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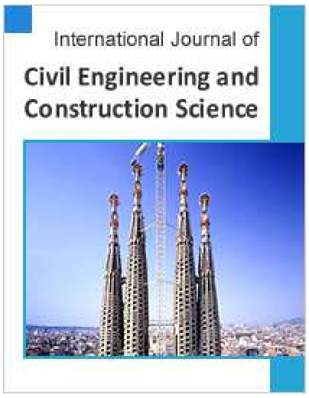

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The Economic Benefits Analysis on Rural Energy-Saving Housing of Northern China-A Case Study of Woniuhe New Rural Construction, Zhalantun City, China

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Abstract
The construction of rural houses in severe cold regions is mainly the personal way with self-raised and self-built, lacking of the professional design and guidance. Survey shows that villagers pay more attention to the construction cost, resulting in the energy conservation measures rarely applied in the new houses or existing buildings reform because of the additional investment and the building heating consumption increased significantly. This paper aims to investigate the economic benefits of Woniuhe new rural house, which applied several energy saving measures in terms of building shape, functional layout and envelop structure. On the basis of calculating the energy saving house's additional investment and saving cost for heating, the method of dynamic economic analysis was adopted to calculate the dynamic payback period under different growth rate of energy price and energy saving rate in life cycle, It turn out that energy-saving house has well economic benefit in the long turn, and the additional investment can be withdrawn in about eight years. Meanwhile, the field measurement was used to verify the advantages of energy saving house in the indoor thermal environment, the results shows that in winter the energy saving house presents high temperature, in the bedroom about 4-5°C higher than traditional house, and the internal surface temperature of exterior walls and ceiling is always higher than the dew point temperature.

1. Introduction

In recent years, the construction amounts of rural houses in China increased rapidly. The areas of rural houses are about 230 hundred million square meters in the year of 2010, accounting for about 50% of the total construction areas of China [1]. Due to the limits in the climatic environment, conditions of resource and energy, economic development level, construction technique and production & living habits of rural areas, although the living conditions have been improved dramatically, led to the rural houses increase the consumption of resources and energy. Survey shows that China has get lots of achievement in the aspect of building energy efficiency, but have not been well popularized in the construction of rural houses, where the construction model still adopts the traditional methods. As shown in figure1, taking exterior wall for example, more than 94% were 370 mm or 490 mm solid clay brick wall and rarely adopted the heat preservation measures. The main cause of this problem is restricted by economic factor, because energy-saving houses will increase the initial investment comparing to traditional houses, while the further economic benefits are unclear. However, the current studies about economic benefits of building energy efficiency or renovation mainly focus on the public buildings[2], urban residential buildings[3,4], upgrading the heating equipment[5,6] and have obvious regional[7,8], lacking of attention to the research of economic benefices for rural energy-saving houses in Northern China.

