerations for residential building design since the green and energy saving building has become the trend in the building industry. China is actively popularizing high energy-effective and environment harmonious buildings that integrate new techniques, new materials and new equipment. It is absolutely essential to summarize and demonstrate the application of energy-saving building in cold climates for the sake of a favorable economy and directions in the modern building industry. This paper discusses the cold climate features in China vis-à-vis the residential building layout, construction, building materials, envelope and cost from the aspects of environmental optimization and energy efficiency. The investigation combines indoor microclimates in order to decrease the building life cycle energy consumption. The air wall technology is studied for adoption of cold climate features. The research results through a National Demonstration Building Project (NDBP) show that the exterior wall total heat transfer coefficient is K=0.3w/(m^2.k). Moreover, this four-layer dual heat-preservation exterior wall has more conformability and higher energy efficiency. It is completely successful for energy saving building project NDBP that deserves generalization because of adoption of cold climates features. The application of energy saving buildings can achieve social, environmental and economical benefits.

Key words: cold climates, residential building, air-wall, energy saving, envelope

1. INTRODUCTION

Rapid population increases as well as crude but rapid economic development style brings more and more resources and energy pressure for China. China is currently suffering from the increasing energy shortage and environmental depravation pressure. For example, in the winter of 2003, 16 provinces of in China 31 provinces were forced to shut down power supply due to the electricity net load too large for consideration transfer safety, which is never seen before in China winter [1]. In addition, most lands of China locate in cold or rigid cold climate, which may cause large-scale power paralysis in winter once heating demand sharply increases. It is estimated that China currently consumes 130 millions tons of standard coal equivalent (MTSCE) per year for spacing heating urban residential and commercial buildings [2]. Meanwhile, the execution of energy efficiency regular for new buildings remains inefficient in recent 10 years in China. For example, even Beijing is relatively better in the fields of building energy saving in present China, but it is still estimated to consume 50%-100% more energy for space heating as compared to that of the building in similar cold climates in West Europe and North America [3]. Fortunately, China is focusing more attention on building efficiency, and encourages taking new building materials and technique to settle inefficient buildings. Now China has formulated the national health buildings demonstration projection outlines in order to promote residential industry modernization and improvement of residence quality.

In 1999, buildings energy consumption during operation and maintain accounted for 27.8% of total national energy utilization [4], which is still rapid augment with economy development, and of building energy consumption, about 60% is utilization by heating, ventilation and air-conditioning (HVAC). There are some existing studies on the relationship between building location, shape, climates and energy consumption [5~6]. Climate is the one of main elements about residential building design except the equipment energy efficiency improvement since the green and energy saving building becomes the trends of building industry. Different building construction and configuration must be accommodated with different climates and geography features. As above mentioned, considerable land in China locates in cold climate, if building energy efficiency can be improved a little in cold climate, it will absolutely contribute the comfortable indoor thermal environment as well as national energy shortage problems. Due to the cultural and economic reason, universal oversea building energy saving methods may be not agreement with the state of China. The objective of the paper is summarization and popularization the application and design of residential building energy saving methods in cold climates, and rectification proper energy saving technique and materials as well. Due to rural households depend on biomass energy and bearing without universality, the paper mainly focuses on the cities application and design of residential building energy saving. The cold features and spectrum in China was firstly introduced in the paper, and then the residential building energy saving materials and techniques adaptive to China cold climates were investigated. Furthermore, several applications of residential buildings energy saving in cold climates are illuminated and compared. Finally, the economic feature analysis was carried out corresponding to residential buildings features.

2. COLD CLIMATE FEATURES IN CHINA

In China, besides obvious monsoon influence, territorial weather is also multifold due to multifarious landform. Cold and rigid cold climate zone accounts for comparable scale, more than ten provinces. Fig. 1 illuminates the cold climate zone in China at the top and left of the dark and bold line in the map.

