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ANALYSING THE PROBLEMS OF BUILDING ENERGY EFFICIENCY IN CHINA, AND RESOLUTION METHOD EXPLORATION, EXPERIMENTATION

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ABSTRACT
Architecture is a huge sector of energy consumption. According to some relevant statistics, it consumes nearly 40% of total energies in all industries globally. In recent decades, the whole world is in the presence of a severe energy crisis, the conservation amount of fossil resources are decreasing continuously. Energy saving has been a compelling task for all human beings. Among all energies consumed by buildings, the buildings that have existed for a long term is a crucial section. Most of them were constructed in or before the middle of last century without the consideration of energy efficiency design. And new buildings have a replacement ratio of 1% to 3% annually. Reducing the total energy loads caused by buildings, the existing ones will be a key. It is extremely necessary to analyse the existing buildings to discover their weakness in energy efficiency for finding suitable measures to address the problems.

Keywords: Energy Efficiency Improvement, Building Energy Standards, Insulation, and Renovation.

I. INTRODUCTION
Architectures consume a huge amount of energies among all industries. It is doubtless. According to some relevant statistics from the Europe, 40% of totally global energy consumption results from buildings [xi]. As to the decrease of worldwidely non-renewable resource storage, human beings are in the presence of serious energy crisis. Hence reducing energy loads has been a compelling task for the whole world. The United Nation and some single countries have enacted aims for energy saving in the next half a century. They have regulated that the whole world would reach zero-carbon emission five decades later. In order to approach goals like this while resolving certain problems, some developed nations have enacted laws and standards for decreasing the amount of architectural energy consumption. Instantly, the UK has set a goal of reducing energy consumption needs by 20% in 2020 in comparison with 2007, while shrinking 80% of carbon dioxide release on the level of 1990 by 2050 [xxviii].

As the large proportion of energy consumption results from architectural field, descending energies consumed by buildings is a key of achieving the goal of universal energy saving. Based on the aim of energy load reduction, the UK has enacted Code for Sustainable Homes (CSH), regulating that new residential buildings must achieve Level 6 in this standard, that is zero-carbon emission [ii].

In present-day world, as the advancement of science and technologies, there are certain techniques integrated into building industry for improving the occupation quality. The advanced materials and installations are able to assist buildings to achieve higher levels of sustainability. New residential buildings based on CSH in the UK can achieve the energy efficiency standards. It sees that the prospect of architectural energy saving is optimistic. However, there are other problems relating to building energy load existing. A number of currently existed residential buildings were built before or during the middle of last century, they were erected more simply hence do not achieve present standards of energy performance, for no insulation placed. More seriously, there is only an annual replacement ratio of 1.0-3.0% for buildings in the Europe (in developed countries it would be below

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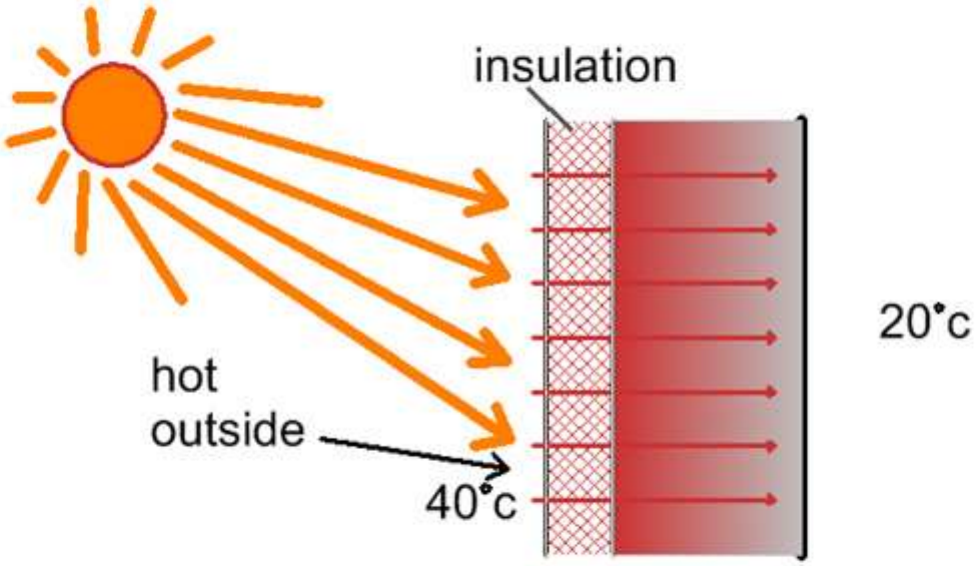
this figure) [xx]. Resultantly, if only depending on the low-energy effect of new buildings, there would be little possibility to reach the aim of whole decrease in global energy load. Thus it is essential to switch people's attention to existing buildings, especially those have existed for a long time without energy saving design. Exploring new ideas on renovating them to improve their energy efficiency for reaching the goal of total energy requirement reduction.

Architecturally, facility running is the main aspect of energy loads, it includes the requirements for heating, cooling, lighting, cooking, and other appliances). Renewable energy development and use is another factor in modern building design. The CSH involves all factors of them. Among the all sectors for energy demand, interior comfort maintaining (the running of heating or cooling equipment) is the key contributor (Fig. 1 [xxiv]). They are highly efficient in electricity consuming. In accordance with some appliance figures, heaters and coolers have the highest working efficiency and longest working time, such as air conditioners. In very cold or hot weathers, for the interior temperature adjustment, there needs to be facilities working for keeping warm or cool, which causes temperature difference between indoor and outdoor areas. If the building envelopes are not well thermally insulated, so that heat exchange between indoor and outdoor spaces would happen frequently (this is called heat loss), the temperature conditioners have to work endlessly for maintaining the interior area comfortable. In fact this phenomenon is happening in the maintenace of most currently existing buildings. It is not hard to see that a high ratio of building-related energy is consumed for adjusting internal temperature, more exactly heat loss. If the architectural envelopes can be well insulated, heat transmission through building fabrics would be prevented, so that the mission time of conditioners could be reduced noticeably (Fig. 1 [xxvii]). Therefore, to renovate the existing buildings for better energy efficiency, enhancing the envelope insulation effect (pursuing lower U value) is a key.



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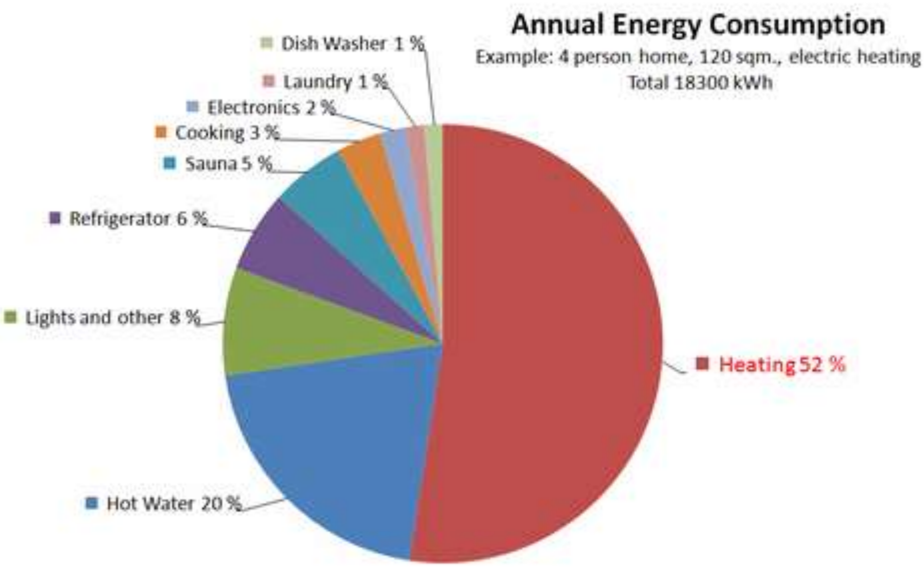

Fig. 1. Thermal Effect of Insulation on Exterior Wall (Left) and Domestic Energy Consuming Distribution (Right)

II. PROBLEMS AND SCOPE

Globally, there are several key high-density building regions, the Europe, America, and China. Among them, China is a typical area that has huge potential for building energy reduction. Initially, China is the most important construction producer universally. In accordance with the statistics in recent years, half of the globally fresh construction areas (㎡) take place in China [viii]. Moreover, energy wasting is an obvious issue in China nowadays. As being weak in scientific field, domestic facilities for Chinese families are low ratio in energy transferring. The poor-efficiency products are popular in China for their low cost in manufacture and installation. Meanwhile, its building envelopes are not strong in heat conservation. Insulation idea was introduced into and implemented in China very late. Chinese constructions were designed in insulation after 2000. Yet the most severely, for being technically weak, the insulated buildings in this region do not achieve high standards. The U-values of most insulted buildings are three times higher than the European degrees. For example, the thickness of insulation in buildings of China are only 1/3 of that in the Europe. Finally, sustainable development has not been implemented in China. The running of industrial production and daily life are supported by burning fossil fuels. While emitting waste gas, it wastes lots of mine resources. Resultantly, China has been a key energy consumer internationally. For getting the international target of energy requirement descent, improving energy efficiency of buildings in China is crucial.