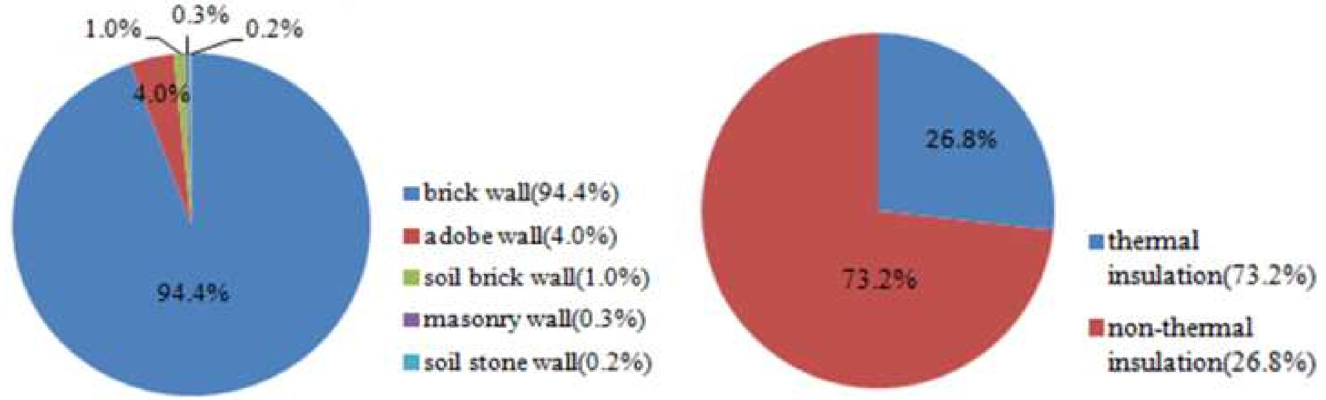

Figure 1. *Wall types and heat preservation conditions.*

This paper, taking Woniuhe new rural energy-saving house designed by ourselves as an example, applies the method of dynamic economic analysis to calculate the dynamic payback period of energy-saving house in life cycle. This study mainly considers the cost of construction and operation period, assuming that during the operation period there is no need to maintain and the insulation materials have no recovery value. Through the analysis, it can make the villagers understand the income from investment, and enhance the agreement on the construction of energy-saving house, so as to promote the energy saving technologies' popularization and application in the new village construction.

2. Methods

Considering the time value, the dynamic economic analysis will bring the entire life cycle of project into analysis scope. The net present value method was selected to analysis and assessment. This method can evaluate the capacity of energy saving benefit of whole life cycle, which builds the net cash flow present value and the cumulative net cash flow present value (net present value) models of energy-saving house under considering the comprehensive influence of energy price, discount rate and actual energy saving rate etc [9]. The calculation models as shown in formula (1) and formula (2).

Using NPVt represents the net cash flow present value of saving cost for reducing energy consumption every year of energy-saving house.

$$NPVt=\alpha \triangle C\ (F/P,\ \eta,\ n)\ (P/F,\ i,\ n) \quad (1)$$

Using NPV represents the cumulative net cash flow present value (net present value) of difference value by saving cost deducting the additional investment of energy-saving house.

$$NPV=\sum_{n=0}^{n} \alpha\triangle C\ (F/P,\ \eta,\ n)\ (P/F,\ i,\ n)-\gamma\ C_o \quad (2)$$

Based on the net present value, calculating the dynamic investment pay-back period of energy-saving house, it indicates the time that economic benefits of energy efficiency compensate for the additional investment during the operation period, which is the year of NPV≥0. After the time, the project will be in a state of earnings. This index is an important parameter for the financial evaluation of construction project [10].

$$P_t=m-1+\frac{|NPVt(m-1)|}{NPVm} \quad (3)$$

Where (F/P, η, n) = $(1+\eta)^n$ is one-time payment final value coefficient, η is the escalation rate of energy prices; (P/F, i, n) = $(1+i)^{-n}$ is the discount coefficient, i is the discount rate; n is the whole life cycle; α is the real energy-saving rate; △C is the difference value of energy cost during operation period between energy-saving house and traditional house; γ is the change rate of construction cost; C_o is the additional investment of energy-saving house; m is the year of NPV≥0; t is the operation time.

3. Discuss and Results

3.1. Energy-Saving House Design

Zhalantun belongs to the continental semi-arid climate region with the features of long and cold in winter, short and cool in summer, the average temperature of the coldest month is -17.0°C, and the extreme cold temperature is -39.5°C. The bad weather conditions result in the region's houses has the characteristic of high energy consumption and low comfort in winter. As shown in Figure 2, new rural energy-saving house is the detached building with an area of 122.48m^2 and interior ceiling heights of 2.8m, which adopts several energy-saving measures in terms of the building shape, functional layout and envelop structure etc.

(1) Building shape. To reduce the shape coefficient,

building plane is designed as the shape of close to square. The shape coefficient of energy-saving house is 0.74, reducing 20% compared to the traditional house.

(2) Functional layout. As shown in Figure 2, according to the request for thermal environment of different rooms, the house is divided into two main areas: major functional areas——the frequently used and require high indoor temperature——such as the bedroom, living room, etc., are arranged in the south; the store room, north hall and other auxiliary space are arranged in the north to function as a "temperature buffer" to avoid cold air infiltration effects on the main functional areas.

(3) Envelop structure. As shown in figure 3, considering the intermittent heating of rural house and villager's living habit, the composite insulation form is used in the exterior wall, with 100mm EPS insulation layer in it. The roof is wooden frame with 150mm EPS insulation layer on the ceiling. The plastic steel window with single frame triplex glass is adopted in the south room, while the north room having the plastic steel window with double frame double glass, so as to enhance the thermal insulation properties. In order to make a contrastive analysis, the commonly used materials of traditional house's envelop are selected as reference, as shown in Table 1.