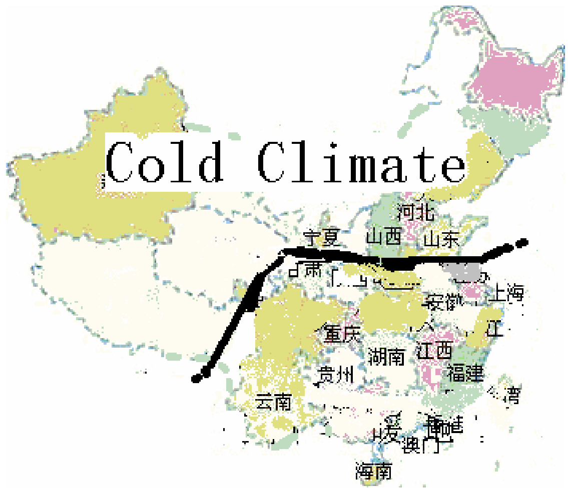

Fig.1 Cold climate zone in China (left and top parts of the dark and bold line)

The weather parameters of 20 cities in cold and rigid cold climate zone are calculated. The coldest city, Harbin, the multi-years' mean outdoor air temperature in the coldest days in winter gets to –33^{o}C, and the mean outdoor air temperature of these 20 cities reaches to –21.12^{o}C. The primary weather feature of cold climate zone is lengthy and chilly winter, warm and absent of rain spring and autumn. Stormy climate in winter and short summer in cold climate zone renders the height of residential buildings comparative low, and the airtight and insulation feature of the envelopes are the most essential elements of buildings energy saving, and the consideration of heating in winter is more than cooling in summer.

The influence of climate to the building energy efficiency is tremendous in building life cycle (BLC). The heat preservation of envelope for residential buildings in cold climate should be specially considered so as to be adoptable with adverse local weather, such as storm, windy and low temperature. A favorable energy saving design of residential building will be improvement not only comfortable but also economical.

3. RESIDENTIAL BUILDING DESIGN ABOUT ENERGY SAVING TECHNOLOGY IN COLD CLIMATE

Low energy consumption residential buildings in cold climate should be comfortable and practical. Due to the cultural and economic consideration, oversea universal used building energy saving methods may be not agreement with the state of China. The main design principles of residential building energy saving in cold climate should consider below aspects: (1) building heating in winter and refrigeration in summer no adoption one-off energy saving as possible; (2) investment focus on external wall, window and rooftop as the scale of energy consumption; (3) utilization ready-made materials and resources under the condition of economic, climate, life habit and life styles; (4) possessing widespread application value of low cost, high efficiency fabrication technology.

3.1 Air-Wall Configuration in External Envelopes

A so-called air-wall technology can solve moisture in wall envelope and provides favourable thermal insulation. Furthermore, air-wall settles the contradiction between the thickness of heat preservation layer and ugly exterior decoration. Fig.2 indicates the configuration of dual thermal insulation effect air-wall envelope. 4 layers from inside to outside constitute air-wall configuration, which includes bearing wall, 100mm thick polymer, and 100mm thick air layer as well as decoration ceramic tiles. If air-wall envelope embeds underground deep to 1.5m, the thermal insulation effect is better. For example, typical cold climate city—Beijing in China, the depth of frozen earth layer is deep about 0.8m. Such air-wall can completely insulated thermal loss from underground and the residential buildings locate considerable heat preservation and insulation situation. The compositive heat transfer coefficient (*K*) of air-wall is less than 0.3w/(m^2.k) in cold climates built-up several years.

Air-wall heat preservation technology first applied in 2003 in high-rise residential building in Beijing. It is calculated that more than 5 millions tons of standard coal equivalent per year can be saved if adoption of air-wall in cold climate in China, provided the average residential area per person as 10 m^2 calculation.