The latest four decades were are key period of building development in China. After beginning to implement the Policy of Opening and Revolution in 1978, for the cultural exchange and import, some advanced techniques were also introduced into China, such as the technology for envelope insulation.The technologies of external wall insulation were original from the Europe by 1940s, more exactly in Germany and Sweden for repairing the envelope leaks caused by the World War II. Users of this discovered that the repair materials were not only thermally and soundly insulated, but also water proofed, which improves the interior comfort degrees for occupants. [iv and v]

A rapid development of this technology took place in the 1970s. For the effect of global energy crisis, many countries have been aware in the necessity of energy saving. The technology of exterior wall insulation was introduced into China during the 1980s. It was initially used in the northern regions that are severe cold at the interior sides of walls. Through practical implementation, its shortages were exhibited obviously. For the considerable temperature difference between the two sides of exteriors walls, some cold water formed on the surface of walls, leading to the material erosion. [xxiii]

To combat problems like this, investigators started to research and develop more suitable measures toward the climate and building features. Through a period of nearly one decade for studying and importing advanced

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technologies from developed countries (from 1980 to 1990), there is a wholy theoretical norm developed. Issuing laws and standards for reducing building energy needs started in 1995. In that year the government enacted the <Design Standards of Energy Efficiency for Buildings (Residential)> (DSEEBR), regulating to approach the aim of saving half of energy. In 1998, <The Law for Energy Saving of the PRC> was formally released and implemented. Yet in 2002, the working office of construction continuously issued several specifications, they are the <Exterior Wall Formulation of Buildings I (02J121 (2002-9-1))>, <Standards for Building Energy Saving Design in Hot-Summer and Cold-Winter Regions>. Since 2004, some big cities, Bei jing and Tian Jin, began to implement the standards that save energy by 65%. After that, each area started to release their regionally sole standards for energy efficiency. A timeline for the process of the energy saving standards is being exhibited in the following table. [xvii]

China is a big area that stretches across several climate zones. From the south to the north, in the same season, the air temperatures change considerably. For the considerable climate differences in various regions, there should be suitable standards of architectural insulation levels to adapt to the regionally characteristic climates. Hence the standards divide the whole nation into several climate regions, each of them has their special energy relating regulation. Although there are regional standards, the constructions in different areas are not considerably various. They are developed based on a central standard, the DSEEPB. In 2005, <Design Standard for Energy Efficiency of Public Buildings> was formally issued on 4 April, while being formally implemented since 1 July 2005. [xxxiii]

Despite being titled as 'Public', it is available in all kinds of buildings. This standard is used continuously till now. During the period from 2005 to present, many provinces have enacted their regional laws or standards for improving architectural energy efficiency within one's management scope. In design tasks, designers could select to follow their local specification or the national one for building energy saving design. Meanwhile, as the distinctive climate features of various locations of China, the whole region is divided into several parts for following regionally various standards. They are Severe Cold Region (Containing A and B), Cold Region, Hot-Summer and Cold-Winter Region, Mild Region, Hot-Summer and Warm-Winter Region. The chosen precedents for study would be in different climate regions, to show their differences in insulation. Their difference in energy saving design will be illustrated in the words and tables in the section of each case study.

However, the implementation of energy efficiency standards does not mean that China has been a energy-saving region. For the technique shortages, most energy-efficiency buildings do not reach the levels of developed countries. As to the standards in severe cold regions the U value is only less than 1 W/(m2.K) only, but this in the Europe is about 0.1W/(m2.K) in most regions. Besides, China has a late start of energy-saving design. Buildings constructed under the management of government after 2000 are insulated. A huge proportion of them, the earlier constructed ones, are not energy-efficient. In another words, very few buildings in China has reached the energy standards of Europe. There is still much space to improve the quality of buildings in China for achieving higher energy efficiency. Here a couple of construction works in a same climate region based on the background of China will be selected for study, and then to be experimented on some renovation measures, for improving their energy efficiency. All energy related data in this paper are calculated by TArch, an energy saving software based on AutoCAD. It focuses on the results of calculation, rather than deduction processes. [xxxiii]

III. CASE STUDY, A PRECEDENT IN HOT-SUMMER AND COLD-WINTER REGION

3.1 Introduction and Regional Information

The Residential of Cheng Yue Food Company (Cheng Yue Residential, CYR) is located at Jian Yang City (an outskirt town of Cheng Du), Si Chuan Province, belonging to the regions with hot summers and cold winters in China. Its regulations in energy efficiency will be shown as follows (Table 3.1) [xxxiii].

Hot-Summer and Cold-Winter Region is characterised for the the distinctive varation of temperatures in four seasons all year around, including five provinces in the central areas of China and some districts to the south of downstream for Chang Jiang River.

This building was constructed at the end of 2012 (Fig. 3.1). As a public housing for a company in the city, it follows the regional norms and standards of construction. It is a six-level dwelling with flat roof. The envelope is roughly insulated by traditionally regional materials, such as Hollow Glass Bead Inorganic Insulation Mortar

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and Extruded Polysty rene Insulation Board. It represents an average degree of housing for residents in this region. All construction information of this project is provided by the architect of this building. The energy saving data is calculated by an aiding software call TArch.

Table 3.1. Envelope Figures for Thermal Insulation in Hot-Summer and Cold-Winter Region

	Hot-Summer and Cold-Winter Region	Hot-Summer and Cold-Winter Region
	Shapes Coefficient of Building≤0.3	0.3<Shapes Coefficient of Building≤0.4
Envelope Components	Design U value Demands <W/(m^2*K)>	Shading Coefficient (East, West, South/North)
Roofs	≤0.70	
Exterior Walls	≤1.0	
Ground Floor or Overhangs that Contact External Air	≤1.0	
Partition Walls for Dividing Warm Rooms and Others	≤0.8	
Single Orientation Exterior Windows (Including Curtain Walls)		
Area Ratio of Window to Wall≤0.2	≤4.7	—/—
0.2<Area Ratio of Window to Wall≤0.3	≤3.5	≤0.55 /—
0.3<Area Ratio of Window to Wall≤0.4	≤3.0	≤0.50 /0.60
0.4<Area Ratio of Window to Wall≤0.5	≤2.8	≤0.45 /0.55
0.5<Area Ratio of Window to Wall≤0.6	≤2.5	≤0.40 /0.50
Roof Glazing	≤2.7	≤0.40