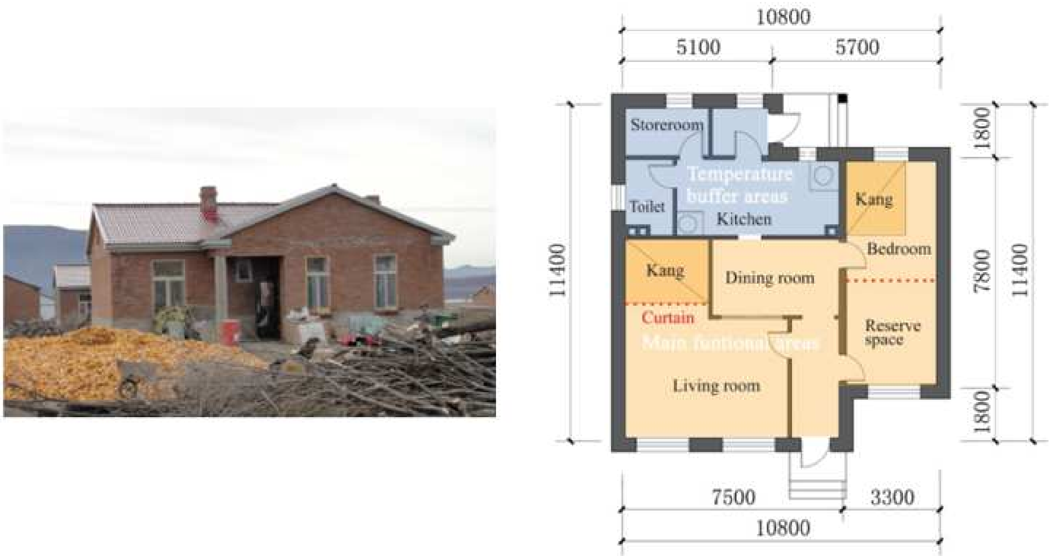

Figure 2. *The appearance and plane of new rural energy-saving house*[11].

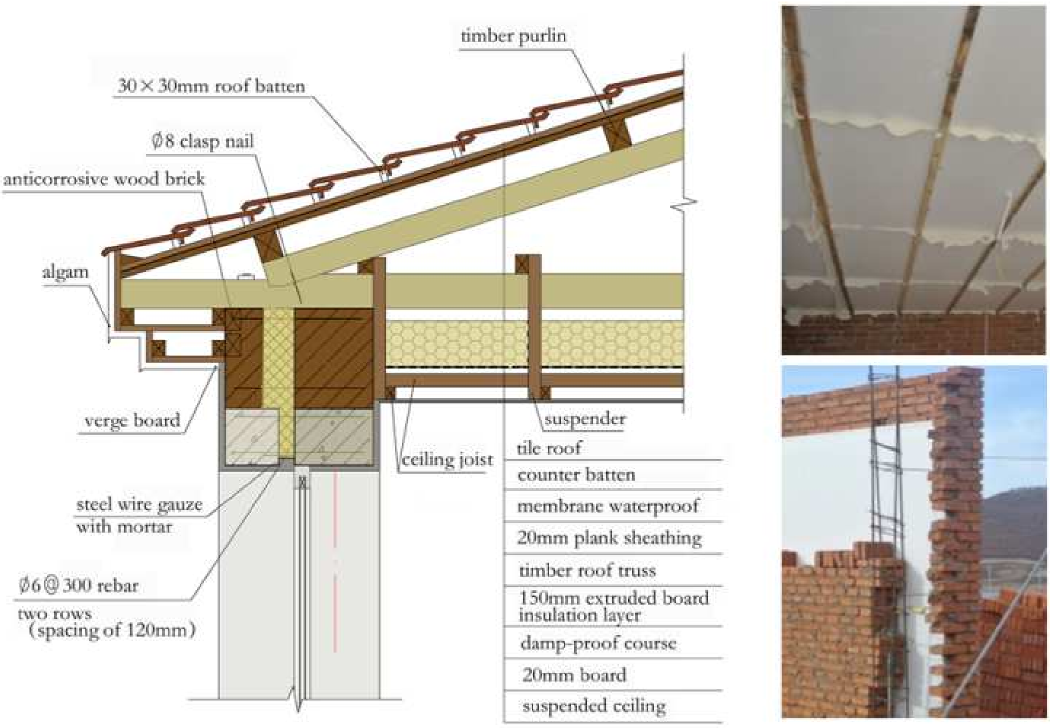

Figure 3. *Exterior wall and roof construction of energy-saving house*[11].