3.2 Cut-off Bridge Multifunctional Exterior Window Energy Saving Technology

Exterior window is the key and difficult component of energy saving. A high-efficient heat preservation window such as dual layers, three layers, middle-empty and air-charged glass (Tab.1) with cut-off bridge aluminum alloy airtight window frame roundly settles the problems. According to our investigation, present used heat insulation glass in China its thermal reflectivity is too large but daylight diaphaneity too low (less than 40%). If utilization in cold climate as window, the affect of lighting in spring and autumn will be rigidly decrease, which maybe increase energy consumption in lighting with adverse comfort. Great heat reflectivity but low diaphaneity glass doesn't suit for Chinese customer, which is not adaptable to residential buildings window. Furthermore, in cold climate the residential building energy saving main elements is envelope (wall, window, rooftop, etc) not solar radiation energy.

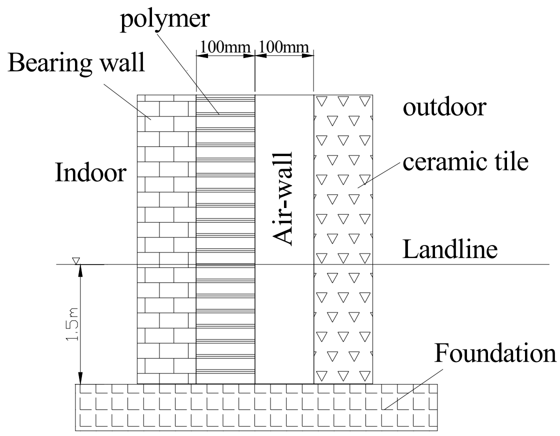

Fig. 2 Schematic of typical air-wall configuration

Those 60%-80% heat reflectivity and 70%-90%diaphaneity glass, is right to residential window. If equipped with high quality aluminum alloy shadow shelter (horizontal and vertical) at outdoors, the energy saving effect will be excellent. However, it is estimated that average heat transfer coefficient of exterior window can attain to *K*=2.0w/(m^2.k), even to *K*=1.0w/(m^2.k) in some residential buildings in cold climate, which is far more than national energy saving demand. It is obvious that cut-off bridge multifunctional exterior window energy saving technology is practical and meaningful to popularization in China not only in cold climate but also in warm and humid districts.

Tab. 1 Visible light characters of several kinds of glasses

Item	Air layer thickness	Diaphaneity (%)	Reflectivity (%)
float glass		89	8
plating film glass		8-40	20-60
dual float glass	6 mm	83	15
middle-empty glass		82	13.5

3.3 Rooftop Heat Insulation Technology

The heating energy consumption of rooftop in China cold climate is about 2.5~5.5 times compared with that of the climate adjacent developed countries. The heat transfer coefficient demand in cold climate of rooftop regulated in China by national energy saving certification is no more than 0.5w/(m^2.k), but practical energy consumption is far more than the national standard. It is estimated that 1/3 buildings belongs to multilayer buildings (less than 18m height) and 2/3 high-rise buildings in Beijing, which is the typical cold climate in China. The weight load of these built rooftops generally attains to 150kg/m^2. That is to say, the rooftop can be adoption to plant after appropriate retrofit. The study indicates that 70% rainwater can be intercepted and deposited by green plant within some periods after rainfall, which is gradually absorbed by plant into air as steam evaporation. Rooftop plant in residential building can improve local zoology environment to alleviate city “hot-island effect” in summer, and take on residential heat preservation to decrease energy consumption in winter. The layout of Beijing City Environment (2004-2008) specifically points out 60% low-rise and 30% high-rise buildings rooftops virescence for the sake of forthcoming Olympic games.

Generally speaking, new residential building rooftop can reach heat preservation requirements through selection low conductivity materials according to our investigation. But for several years after the residential building completion, the heat preservation effect of the rooftop material will degrade greatly due to aging and moisture. So it is not adaptable to introduction bibulous material as rooftop. In case of bibulous material as rooftop, the vents should be set in rooftop for discharging moisture. Present high efficiency heat preservation materials in cold climate rooftop are bulged pearl rock and polymer plank, which substitute conventional pitch pearl rock or concrete pearl rock. According to our research, 200mm thick polymer plank heat preservation plus local plant, even under the worst outdoor conditions the average heat transfer coefficient is no more than 0.2w/(m^2.k), which renders top rooms of residential buildings favorable thermodynamics characters.