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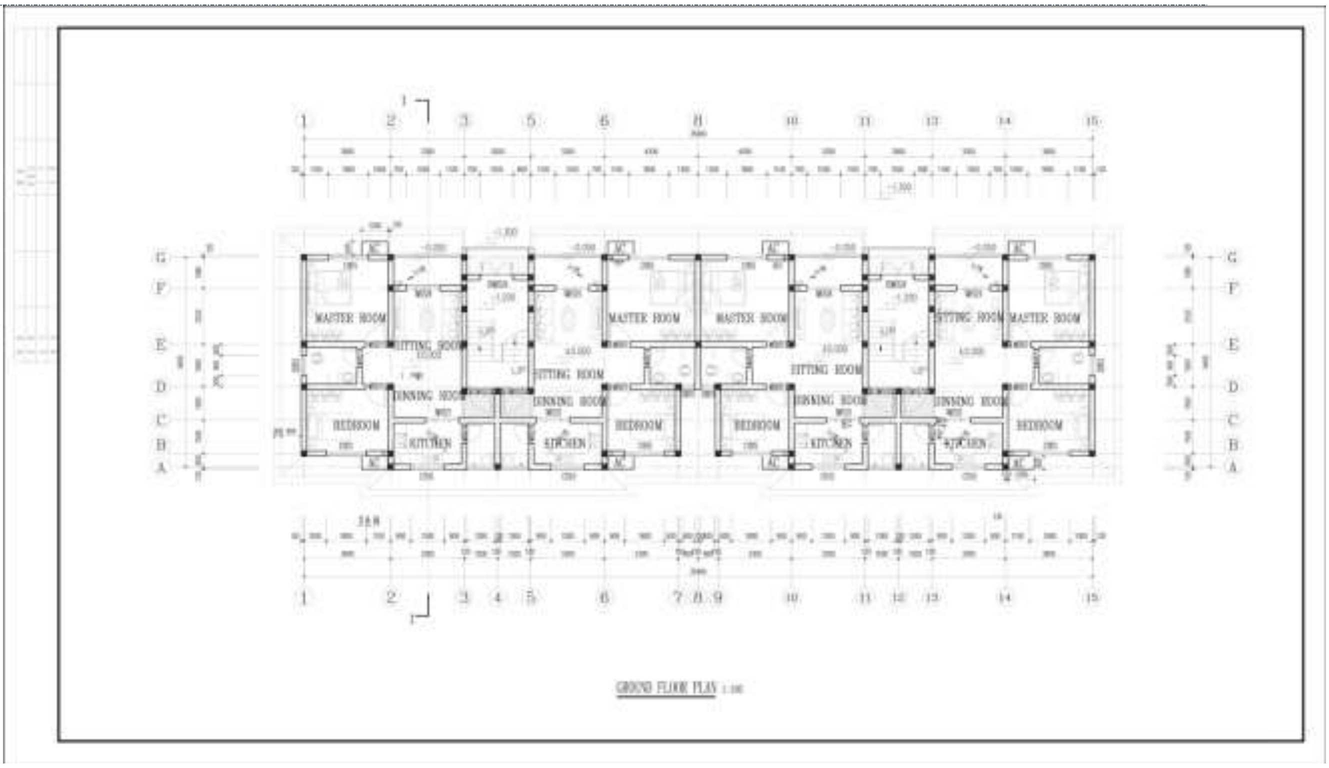

3.2 Brief Information of Building and Design Context

3.2.1 Hot-Summer and Cold-Winter Region. It includes five provinces in the central areas of China and districts to the south of downstream for Chang Jiang River.

Regional Cities Include: Nan Jing, Beng Bu, Yan Cheng, Nan Tong, He Fei, An Qing, Jiu Jiang, Wuhan, Huang Shi, Yue Yang, Han Zhong, Shang Hai, Hangzhou, Ningbo, and Yichang, and Nanchang, Zhuzhou, Yongzhou, Changsha, Ganzhou, Shaoguan, Guilin, Chongqing, Wanzhou, Fuling, Dalian, Nanchong, Yibin, Chengdu, Guiyang, Zunyi, Kaili, Mianyang

3.2.2 General Information of Energy Efficiency Design for the Building
Judgment Basis: Energy Saving Standards of Residential Buildings in Si Chuan

Project Title: Cheng Yue Food Company Residential
Construction Location: Shi Pan County, Jian Yang, Si Chuan
Construction Company: Cheng Yue Food Company
Architect: Mr Zhang Jian

Reference Specifications:
<Code for Thermal Design of Common Buildings>
<Standard for Energy Efficiency Design of Residential Buildings in Si Chuan>
<Mandatory Provisions of Project Construction (Housing Construction)>
<Classification Method for Air Tightness, Water Tightness and Wind Pressure Resistance of Exterior Windows>
<Technical Measures for Common Project Design in China>

Physical Information of Project
Location (City): Cheng Du (the Urban Outskirts, North Latitude 30.66° and East Longitude 104.01°)
Climate Region: Hot-Summer and Cold-Winter Region
Building Orientation: 1.9 ° South by West
Shape Cofficient: 0.46

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Energy Efficiency Design Area: Floor Area 1688.56㎡, Volume: 5065.67m³, Surfacial Area: 2308.936㎡
Level Figure: 6
Height: 18.00m

Table 3.3. The Ratios of Windows to Walls on Each Elevation

Orientation	**Windows (㎡)**	**U value of Windows (W/㎡*k)**	**Exterior Wall(㎡)**	**Ratio of Window to Wall**
East	8.10	3.10	376.56	0.02
South	140.40	3.10	637.21	0.22
West	8.10	3.10	376.56	0.02
North	180.00	3.10	637.21	0.28
Total	336.60	3.10	2027.53	0.17

Shape Cofficient Judgment
Shape Cofficient:

Table 3.4. Building Shape Cofficient

Shape Cofficient Value	**0.46**	**Shape Cofficient Limit**	**≤0.45**
Status	Not Meet		

Insulation Materials for Each Component

Table 3.5. Insulation Materials for Each Component

	Insulation Materia ls	**Insulation Thermal Conductivity (W/m *k)**	**Total Componen t U value (W/㎡* k)**
Exterior Wal l	Hollow Glass Bead Inorganic	0.035	1.250
Ground Floo r	Hollow Glass Bead Inorganic	0.035	1.808
Roof	Extruded Polystyren e Insulation Board	0.03	1.264

3.3 Energy Efficiency Data of Each Component
3.3.1 Exterior Wall

Main Part of Wall

Table 3.6. Thermal Effect in Exterior Wall

Exterior Wall	Thickness (mm)	Thermal Conductivity(W/(m.K))	Coefficient of Thermal Storage (W/(㎡.K))	Thermal Resistance((㎡.K)/W)	Thermal Inertia I ndex (D=R.S)	Coefficient of Correctio n (α)
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Hollow Glass Bead Inorganic I nsulation	15	0.035	1.10	0.33	0.471	1.30

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Mortar						
Brick Wall	240.00	0.870	10.75	0.28	2.97	1.00
Hollow Glass Bead Inorganic I nsulation Mortar	20.00	0.070	1.10	0.22	0.31	1.30
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
The Sum of all L ayers	340.0			0.98	4.40	
Wall Thermal Resistance: Ro=Ri+∑R+Re= 0.800 (m^2.K/W)			Ri= 0.11 (m^2.K/W);Re= 0.04(m^2.K/W)			
Wall Heat Transfer Coefficient (U value): Kp=1/Ro= 1.250 W/(m^2.K)						
Solar Radiation Absorbility Factor: ρ=0.50						

Exterior Wall Thermal Bridge Calculation

Table 3.7. Thermal Effect of Conformation Layers in Other Elements of Exterior Wall

Thermal Bridge Column	Thickness (mm)	Thermal Con ductivity (W/(m.K))	Coefficient of Thermal Storage (W/(m^2.K))	Thermal Resistance ((m^2.K)/W)	Thermal I nertia Index (D=R.S)	Coefficient of Correction
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Insulation Mortar	20.00	0.29	4.44	0.07	0.31	1.00
Hollow Glass B ead Inorganic Insulation Mortar	40.00	0.070	1.10	0.44	0.63	1.30
Steel Reinforced Concrete	240.00	1.74	17.19	0.14	2.37	1.00
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
The Sum of all Layers	340.0			0.69	3.80	
Wall Thermal Resistance: Ro=Ri+∑R+Re=0.85 (m^2.K/W)			Ri= 0.11 (m^2.K/W);Re= 0.04 (m^2.K/W)			
Wall Heat Transfer Coefficient: Kp=1/Ro= 1.18 W/(m^2.K)						

Heat Transfer Cofficient of Exterior Wall in Average

Table 3.8. Thermal Effect of Conformation Layers in Exterior Wall in Average

Use Parts	Main Wall (Not I ncluding Windows)	Thermal Bridge Parts				
		Columns	Beams	Sub Beams	Interior Floors	
Coefficient of Thermal Storage (W/(m^2.K))	0.88	1.18	1.32	1.32	1.36	1.00
thermal inertia index	4.4	3.8	3.1	3.1	2.85	1.00
Percentage (%)	75	25				

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Dm	Dm=Dp*A+Db*B=4.13	ρ=0.5	β=1	1.00
Dm'	Dm'=Dm/β=4.13			
Km [W/(㎡.K)]		Km=Kp*A+Kb*B=0.98		
Meeting the Standard Requirement, K≤1				

3.3.2 Floor

Table 3.9. Thermal Effect of Conformation Layers in Floor

Floor	Thickness (mm)	Thermal Conductivity (W/(m.K))	Coefficient of Thermal Storage (W/(㎡.K))	Thermal Resistance ((m2.K)/W)	Thermal Inertia Index (D=R.S)	Coefficient of Correction(α)
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Steel Reinforced Concrete	120.00	1.740	17.20	0.07	1.19	1.00
Hollow Glass Bead Inorganic Insulation Mortar	10.00	0.035	1.10	0.22	0.314	1.30
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
The Sum of all Layers	180.0			0.31	1.90	
Floor Thermal Resistance: Ro=Ri+∑R+Ri= 0.553 (㎡.K/W)			Ri= 0.11 (m2.K/W);Re= 0.11 (㎡.K/W)			
Floor Heat Transfer Coefficient: Kp=1/Ro= 1.808 W/(㎡.K)						