Table 1. *Building envelop structure and materials of energy-saving house and traditional house.*

Building envelops	Traditional house	Heat transfer coefficient W/(m²·K)	Energy-saving house	Heat transfer coefficient W/(m²·K)
Exterior wall	370mm brick wall	1.55	120mm brick wall +100mm EPS board +240mm brick wall	0.38
Exterior window	Double wooden window	2.30	Double single frame double glass plastic-steel window	1.46
Exterior door	Double wooden door	2.33	Metal insulation and security door	1.70
Roof	Ceiling+100mm plant ash (on the roof truss lower chord) +wooden frame+ tiled roof	0.93	Ceiling+150mm EPS board+ wooden frame + tiled roof	0.35

3.2. The Analysis of Additional Investment

The heat preservation materials and energy saving windows & doors are applied in the energy-saving house will increase the invest cost of building materials. This paper aims to analyze the payback period of additional investment, while the building envelops structure of energy-saving house and traditional house are same in some aspects. So it does not need to calculate the absolute construction cost of the whole house, only need to calculate the investment difference of exterior wall, roof, exterior window and door. The price of building materials refer to the local market prices, combining the Table 1 and building construction drawing, the additional investment of energy-saving house is calculated as shown in Table 2. Compared to the traditional house, the energy-saving house will increase ¥ 12711.3 in initial investment, and unclear the rate of return, thus degrading villages' agreement on the energy-saving house.

Table 2. *The additional investment of energy-saving house.*

Building envelops	Areas	Additional investment
Exterior wall	102.9m^2	¥ 3087.0
Exterior window	17.22 m^2	¥ 4305.0
Exterior door	4.20 m^2	¥ 1050.0
Roof	101.65 m^2	¥ 4574.25
Total	——	¥ 13016.25

3.3. The Calculation of Operation Benefits

Compared with the traditional house, the energy-saving house can obviously reduce the building energy consumption during the operation, due to the adaptation of energy saving and efficient heat preservation materials, thus saving the cost of energy consumption. In Northern China, the winter heating period is about half a year, and the house is given priority to natural ventilation in summer, almost not using the cooling equipment, so the energy-saving benefits mainly come from the saving of energy consumption for heating.

Applying ENERGYPLUS software to simulate the heating energy consumption of energy-saving house and traditional house, selecting the typical meteorological year of Zhalantun as the boundary conditions, the simulation time is set from 20 October to the next year 20 April, that is the whole heating period in winter, and the indoor temperature is set as 16℃, air changes is 0.5 h^{-1}. The heat dissipation of indoor equipments, human body clothing & metabolism and solar radiation are in line with the actual situation to set. As shown in table 3, the energy consumption of 20182.32kWh can be reduced every year of energy-saving house, energy efficient rate reaches to 68.7%. Converting into the standard coal to calculate, taking 0.7 as the average operation efficiency of heating equipment, the heating costs of ¥ 1735.58 can be saved.

Table 3. *Operating earnings of energy-saving house.*

Type	Heating energy Consumption (kWh)	Convert into standard coal (kg)	Coal price (¥/ton)	Energy consumption cost (¥/year)
Traditional house	29377.66	3609.05	600	3093.47
Energy-saving house	9195.34	1129.65	600	968.27
Energy saving benefits	20182.32	2478.40	——	2125.2

3.4. The Calculation of Dynamic Payback Period

Formula (1), formula (2) and formula (3) are adopted to calculate the dynamic payback period of energy-saving house. Refer to the existing research results, assuming the actual energy efficient rate α of energy-saving house is 100%, but in the process of actual operation, the energy efficient rate might be changed because of the different heating mode and time, so fluctuate 20% namely α=80% and α=120% are also calculated. The discount i set as 6% [12]. The growth rate of energy prices η for two cases that is η=0% and η=7% to calculate [9]. Because of the construction period much shorter than the operation period, the cost nearly no change, so the variable rate of cost γ set as 100%. The calculated results are shown in Table 4 and Table 5.