3.4 Residential Building Shape

In China, regardless anywhere, any climate, people prefer those residential buildings that face to south but sit to north. In fact, by the simulation of software (DOE-2, eQUEST) indicates that relationship between the orientation of residential buildings and the energy consumption is small in cold climate, which is obviously different from winter cold and summer hot climate zone in China. One unit residential building in China, its shape coefficient (the rate of building exterior surface to the volume) is about 0.34, two units combination residential building about 0.3 and three units about 0.29. In our research, if others condition uniform, the smaller of shape coefficient, the better building energy saving effect in cold climate. So square residential building is better than rectangle, and round than square as well. Of course, the affect extent of shape coefficient depends on envelope, window, floor numbers and sun radiation. It is not meaningful to simply compare the two residential buildings shape coefficient. Early in China, building energy saving is focused on cold climate zone due to far more heating energy consumption in winter compared with others district building, but the shape coefficient hardly bring attention until recent age. It is believed that shape coefficient will be pay more attention at the tradeoff between energy saving and pretty appearance.

4. APPLICATION OF RESIDENTIAL BUILDINGS ENERGY SAVING IN COLD CLIMATES

National Demonstration Building Project (NDBP) formulated by Ministry of Construction (MOC) in the 10^{th} Year Plan (2000-2005) aimed at to construct 1 or 2 integrated and compositive residential buildings district in two or three years which incarnate house industrialization collectivity technology, and establish several tens demonstration project sections which answer for the energy saving direction bearing advanced energy efficiency demonstration meaning in 4or 5 years. Marketable demand and industrialization direction of residential buildings system will gradually form to boost series of residence focalization development and commercial accommodation through popularization and application of new dwelling technology, technique, products and equipments. Up to now, several NDBP in cold climate were achievement as energy saving and ecological residential buildings. Several applications of residential building energy saving in cold climate are listed below in Tab.2.

Tab.2 Application and design of residential buildings energy saving in cold climate

item	1	2	3	4
Name	Shuixie Hua Capital	Wan-ke Gardon	Xin-dou Manor	Feng-shang Fame Residence
Location	($38^0 02^{'}$/ $114^0 25^{'}$)	($41^0 46^{'}$/ $123^0 26^{'}$)	($39^0 06^{'}$/ $117^0 10^{'}$)	($39^0 48^{'}$/ $116^0 28^{'}$)
Building area(10^4 m^2)	24.67	24.6	49.0	8.0
main energy saving technology and materials	"L"+"T" shape layout, gas-charged compound exterior wall, dual-layer middle-empty glass, low temperature radiation heating	court-yard space, exterior wall heat preservation technology, compound door and window garbage biological treatment	polymer plank exterior wall and rooftop, middle-empty glass, floor radioactive heating,	rooftop plant and 200 mm polymer air-wall, low radiation and high transparence glass
test result	20% energy saving than conventional buildings	------	30-65% energy saving	≤12.4 w/m^2
evaluation	price and operation cost agreement to present residence economic level (RMB12000/m^2), 20% more than congeneric building	favorable ventilation and outdoor scenery	energy saving advanced in China	too expensive and luxury

Note: *The data in the bracket at location line in Tab.2 means north latitude/ east longitude.*