3.3.3 Roof

Table 3.10. Thermal Effect of Conformation Layers in Roof

Roof	Thickness (mm)	Thermal Conductivity (W/(m.K))	Coefficient of Thermal Storage(W/(m2.K))	Thermal Resistance ((㎡.K)/W)	Thermal Inertia Index (D=R.S)	Coefficient of Correction(α)
Gravel Concrete	40.00	1.510	15.36	0.03	0.41	1.00
Cement- sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Extruded Polystyrene Insulation Board	10.00	0.030	0.301	0.333	0.100	1.00
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Hydrophobic Perlite	30.00	0.140	2.44	0.21	0.52	1.00
Steel Reinforced Concrete	120.00	1.740	17.20	0.07	1.19	1.00

Lime and Cement Mortar	20.00	0.870	10.75	0.02	0.25	1.00
The Sum of a ll Layers	260.0			0.709	2.953	
Roof Thermal Resistance: Ro=Ri+∑R+Re= 0.859 (m^2. K/W)				Ri= 0.11 (m2.K/W);Re= 0.043(m^2.K/W)		
Roof Heat Transfer Coefficient: K=1/Ro= 1.164 W/(m^2.K)						

3.3.4 Figure Comparison between A Reference Building and the CYR

Table 3.11

Prescribed Items			Reference Building K=W/(m^2. K)			The CYR K=W/(m^2.K)	
Shape Coefficient			0.45			0.46	
Roof			0.8 (Dm=9.15)			0.56 (Dm=9.15)	
Exterior Walls			1.00 (Dm=4.40)			0.99 (Dm=4.40)	
Party Walls			2.00			1.82	
Floors			2.00			1.78	
Doors			3.00			2.77	
Room Type of Exterior Win dow Exist	Existence Level	Exterior Window Area in Total (m^2)	Heat Trans fer Cofficient	Orientat ion	SC Limi tation V alue	Heat Trans fer Cofficient	Shading Cofficient
Bathroom	1-6	1.35	4.5	East		3.1	0.58
Sitting Roo m	1-6	3.6	3.2	North		3.1	0.58
Bedroom	1	2.7	3.2	South		3.1	0.58
Bedroom	1	2.7	3.2	North		3.1	0.58
Other	1-6	2.25	4.5	South		3.1	0.58
Bathroom	1-6	0.9	4.5	South		3.1	0.58
Bathroom	1-6	1.35	4.5	West		3.1	0.58
Bedroom	2-6	3.24	3.2	South		3.1	0.58
Bedroom	2-6	3.24	3.2	North		3.1	0.58
Indoor Stair	2-6	1.8	4.5	North		3.1	0.58

3.3.5 Calculation Outcome of Energy Efficiency Design*
It could be concluded that the CYR has an annual energy amount of 32.04(kWh/m2).

*Data in Table 3.13 is acquired through scientific calculation based on regional factors by a calculation software named TArch, all information of specifications is included in it, that in rest chapters will be same. The Reference Building is a virtual object formed by TArch, it is similar with the CYR in some physical features. Standards regulate that the annual energy amount of the designed work should be less than the reference.

IV. CASE STUDY, A SIMILAR PROJECT FOR COMPARISON (ABH 1)

4.1 Introduction
Artist Base Housing (Artist Base Housing, ABH) is a dwelling located at the same city with CYR. It belongs to the Hot-Summer and Cold-Winter Region of China as well. All construction information of this project is provided by the designer of this building.

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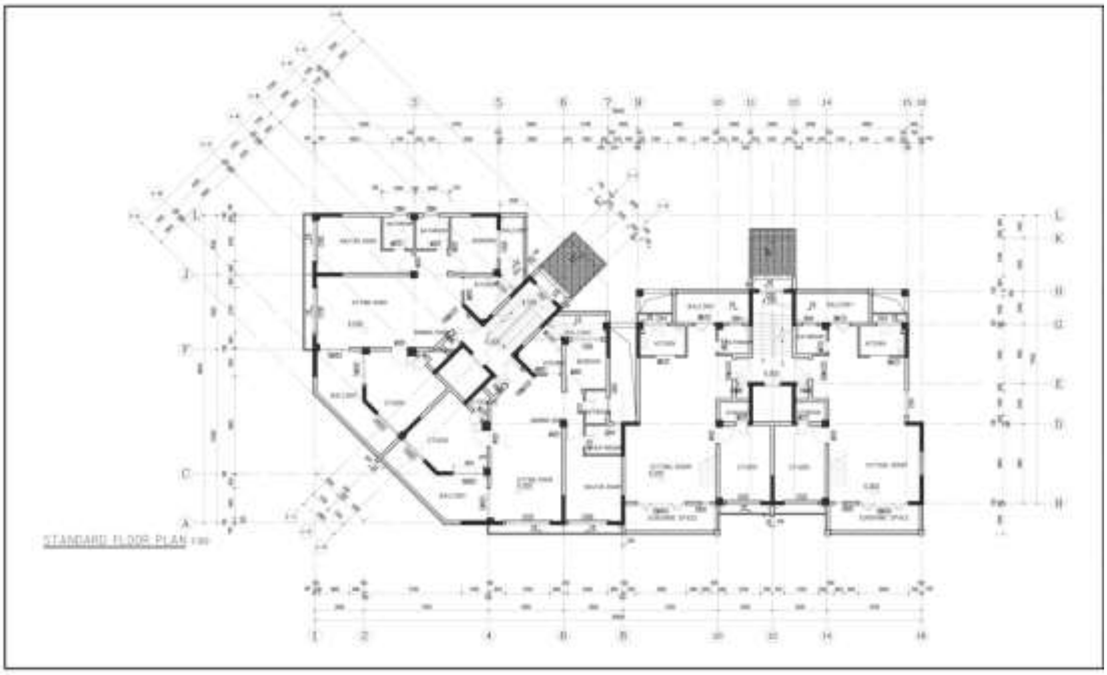

Fig. 4.1. Standard Floor Plan of ABH

4.2 Brief Information and Design Background

4.2.1 General Information of Energy Efficiency Design for the Building

Physical Information
Building Orientation: 148.5 ° by North
Shape Cofficient: 0.36
Energy Efficiency Design Area: Floor Area 2834.91 m^2, Volume: 8158.98m^3, Surfacial Area: 2507.60 m^2
Level Figure: 6
Height: 20.137m

Reference Specifications
<Code for Thermal Design of Common Buildings>
<Standard for Energy Efficiency Design of Residential Buildings in Si Chuan>
<Mandatory Provisions of Project Construction (Housing Construction)>
<Classification Method for Air Tightness, Water Tightness and Wind Pressure Resistance of Exterior Windows>
<Technical Measures for Common Project Design in China>

Other Information
Project Title: Artist Base Housing
Climate Region: Hot-Summer and Cold-Winter Region
Construction Location: Cheng Du, Si Chuan
Architectural Designer: Miss Feng Shuangyan

4.2.2 Thermal Data of this Building
Ratio of Windows to Exterior Walls

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Table 4.1. The Ratios of Windows to Walls on Each Elevation

Orientation	**Windows (㎡)**	**U value of Windows (W/㎡*k)**	**Exterior Wall (㎡)**	**Ratio of Window to Wall**
East	39.24	5.00	488.50	0.08
South	171.00	5.00	582.97	0.29
West	77.04	5.00	502.58	0.15
North	92.54	5.00	781.90	0.12

Shape Cofficient Judgment
Shape Cofficient:

Table 4.2. Building Shape Cofficient

Shape Cofficient Value	**0.36**	**Shape Cofficient Limit**	**≤0.40**
Status	Meet		

Thermal Data of Building Materials

Table 4.3. Insulation Materials for Each Component

	Insulation Materials	**Insulation Thermal Conductivity**	**Total Component U value (W/㎡*k)**
Exterior Wall	Hollow Glass Bead Inorganic	0.07	0.88
Ground Floor	Hollow Glass Bead Inorganic	0.1	1.85
Roof	Extruded Polystyrene Insulation Board	0.03	0.56

4.3 Energy Efficiency Data of Each Component

4.3.1 Exterior Wall
Main Part of Wall

Table 4.4

Exterior Wall	Thickness (mm)	Thermal Conductivity (W/(m.K))	Coefficient of Thermal Storage (W/(㎡.K))	Thermal Resistance ((㎡.K)/W)	Thermal Inertia Index (D=R.S)	Coefficient of Correction (α)
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Hollow Glass Bead Inorganic Insulation	10.00	0.035	1.10	0.44	0.63	1.30