As shown in Tab.4, when the growth rate of energy prices η=0%, the dynamic payback period of energy-saving house is 8 years, that is the additional investment of construction can be withdrawn in 8 years, NPV=0; when the growth rate of energy prices η=7%, the additional investment can be withdrawn in 7.2 years. As shown in Tab.5, when the growth rate of energy prices η=7%, the energy saving rate α=80%, the additional investment need 9.6 years to be withdrawn; when the energy saving rate α=80%, the dynamic payback period greatly cut down, 5.8 years can be withdrawn. After the payback period, the house will be in a state of earnings.

Table 4. *The dynamic payback period of energy-saving house（α=100%）.*

Operation time (year)	γ=100%，i=6%，η=0，α=100%		γ=100%，i=6%，η=7%，α=100%	
	the net cash flow present value every year (¥)	the cumulative net cash flow present value (¥)	the net cash flow present value every year (¥)	the cumulative net cash flow present value (¥)
1	2004.9	-11011.3	2145.2	-10871.0
2	1891.4	-9119.9	2023.8	-8847.2
3	1784.4	-7335.6	1909.3	-6937.9
4	1683.4	-5652.2	1801.2	-5136.7
5	1588.1	-4064.1	1699.2	-3437.5
6	1498.2	-2566.0	1603.1	-1834.4
7	1413.4	-1152.6	1512.3	-322.1
8	1333.4	180.8	1426.7	1104.6
Dynamic Payback period	8.0 years		7.2 years	

Table 5. *The dynamic payback period of energy-saving house (α=80% and α=120%）.*

Operation time (year)	γ=100%，i=6%，η=7%，α=80%		γ=100%，i=6%，η=7%，α=120%	
	the net cash flow present value every year(¥)	the cumulative net cash flow present value(¥)	the net cash flow present value every year(¥)	the cumulative net cash flow present value(¥)
1	1716.2	-11300.1	2574.3	-10442.0
2	1619.1	-9681.0	2428.6	-8013.4
3	1527.4	-8153.6	2291.1	-5722.3
4	1441.0	-6712.6	2161.4	-3560.8
5	1359.4	-5353.2	2039.1	-1521.7
6	1282.4	-4070.8	1923.7	401.9
7	1209.9	-2860.9		
8	1141.4	-1719.6		
9	1076.8	-642.8		
10	1015.8	373.0		
Dynamic Payback period	9.6 years		5.8 years	

3.5. The Analysis of Indoor Thermal Environment

Beside the economic benefits, the indoor thermal environment of energy-saving house also has great improvement. In January 2015, the indoor thermal environment of both energy-saving house and traditional house has been synchronization tested by the research group. The field measurement shows that although the outdoor temperature is very low in winter, the indoor temperature of energy saving house still be able to remain in a comfortable range, as shown in figure 4, the bedroom's temperature is obviously better than the traditional house, about 4-5°C higher in average. This is accordance with the subjective survey result. The villagers generally reflect that the indoor environment is more stable and comfortable than the traditional house.