Present application of residential buildings energy saving in cold climate in China is more than ten cases. Tab. 2 lists main energy saving methods and used materials on envelope, but not includes all aspects. Additional energy saving technique application in NDBP involves health fresh air system, daylighting and wise illumination, solar energy utilization, ventilation and kitchen technology, etc. Many techniques or methods of energy saving projects are first utilized in China or Asia, for example, air wall and argon-charged window glass, which is utilized in Feng-shang Fame Residence (Item 4 in Tab. 2) only supported in China by Association of Global Sustainable (AGS). Conventional envelope material and techniques are preferential consideration on residential buildings in cold climate zone in China. 20%-65% energy consumption can be implemented through application of advanced and high quality insulation materials and techniques in Tab.2. But too expensive and luxury residential buildings means excessive investment in energy saving, people may be reluctant to purchase these not practical energy saving buildings, which is reversely to affect the popularization of energy saving residential buildings.

5. RESULTS AND DISCUSSION

Present application and design of residential building energy saving in cold climates in China focuses on envelope technology and materials. New built or retrofit residence is adoption of energy saving materials: 1) polystyrene plank and polymer sands as enforced glass fibrins attached exterior wall; 2) sandwich of polystyrene plank and air wall in the middle concrete bricks; 3) polystyrene plank attached to interior wall; 4) hydrophobic nature pearl rock or polystyrene plank as heat preservation layer, plus waterproof layers. Rooftop material and technique is general adoption below four methods: 1) heat preservation below waterproof (polystyrene plank, pearl rock); 2) heat preservation on top of waterproof (polystyrene plank plus concrete); 3) hard and soft waterproof; 4) planting on rooftop. Window is key and difficulty of residential building, which is mainly utilized following material and techniques: 1) plastic frame and dual-layer or three-layer glass plus airproof; 2) plastic- steel frame and dual-layer middle-empty glass; 3) low radiant and high transmission glass. If rigid construction technique and high quality is introduction during fabrication process, the best integration heat transfer coefficient of envelope wall achieves even to 0.3 $w/(m^2.k)$, rooftop for 0.2 $w/(m^2.k)$ and window for 1.0 $w/(m^2.k)$.

Middle-empty glass plated metal or oxide film has low radiance and high transparency, which can reflect 90% far infrared ray back to indoor with excellent energy saving effect. Because of its high price, it is selective for cold climates. In Northwest and Northeast of China cold climate, planting on rooftops should be careful and argumentation due to comparative storm in winter. Air-wall technology is also expensive for energy saving. Many applications and design of residential building energy saving project in cold climate may be not practical for resident if the energy saving investment is more than 20% building cost from the experience of NBDP. Too expensive and luxury energy saving investment in residential building may restrain the popularization of energy saving building.

6. CONCLUSIONS

It is meaningful to generalize the application and design of residential building energy saving in cold climate through NBDP projects discussed in the paper. Analysis for 4 residential buildings in cold climate indicates 20%-65% energy consumption saving can be achieved, but people may not accept the price of residential buildings if energy saving investment exceeds their economic burden ability (20% more than common residential buildings price), which will adversely affect the popularization of energy saving residential buildings. Harmony of environment, energy saving and economic benefit should be considered.

REFERENCE

[1] LI Zhi-sheng, ZHANG Guo-qiang, LIU Jian-long. Building energy efficiency and energy saving analysis in subtropical climates zone [J]. Journal of Guangdong University of Technology. 2006, 23(1): 1-8. (In Chinese).

[2] Ministry of Construction (MOC), Outline of 10th Five Plan of Building Energy Efficiency of MOC, Beijing: 2002. (In Chinese).

[3] Yinxin Zhu, Borong Lin. Sustainable housing and urban construction in China [J]. Energy and Buildings, 2004, 36(12), 1289-1297.

[4] National Development and Reform Commission (NDRC). The key program of energy development in 10th Five-year Plan by National economy and social development. http://www.sdpc.gov.cn. (In Chinese).

[5] Depecker P. Design of buildings shape and energetic consumption [J]. Building and Environment. 2001, 36(5). 627-635.

[6] Mark W. Multicriteria optimization of shape of energy-savings buildings [J]. Building and Environment.1997, 32(4): 331-319.