Mortar						
Concrete Brick Wall	200	0.790	8.338	0.253	2.111	1.00
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
The Sum of all Layers	250			0.98	4.40	
Wall Thermal Resistance: Ro=Ri+∑R+Re=0.707 (㎡.K/W)			Ri= 0.11 (㎡.K/W);Re= 0.04 (㎡.K/W)			
Wall Heat Transfer Coefficient: Kp=1/Ro= 1.414 W/(㎡.K)						
Solar Radiation Absorbility Factor: ρ=0.50						

Exterior Wall Thermal Bridge Calculation

Table 4.5

Thermal Bridge Column	Thickness (mm)	Thermal Conductivity (W/(m.K))	Coefficient of Thermal Storage (W/(㎡.K))	Thermal Resistance ((㎡.K)/W)	Thermal Inertia Index (D=R.S)	Coefficient of Correction (α)
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Insulation Mortar	10.00	0.035	1.1	0.260	0.314	1.00
Concrete Brick Wall	200	0.790	8.338	0.253	2.111	1.00
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
The Sum of all Layers	250			0.69	3.80	
Wall Thermal Resistance: Ro=Ri+∑R+Re=0.569 (㎡.K/W)			Ri= 0.11 (m2.K/W);Re= 0.04(㎡.K/W)			
Wall Heat Transfer Coefficient: Kp=1/Ro= 1.757 W/(㎡.K)						

Heat Transfer Cofficient of Exterior Wall in Average

Table 4.6

Use Parts	Main Wall (Not Including Windows)	Thermal Bridge Parts				
		Columns	Beams	Sub Beams	Interior Floors	
Coefficient of Thermal Storage (W/㎡.K))	1.52	1.76	1.76	1.76	1.91	1.00
Percentage (%)	67.22	32.18				
Km [W/(㎡.K)]				Km=Kp*A+Kb*B=1.61		
Not Meeting the Standard Requirement, K≤1.50						

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4.3.2 Floor

Table 4.7

Floor	Thickness (mm)	Thermal Conductivity (W/(m.K))	Coefficient o f Thermal St orage (W/(m2.K))	Thermal Resistance ((m2.K)/W)	Thermal I nertia Index (D=R.S)	Coefficient o f Correction (α)
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Steel Reinforced Concrete	120.00	1.740	17.20	0.07	1.19	1.00
Hollow Glass B ead Inorganic Insulation Mortar	10.00	0.035	1.10	0.260	0.314	1.10
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
The Sum of all Layers	180.0			0.31	1.90	
Floor Thermal Resistance: Ro=Ri+∑R+Ri= 0.593 (㎡.K/W)				Ri= 0.11 (㎡.K/W);Re= 0.11 (㎡.K/W)		
Floor Heat Transfer Coefficient: Kp=1/Ro= 1.686 W/(㎡.K)						

4.3.3 Roof

Table 4.8

Roof	Thickness (mm)	Thermal Conductivity (W/(m.K))	Coefficient of Thermal Storage (W/(㎡.K))	Thermal Resistance ((㎡.K)/W)	Thermal I nertia Ind ex (D=R.S)	Coefficient o f Correction (α)
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Water Proof	4	0.27	6.79	0.015	0.101	1.00
Extruded Polyst yrene Insulation Board	10.00	0.030	0.301	0.333	0.100	1.00
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Hydrophobic Pe rlite	30.00	0.140	2.44	0.21	0.52	1.00
Steel Reinforce d Concrete	120.00	1.740	17.20	0.07	1.19	1.00
Lime and Ceme nt Mortar	20.00	0.870	10.75	0.02	0.25	1.00
The Sum of all Layers	194.0			0.484	2.124	
Roof Thermal Resistance: Ro=Ri+∑R+Re= 0.634 (㎡.K/W)				Ri= 0.11 (m2.K/W);Re= 0.04 (㎡.K/W)		
Roof Heat Transfer Coefficient: K=1/Ro= 1.577 W/(㎡.K)						

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4.3.4 Calculation Outcome of Energy Efficiency Design

Table 4.9

Calculation Outcome	The ABH	Reference Building
Annually Cooling-Energy Amount (kWh/㎡)	9.30	9.15
Annually Heating-Energy Amount (kWh/㎡)	13.00	17.85
Total (kWh/㎡)	22.30	27.00

It could be concluded that this building has an annual energy amount of 22.30 (kWh/㎡).

V. EXPERIMENT FOR RENOVATION (ABH2, WINDOW)

5.1 Introduction

This project of research aims to explore measures of renovation for improving architecture energy efficiency. For the suitability checking, some methods will be experimented. Through the acquired data of energy saving in each method to measure their advantages and disadvantages. In this chapter and next ones there will be modification on each component, such as replacement of windows and increasing the thicknesses of insulation, for discovering its practical effect of energy efficiency. The modification part will mainly take place at the U value of each component, including roof, floor, exterior walls, and windows. This chapter will focus on windows.

5.2 Ratio of Window to Exterior Walls

As to the Building Renovation, each component related to energy load would be tried, for finding out the best one. This part will focus on replacing windows with lower U value. Other information is same with ABH.

Table 5.1

Orientation	**Windows (㎡)**	**U value of Windows (W/㎡*k)**	**Exterior Wall (㎡)**	**Ratio of Window to Wall**
East	39.24	1.00	488.50	0.08
South	171.00	1.00	582.97	0.29
West	77.04	1.00	502.58	0.15
North	92.54	1.00	781.90	0.12

5.3 Energy Efficiency Data of Each Component

5.3.1 Exterior Wall
Main Part of Wall

Table 5.2

Exterior Wall	Thickness (mm)	Thermal Conductivity (W/(m.K))	Coefficient of Thermal Storage (W/(㎡.K))	Thermal Resistance ((㎡.K)/W)	Thermal Inertia Index (D=R.S)	Coefficient of Correction (α)
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Hollow Glass Bead Inorganic	10.00	0.035	1.10	0.44	0.63	1.30

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Insulation Mortar						
Concrete Brick Wall	200	0.790	8.338	0.253	2.111	1.00
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
The Sum of all Layers	250			0.98	4.40	
Wall Thermal Resistance: Ro=Ri+∑R+Re=0.707 (㎡.K/W)			Ri= 0.11 (m2.K/W);Re= 0.04 (㎡.K/W)			
Wall Heat Transfer Coefficient: Kp=1/Ro= 1.414 W/(㎡.K)						
Solar Radiation Absorbility Factor: ρ=0.50						

Exterior Wall Thermal Bridge Calculation

Table 5.3

Thermal Bridge Column	Thickness (mm)	Thermal Conductivity (W/(m.K))	Coefficient of Thermal Storage (W/(㎡.K))	Thermal Resistance((㎡.K)/W)	Thermal In ertia Index (D=R.S)	Coefficient of Correction (α)
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Insulation Mortar	10.00	0.035	1.1	0.260	0.314	1.00
Concrete B rick Wall	200	0.790	8.338	0.253	2.111	1.00
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
The Sum o f all Layers	250			0.69	3.80	
Wall Thermal Resistance: Ro=Ri+∑R+Re=0.569 (㎡.K/W)				Ri= 0.11 (㎡.K/W);Re= 0.04(㎡.K/W)		
Wall Heat Transfer Coefficient: Kp=1/Ro= 1.757 W/(㎡.K)						

Heat Transfer Cofficient of Exterior Wall in Average

Table 5.4

Use Parts	Main Wall (Not I ncluding Windows)	Thermal Bridge Parts				
		Columns	Beams	Sub Beams	Interior Floors	
Coefficient of Thermal Storage (W/(㎡.K))	1.52	1.76	1.76	1.76	1.91	1.00
Percentage (%)	67.22	32.18				
Km [W/㎡.K)]				Km=Kp*A+Kb*B=1.61		
Not Meeting the Standard Requirement, K≤1.50						

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5.3.2 Floor

Table 5.5

Floor	Thickness (mm)	Thermal Conductivity (W/(m.K))	Coefficient of Thermal Storage (W/(㎡.K))	Thermal Resistance ((㎡.K)/W)	Thermal Inertia Index (D=R.S)	Coefficient of Correction (α)
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Steel Reinforced Concrete	120.00	1.740	17.20	0.07	1.19	1.00
Hollow Glass Bead Inorganic Insulation Mortar	10.00	0.035	1.10	0.260	0.314	1.10
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
The Sum of all Layers	180.0			0.31	1.90	
Floor Thermal Resistance: Ro=Ri+∑R+Ri= 0.593 (㎡.K /W)			Ri= 0.11 (㎡.K/W);Re= 0.11 (㎡.K/W)			
Floor Heat Transfer Coefficient: Kp=1/Ro= 1.686 W/(㎡.K)						