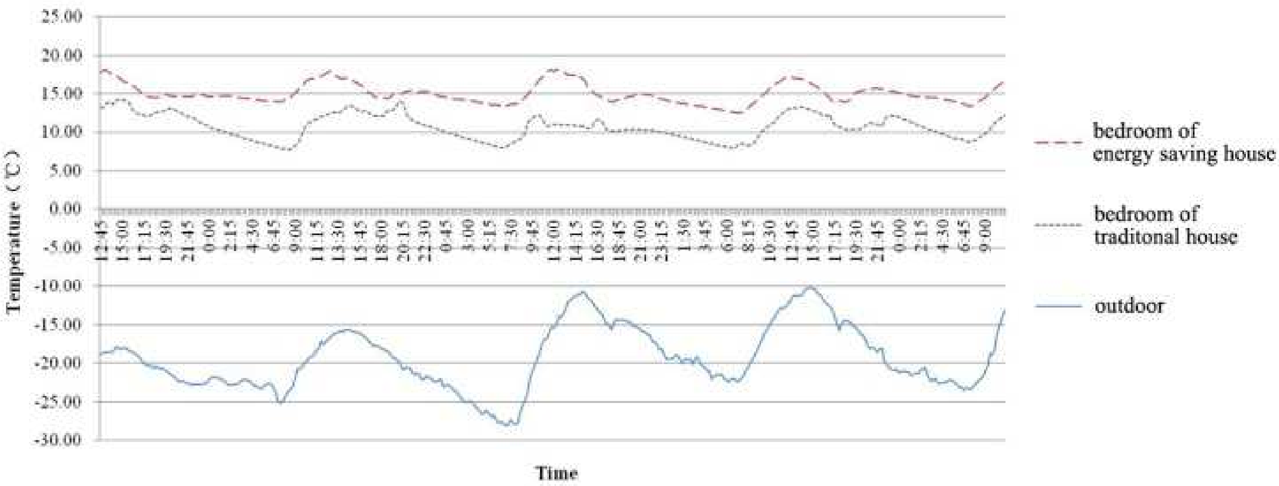

Figure 4. *The bedroom temperature of energy-saving house and traditional house.*

In addition, the internal surface temperature of envelope is also an important index of evaluating the indoor thermal environment. As shown in Figure 5, the internal surface temperature of exterior wall and ceiling of energy-saving house is always higher than the dew point temperature and has little difference with the indoor temperature, so there is neither moisture condensation nor cold radiation in winter.

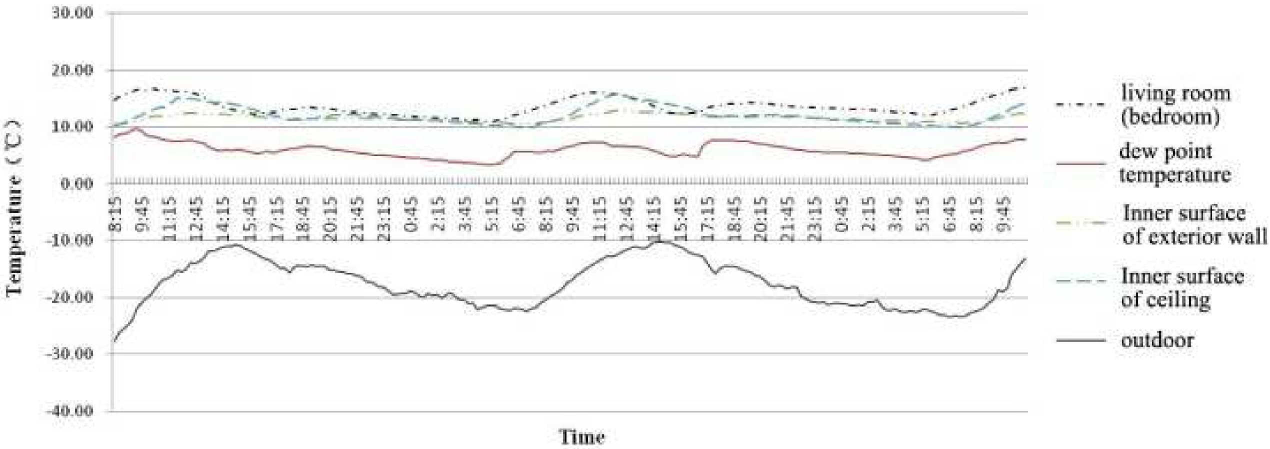

Figure 5. *The inner surface temperature of envelope.*

In addition, the energy-saving house also can reduce the carbon emission at the same time of decreasing energy consumption and improving indoor thermal environment. Therefore, the energy-saving house has good economic and environmental benefits from the view of whole life cycle.

4. Conclusions

Through the contrastive analysis on energy-saving house and traditional house, it can be seen that although the energy-saving house will increase the initial investment, the additional investment can be withdrawn in 8 years of whole life cycle when the growth rate of energy price is 0% and the energy saving rate is 100%. Meanwhile the energy-saving house has good indoor thermal environment which can meet the villagers' requirements. The new rural energy-saving house has promising prospect in popularization and application.

Acknowledgement

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