5.3.3 Roof

Table 5.6

Roof	Thickness (mm)	Thermal Conductivity (W/(m.K))	Coefficient of Thermal Storage (W/(㎡.K))	Thermal Resistance ((㎡.K)/W)	Thermal Inertia Index (D=R.S)	Coefficient of Correction (α)
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Water Proof	4	0.27	6.79	0.015	0.101	1.00
Extruded Polystyrene Insulation Board	10.00	0.030	0.301	0.333	0.100	1.00
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Hydrophobic Perlite	30.00	0.140	2.44	0.21	0.52	1.00
Steel Reinforced Concrete	120.00	1.740	17.20	0.07	1.19	1.00
Lime and Cement Mortar	20.00	0.870	10.75	0.02	0.25	1.00
The Sum of all Layers	194.0			0.484	2.124	
Roof Thermal Resistance: Ro=Ri+∑R+Re= 0.634 (㎡.K/W)			Ri= 0.11 (㎡.K/W);Re= 0.04 (㎡.K/W)			
Roof Heat Transfer Coefficient: K=1/Ro= 1.577 W/(㎡.K)						

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5.3.4 Calculation Outcome of Energy Efficiency Design

Table 5.7

Calculation Outcome	The ABH	Reference Building
Annually Cooling-Energy Amount (kWh/㎡)	10.75	9.16
Annually Heating-Energy Amount (kWh/㎡)	7.63	17.99
Total (kWh/㎡)	18.38	26.95

It could be concluded that this building has an annual energy amount of 18.38 (kWh/㎡).

VI. EXPERIMENT, MODIFICATION ON INSULATIONS FOR ENERGY EFFICIENCY IMPROVEMENT, (ABH3)

6.1 Introduction and Project Information

In comparison with last Chapter, this experiment will focus on the thickness of insulation, e.g. on walls it is increased from 10mm to 20mm

6.2 Ratio of Window to Exterior Walls

Table 6.1

Orientation	**Windows (㎡)**	**U value of Windows (W/㎡*k)**	**Exterior Wall (㎡)**	**Ratio of Window to Wall**
East	39.24	1.00	488.50	0.08
South	171.00	1.00	582.97	0.29
West	77.04	1.00	502.58	0.15
North	92.54	1.00	781.90	0.12

6.3 Energy Efficiency Data of Each Component

6.3.1 Exterior Wall
Main Part of Wall

Table 6.2

Exterior Wall	Thickness (mm)	Thermal Conductivity (W/(m.K))	Coefficient of Thermal Storage (W/(㎡.K))	Thermal Resistance ((㎡.K)/W)	Thermal Inertia Index (D=R.S)	Coefficient of Correction (α)
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Hollow Glass Bead Inorganic Insulation Mortar	20.00	0.035	1.10	0.519	0.629	1.10
Concrete Brick Wall	200	0.790	8.338	0.253	2.111	1.00
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00

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The Sum of all Layers	260			0.816	3.230	
Wall Thermal Resistance: Ro=Ri+∑R+Re=0.966 (m^2.K/W)				Ri= 0.11 (m^2.K/W);Re= 0.04 (m^2.K/W)		
Wall Heat Transfer Coefficient: Kp=1/Ro= 1.035 W/(m^2.K)						
Solar Radiation Absorbility Factor: ρ=0.50						

Exterior Wall Thermal Bridge Calculation

Table 6.3

Thermal Bridge Column	Thickness (mm)	Thermal Conductivity (W/(m.K))	Coefficient of Thermal Storage (W/(m^2.K))	Thermal Resistance ((m^2.K)/W)	Thermal Inertia Index (D=R.S)	Coefficient of Correction(α)
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Hollow Glass Bead Inorganic Insulation Mortar	20.00	0.035	1.10	0.519	0.629	1.10
Concrete Brick Wall	200	0.790	8.338	0.253	2.111	1.00
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
The Sum of all Layers	300.00			1.717	4.353	
Wall Thermal Resistance: Ro=Ri+∑R+Re=1.867 (m^2.K/W)				Ri= 0.11 (m^2.K/W);Re= 0.04(m^2.K/W)		
Wall Heat Transfer Coefficient: Kp=1/Ro=0.536 W/(m^2.K)						

Heat Transfer Cofficient of Exterior Wall in Average

Table 6.4

Use Parts	Main Wall (Not Including Windows)	Thermal Bridge Parts				
		Columns	Beams	Sub Beams	Interior Floors	
Coefficient of Thermal Storage (W/(m^2.K))	1.29	1.21	1.21	1.21	1.28	1.00
Percentage (%)	67.22	32.18				
Km [W/(m^2.K)]				Km=Kp*A+Kb*B=1.13		
Meeting the Standard Requirement, K≤1.50						

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6.3.2 Floor

Table 6.5

Floor	Thickness (mm)	Thermal Conductivity (W/(m.K))	Coefficient of Thermal Storage (W/(m^2.K))	Thermal Resistance ((m^2.K)/W)	Thermal Inertia Index (D=R.S)	Coefficient of Correction (α)
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Steel Reinforced Concrete	120.00	1.740	17.20	0.07	1.19	1.00
Hollow Glass Bead Inorganic Insulation Mortar	20.00	0.035	1.10	0.519	0.629	1.10
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
The Sum of all Layers	180			1.671	3.562	
Floor Thermal Resistance: Ro=Ri+∑R+Ri= 0.852 (m^2. K/W)				Ri= 0.11 (m2.K/W);Re= 0.11 (m^2.K/W)		
Floor Heat Transfer Coefficient: Kp=1/Ro= 1.174 W/(m^2.K)						

6.3.3 Roof

Table 6.6

Roof	Thickness (mm)	Thermal Conductivity (W/(m.K))	Coefficient o f Thermal St orage (W/(m2.K))	Thermal Resistance ((m2.K)/W)	Thermal I nertia Index (D=R.S)	Coefficient o f Correction (α)
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Water Proof	4	0.27	6.79	0.015	0.101	1.00
Extruded Polystyrene Insulation Board	20.00	0.030	0.301	0.667	0.201	1.00
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Hydrophobic P erlite	30.00	0.140	2.44	0.21	0.52	1.00
Steel Reinforced Concrete	120.00	1.740	17.20	0.07	1.19	1.00
Lime and Cement Mortar	20.00	0.870	10.75	0.02	0.25	1.00
The Sum of all Layers	204.0			0.818	2.225	
Roof Thermal Resistance: Ro=Ri+∑R+Re= 0.968 (m^2. K/W)				Ri= 0.11 (m2.K/W);Re= 0.04 (m^2.K/W)		
Roof Heat Transfer Coefficient: K=1/Ro= 1.033 W/(m^2.K)						

6.3.4 Calculation Outcome of Energy Efficiency Design

Table 6.7

Calculation Outcome	The ABH	Reference Building
Annually Cooling-Energy Amount (kWh/㎡)	10.80	9.50
Annually Heating-Energy Amount (kWh/㎡)	4.36	16.79
Total (kWh/㎡)	15.16	26.29

It could be concluded that this building has an annual energy amount of 15.16 (kWh/㎡).

VII. EXPERIMENT, MODIFICATION ON COMPONENTS FOR ENERGY EFFICIENCY IMPROVEMENT, INSULATIONS (ABH4)

7.1 Introduction

In comparison with Chapter 5, this experiment will focus on the thickness of insulation, it is increased by 4 times (40mm).

7.2 Ratio of Window to Exterior Walls

Table 7.1

Orientation	**Windows (㎡)**	**U value of Windows (W/㎡*k)**	**Exterior Wall(㎡)**	**Ratio of Window to Wall**
East	39.24	1.00	488.50	0.08
South	171.00	1.00	582.97	0.29
West	77.04	1.00	502.58	0.15
North	92.54	1.00	781.90	0.12

7.3 Energy Efficiency Data of Each Component

7.3.1 Exterior Wall
Main Part of Wall

Table 7.2

Exterior Wall	Thickness (mm)	Thermal Conductivity (W/(m.K))	Coefficient of Thermal Storage (W/(㎡.K))	Thermal Resistance ((㎡.K)/W)	Thermal Inertia Index (D=R.S)	Coefficient of Correction (α)
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Hollow Glass Bead Inorganic Insulation Mortar	40.00	0.035	1.10	1.039	1.257	1.30
Concrete Brick Wall	200	0.790	8.338	0.253	2.111	1.00

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Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
The Sum of all Layers	280			1.336	3.858	
Wall Thermal Resistance: Ro=Ri+∑R+Re=1.468 (m^2.K/W)				Ri= 0.11 (m2.K/W);Re= 0.04 (m^2.K/W)		
Wall Heat Transfer Coefficient: Kp=1/Ro= 0.673 W/(m^2.K)						
Solar Radiation Absorbility Factor: ρ=0.50						

Exterior Wall Thermal Bridge Calculation

Table 7.3

Thermal Bridge Column	Thickness(mm)	Thermal Conductivity (W/(m.K))	Coefficient of Thermal Storage (W/(m^2.K))	Thermal Resistance ((m^2.K)/W)	Thermal Inertia Index (D=R.S)	Coefficient of Correction (α)
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Insulation Mortar	40.00	0.035	1.1	1.039	1.257	1.00
Concrete Brick Wall	200	0.790	8.338	0.253	2.111	1.00
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
The Sum of all Layers	280			1.198	3.724	
Wall Thermal Resistance: Ro=Ri+∑R+Re=1.348 (m^2.K/W)				Ri= 0.11 (m^2.K/W);Re= 0.04(m^2.K/W)		
Wall Heat Transfer Coefficient: Kp=1/Ro=0.742 W/(m^2.K)						

Heat Transfer Cofficient of Exterior Wall in Average

Table 7.4

Use Parts	Main Wall (Not Including Windows)	Thermal Bridge Parts				
		Columns	Beams	Sub Beams	Interior Floors	
Coefficient of Thermal Storage (W/(m^2.K))	0.69	0.74	0.74	0.74	0.77	1.00
Percentage (%)	67.22	32.18				
Km [W/(m^2.K)]				Km=Kp*A+Kb*B=71		
Meeting the Standard Requirement, K≤1.50						

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7.3.2 Floor

Table 7.5

Floor	Thickness (mm)	Thermal Conductivity (W/(m.K))	Coefficient of Thermal Storage (W/(㎡.K))	Thermal Resistance((㎡.K)/W)	Thermal I nertia Index (D=R.S)	Coefficient o f Correction (α)
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Steel Reinforced Concrete	120.00	1.740	17.20	0.07	1.19	1.00
Hollow Glass Bead Inorganic Insulation Mortar	40.00	0.035	1.10	1.039	1.257	1.10
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
The Sum of all Layers	200.00			1.152	2.933	
Floor Thermal Resistance: Ro=Ri+∑R+Ri= 1.37 (㎡.K/W)				Ri= 0.11 (m2.K/W);Re= 0.11 (㎡.K/W)		
Floor Heat Transfer Coefficient: Kp=1/Ro= 0.725 W/(㎡.K)						

7.3.3 Roof

Table 7.6

Roof	Thickness (mm)	Thermal Conductivity (W/(m.K))	Coefficient of Thermal Storage (W/(㎡.K))	Thermal Resistance ((㎡.K)/W)	Thermal I nertia Index (D=R.S)	Coefficient o f Correction (α)
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Water Proof	4	0.27	6.79	0.015	0.101	1.00
Extruded Polystyrene Insulation Board	40.00	0.030	0.301	1.333	0.401	1.00
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Hydrophobic Pe rlite	30.00	0.140	2.44	0.21	0.52	1.00
Steel Reinforced Concrete	120.00	1.740	17.20	0.07	1.19	1.00
Lime and Cement Mortar	20.00	0.870	10.75	0.02	0.25	1.00
The Sum of all Layers	224.0			1.484	2.425	
Roof Thermal Resistance: Ro=Ri+∑R+Re= 1.634 (㎡. K/W)				Ri= 0.11 (m2.K/W);Re= 0.04 (㎡.K/W)		
Roof Heat Transfer Coefficient: K=1/Ro= 0.612 W/(㎡.K)						

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7.3.4 Calculation Outcome of Energy Efficiency Design

Table 7.7

Calculation Outcome	The ABH	Reference Building
Annually Cooling-Energy Amount (kWh/㎡)	11.59	9.77
Annually Heating-Energy Amount (kWh/㎡)	1.98	16.11
Total (kWh/㎡)	13.57	25.88

VIII. EXPERIMENT, MODIFICATION ON COMPONENTS FOR ENERGY EFFICIENCY IMPROVEMENT, INSULATIONS

8.1 Introduction

In comparison with last Chapter, this experiment will focus on the thickness of insulation, it is increased by 4 times (60mm).

8.2 Ratio of Window to Exterior Wall

Table 8.1

Orientation	**Windows (㎡)**	**U value of Windows (W/㎡*k)**	**Exterior Wall (㎡)**	**Ratio of Window to Wall**
East	39.24	1.00	488.50	0.08
South	171.00	1.00	582.97	0.29
West	77.04	1.00	502.58	0.15
North	92.54	1.00	781.90	0.12

8.3 Energy Efficiency Data of Each Component

8.3.1 Exterior Wall
Main Part of Wall

Table 8.2

Exterior Wall	Thickness (mm)	Thermal Conductivity (W/(m.K))	Coefficient of Thermal Storage (W/(㎡.K))	Thermal Resistance ((㎡.K)/W)	Thermal Inertia Index (D=R.S)	Coefficient of Correction (α)
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Hollow Glass Bead Inorganic Insulation Mortar	60.00	0.035	1.10	1.588	1.886	1.10
Concrete Brick Wall	200	0.790	8.338	0.253	2.111	1.00

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Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
The Sum of all Layers	300			1.855	4.487	
Wall Thermal Resistance: Ro=Ri+∑R+Re=2.005(m².K/W)			Ri= 0.11 (m².K/W);Re= 0.04 (m².K/W)			
Wall Heat Transfer Coefficient: Kp=1/Ro= 0.499 W/(m².K)						
Solar Radiation Absorbility Factor: ρ=0.50						

Exterior Wall Thermal Bridge Calculation

Table 8.3

Thermal Bridge Column	Thickness(mm)	Thermal Conductivity (W/(m.K))	Coefficient of Thermal Storage (W/(m².K))	Thermal Resistance ((m².K)/W)	Thermal Inertia Index (D=R.S)	Coefficient of Correction (α)
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Hollow Glass Bead Inorganic Insulation Mortar	60.00	0.035	1.10	1.588	1.886	1.10
Concrete Brick Wall	200	0.790	8.338	0.253	2.111	1.00
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
The Sum of all Layers	300.00			1.717	4.353	
Wall Thermal Resistance: Ro=Ri+∑R+Re=1.867 (m².K/W)				Ri= 0.11 (m².K/W);Re= 0.04(m².K/W)		
Wall Heat Transfer Coefficient: Kp=1/Ro=0.536 W/(m².K)						

Heat Transfer Cofficient of Exterior Wall in Average

Table 8.4

Use Parts	Main Wall (Not Including Windows)	Thermal Bridge Parts				
		Columns	Beams	Sub Beams	Interior Floors	
Coefficient of Thermal Storage (W/(m².K))	0.51	0.54	0.54	0.54	0.55	1.00
Percentage (%)	67.22	32.18				
Km [W/(m².K)]				Km=Kp*A+Kb*B=0.52		
Meeting the Standard Requirement, K≤1.50						

It could be concluded that this building has an annual energy amount of 13.57 (kWh/m²).

8.3.2 Floor

Table 8.5

Floor	Thickness (mm)	Thermal Conductivity (W/(m.K))	Coefficient of Thermal Storage (W/(m^2.K))	Thermal Resistance ((m^2.K)/W)	Thermal Inertia Index (D=R.S)	Coefficient of Correction (α)
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Steel Reinforced Concrete	120.00	1.740	17.20	0.07	1.19	1.00
Hollow Glass Bead Inorganic Insulation Mortar	60.00	0.035	1.10	1.588	1.886	1.10
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
The Sum of all Layers	220.00			1.671	3.562	
Floor Thermal Resistance: Ro=Ri+∑R+Ri= 1.981 (m^2.K/W)				Ri= 0.11 (m2.K/W);Re= 0.11 (m^2.K/W)		
Floor Heat Transfer Coefficient: Kp=1/Ro= 0.529 W/(m^2.K)						

8.3.3 Roof

Table 8.6

Roof	Thickness (mm)	Thermal Conductivity (W/(m.K))	Coefficient of Thermal Storage (W/(m^2.K))	Thermal Resistance ((m^2.K)/W)	Thermal Inertia Index (D=R.S)	Coefficient of Correction (α)
Gravel Concrete	40.00	1.510	15.36	0.03	0.41	1.00
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
SBS Water Proof	6.00	0.230	225.00	0.03	5.87	1.00
Extruded Polystyrene Insulation Board	60.00	0.030	0.301	2.000	0.602	1.10
Cement-sand Mortar	20.00	0.930	11.37	0.02	0.24	1.00
Hydrophobic Perlite	30.00	0.140	2.44	0.21	0.52	1.00
Steel Reinforced Concrete	120.00	1.740	17.20	0.07	1.19	1.00
Lime and Cement Mortar	20.00	0.870	10.75	0.02	0.25	1.00
The Sum of all Layers	296.0			2.151	2.626	
Roof Thermal Resistance: Ro=Ri+∑R+Re=2.301 (m^2.K/W)				Ri= 0.115 (m^2.K/W);Re= 0.043 (m^2.K/W)		
Roof Heat Transfer Coefficient: K=1/Ro= 0.435 W/(m^2.K)						
Solar Radiation Absorbility Factor: ρ=0.48						

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8.3.4 Calculation Outcome of Energy Efficiency Design

Table 8.7

Calculation Outcome	The ABH	Reference Building
Annually Cooling-Energy Amount (kWh/㎡)	12.32	9.88
Annually Heating-Energy Amount (kWh/㎡)	1.06	15.74
Total (kWh/㎡)	13.38	25.62

It could be concluded that this building has an annual energy amount of 13.38 (kWh/㎡).

IX. DISCUSSION AND CONCLUSION

Data Comparison of Each Architecture

Table 9.1

Dwellings	**Materials Information**	**The CYR**	**The ABH 1**	**The ABH 2**	**The ABH 3**	**The ABH 4**	**The ABH 5**
Exterior Walls	Insulation Materials	Hollow Glass Bead Inorganic Insulation Mortar	Hollow Glass Bead Inorganic Insulation Mortar	Hollow Glass Bead Inorganic Insulation Mortar	Hollow Glass Bead Inorganic Insulation Mortar	Hollow Glass Bead Inorganic Insulation Mortar	Hollow Glass Bead Inorganic Insulation Mortar
	Material Heat Conductivity Cofficient (W/(m.K))	0.035	0.035	0.035	0.035	0.035	0.035
	Thickness of Materials (mm)	15	10	10	20	40	60
	Component Heat Transfer Cofficient (U-value (W/(㎡.K)))	1.250	1.414	1.414	1.035	0.673	0.499

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Roofs	Insulation Materials	Extruded Polystyrene Insulation Board	Extruded Polystyrene Insulation Board	Extruded Polystyrene Insulation Board	Extruded Polystyrene Insulation Board	Extruded Polystyrene Insulation Board	Extruded Polystyrene Insulation Board
	Material Heat Conductivity Cofficient (W/(m.K))	0.03	0.03	0.03	0.03	0.03	0.03
	Thickness of Materials (mm)	10	10	10	20	40	60
	Component Heat Transfer Cofficient (U-value (W/(㎡.K)))	1.164	1.577	1.577	1.033	0.612	0.435
Floors	Insulation Materials	Hollow Glass Bead Inorganic Insulation Mortar	Hollow Glass Bead Inorganic Insulation Mortar	Hollow Glass Bead Inorganic Insulation Mortar	Hollow Glass Bead Inorganic Insulation Mortar	Hollow Glass Bead Inorganic Insulation Mortar	Hollow Glass Bead Inorganic Insulation Mortar
	Material Heat Conductivity Cofficient (W/(m.K))	0.035	0.035	0.035	0.035	0.035	0.035
	Thickness of Materials (mm)	10	10	10	20	40	60
	Component Heat Transfer Cofficient (U-value (	1.808	1.686	1.686	1.174	0.729	0.529

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	W/(㎡.K)))						
Glazing	Glzing Form	Signle Glazing	Signle Glazing	Triple Glazing	Triple Glazing	Triple Glazing	Triple Glazing
	Heat Transfer Coefficient (W/(㎡.K))	3.1	5.0	1.0	1.0	1.0	1.0
Reference Building	Annually Total	32.07 (kWh /㎡)	27.00(kWh/㎡)	26.95(kWh/㎡)	26.29(kWh/㎡)	25.88(kWh/m2)	25.63(kWh/㎡)
Outcome of Energy Efficiency	Annually Total for this Building	32.04 (kWh /㎡)	22.30(kWh/㎡)	18.38(kWh/㎡)	15.16(kWh/㎡)	13.57(kWh/㎡)	13.38(kWh/㎡)

It is exhibited in the table that the considerable relationship between component U values and the energy loads of buildings.

The CYR and ABH are located in the region with same climate feature. Their energy saving designs follow the same regional standards. Hence they have the similar annual energy load. The slight differences result from the architectural features, such as shape cofficient and building orientation.

The next step of this research work is to experiment the possible measures of architectural renovation for improving energy efficiency. It mainly takes place on the components, roofs, floors, exterior walls, and windows. Each component mentioned above can influence the energy demand amount. While ABH 1 was designed for meeting the energy saving requirement of local standards, the rest ones are improved in various factors, windows or insulations, thus more energy-efficient. In ABH 2, one element is modified, replacing the windows. This building's original U value for windows is 5.00 W/(m2.K). In the experiment, window U value is reduced to 1.00 W/(m2.K). As showing in the energy outcome, it results in a reduction of energy load, decreasing by nearly 4 (kWh/m2). Afterwards, based on the low U value windows, this architecture is further renovated on the solid elements. Insulation layers on each envelope component (wall, floor, and roof) are all doubled. The energy load exhibits another decrease, from about 18 to around 15 (kWh/m2). For better energy efficiency, other methods are experimented as well. With a continuous increase of insulation thickness, annual energy load could be reduced to around 13 (kWh/m2). Yet more thicker insulation does not affect the energy load anymore. The least energy load for the building would be around 13 (kWh/m2). Data results from the experiments illustrate that the U value of fabrics are closely linked with the energy need quantity of buildings. Windows and insulations can respectively affect the building energy load independently. This series of experiments show that renovating envelope elements is able to achieve an energy saving of 40% in comparison with regional-standard level theoretically. It illustrates that advancing the effect of envelope insulation is a prospective method for improving energy efficiency architecturally.

In accordance with the experimental outcomes the renovation methods for energy efficiency improvement could be concluded as follows:

Increasing the thickness of insulation. As the original insulations on the experiment residential are covered by solid furnish layers, there is little possibility to use another insulation material to replace the original ones. It could place an extra layer of insulation on the surface of original solid wall with another protector above for fixing. As to the increase level of total thickness of wall, preventing negative effects on the function of spaces need to be considered. It means that the added layers cannot be too thick to affect the original rooms.

Using higher quality and better insulated insulation. As being limited by the dimension of interior spaces of buildings, the addional insulation layers cannot be too thick. Another kind of insulation material that without occupating too much functional space (low U value) could be considered for suitably using.
Replacement of Windows. It is obviously shown in the table, the decrease of U value for windows are functional in energy load decline independently. A certain proportion of heat loss is caused by the poor insulation effect of single-glazing windows. They could be replaced by double or triple glazing ones for being better insulated.

The yearly energy loads (kWh/m2) from ABH 1 (22.3) to ABH 5 (13.38) fall gradually. But the figures of ABH 4 (13.57) and ABH 5 are very close, althrough their insulation thicknesses are dramatically different. It exhibits that it has reaches the top level of energy efficiency through improving insulation effect in this object. It illustrates that the enhancement of insulation effect on architectural envelope can result in an energy saving by 40% at most in this project. Contribution of energy saving due to building insulation improvement is doubtless, for it decreases approximately half of energy needs on original level. Nevertheless, in contrast with the goal of shrinking by 80% in 2050, it is too little. There is necessity to explore some other methods for further energy demand reduction, so that it is necessary to find out other elements that cause the architecturally high-energy load and avoid them. In fact, there are still other aspects that affect the energy loads in this building, the measures on renovation for approaching higher energy efficiency would be based on them. In modern world, selecting low-energy appliances has been a key in sustainable design. In developed countries, standards of appliance energy efficiency for new constructions has been stricted on codes. All housings in the BRE Park, for instance, are installed in white goods or energy efficient appliances. The advanced appliances that are more sensitive in energy consumption are capable to decline around 50% of power amount being contrasted with ordinary-facility degree. Some existing buildings have utilised these appliances to replace their original ones. It can achieve a certain proportion of energy efficiency improvement. The renovation work on the ABH and other similar residentials could approach another descent of energy load if this measure can be implemented experimentally. It illustrates the nice prospect of architectural renovation in future.

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