A Brief Investigation on the Add-on Slope Roofs of Residential Buildings in the Ningqiang Region

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Abstract. Ningqiang region in the south Shaanxi province of China belongs to the hot in summer and cold in winter climate zone. It was interesting to find out that, in recent years, many of residential buildings in this region had built slope roofs on top of their existing flat roofs. This paper introduces a brief investigation on this phenomenon. The background reasons for the construction of the add-on slope roofs are explored, comparison and suggestions for the selection of materials, structures and slopes of such roofs are provided.

Background

Roofs are important component of buildings, which can facilitate sun shading, rainwater protection ventilation, and many other functions. The forms of building roofs have significant influence on the energy consumption and indoor thermal comfort of buildings.

It was interesting to find out that, in recent years, many of the residential buildings in the rural areas of Ningqiang region in the Shaanxi province of China had built slope roofs on top of flat roofs of their houses. A brief investigation was conducted to reveal the background reasons of this phenomenon, as well as to compare or optimize the alternative materials, structures and slopes of such roofs in this region.

Field Investigation

Ningqiang region locates in the south Shaanxi province of China and belongs to the hot in summer and cold in winter climate zone. The traditional houses in this region usually have large double slope roofs. Contemporary local houses are mostly built with flat roofs. In the recent 10-20 years, slope roofs are added on top of the existing or newly built flat roofs (Fig.1). Such slope roofs are addressed as add-on slope roofs in this paper.

A filed investigation (including building survey and face-to-face interviews) was conducted targeting the add-on slope roofs in the Ningqiang region between September 2016 and July 2017. The results show the following:

Main Reasons for Building of the Add-on Slop Roofs. Ningqiang is a region with quite a lot of heavy rains, especially in the summertime, comparing to the flat ones, slop roofs are better for rapid
drainage of rainwater. Ningqiang is hot in summer, add-on roofs can provide sun shading for the underneath flat roofs; at the same time, ventilation in the space between the two roof layers also helps to cool the underneath space.

**Forms, Materials and Structures of the Add-on Slope Roofs.** There are a variety of forms, materials and structures of the add-on slope roofs. The falling gradient of the slope roofs are also different. Roof materials vary among clay tiles, glazed tiles and color plate tiles, etc. The load-bearing systems vary among brick walls, timber frames, steel frames, and a combination of different structures.

![Figure 2. A variety of heights of the add-on slope roofs.](image)

**Considerations of Local Households.** Local households have very different basis and starting point considering the roofs of their houses. Some first consider the cost and economy of the roof, while others start off with the usage of the under-roof space. There are a variety of the heights of the add-on slope roofs and the heights are mainly depend on whether the family want to use the under-roof space or not (Fig 2. If no, they may be very low; otherwise, they can be quite high. The envelop of the under-roof space are usually simple, some even completely open. The under-roof spaces are commonly used for drying and storing in this region.

**Optimization of the Add-on Slope Roofs**

Based on results of the above brief investigation, combining with considerations about local specific conditions, like climate, economic and users’ habits, etc., following of this paper explores how the materials, bearing systems and falling gradient of the add-on slope roofs may be selected.

**Selection of Roof Materials.** A variety of roof materials are available in the market place in China, including clay tiles, cement tiles, asphalt tiles, colored steel tiles and synthetic resin tiles, etc.

![Figure 3. Chinese style clay tile.](image) ![Figure 4. Some colors of the cement tiles.](image)

The Chinese style clay tile, also called Xiaoqing tile or Yin-yang title, was commonly handmade(Fig.3). Its size varies among 30×24cm, 24×20cm, 20×18cm. Local price of such tile is about 1¥/piece, 140¥/m2. Such tiles had been widely used in China for a long history. However, they are gradually replaced by some new building materials (like cement tiles, colored steel tiles, etc.) which have a larger variety of colors and sizes, can achieve better decorative effects, are more durable or easier to use.
Cement tiles are made of silicate cement, yellow sand, water and coating materials (e.g. acrylic) (Fig.4). Comparing to the traditional clay tiles, they possess higher density, higher strength and good thermal insulation, rain-proof & frost resistance performance. Their surface are also more flat and accurate. However, cement tiles are not very durable and easy to be broken. Their installation are relatively complex and time-consuming, so their application is limited but can be used in the rural houses.

Colored steel tiles, also known as metal tiles, or aluminum zinc steel plate tiles (Fig.5), are made of aluminium zinc steel plate, which are pressed into different shapes. Comparing to the traditional clay tiles, on the one hand, they are lighter, with higher strength, more durable, more colorful, easier to be installed (the construction time can be cut by over 40%) and easily adapted to different shapes of roof; on the other hand, they are more expensive in price; possess worse thermal insulation performance, can be noisy in the raining days, so are not considered very suitable to be used in the rural houses.

Selection of Roof Structures. The support structure of the add-on slope roofs in the researched are mainly wooden frame structure, steel truss structure and steel-wood mixed structure. Considering that, the researched region is a mountainous area and there are quite abundant wood resources in this area, a wooden frame structure is recommendable for houses with small spans (e.g. $\leq 5$ m). When the span is larger (e.g. $>5$ m), bracing is recommended to be added to the structures for even larger spans.

Selection of Roof Slopes. For roofs with same materials, the greater the slope, the smoother the drainage is. Also, the higher the roof, the more indoor space is usable and the higher the construction cost is. Considering the minimum clear height of indoor space, the need for rainwater drainage and the overall appearance of a building, the slope of roofs are recommended to be between 20° and 45°.

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1992 years of Chinese traditional local-style dwelling houses building form natural divisions, because of the influence of the rainfall, the traditional local-style dwelling houses of roof slope can be
divided into flat roof area (slope < 10°), gentle slope zone (< 30°) and the steep slope zone (> 30°) (Fig.7). Will be above the roof slope zoning maps with our country "the average annual rainfall zoning map", as compared average annual precipitation in the area of 0 ~ 250 mm basically is flat roof area. The average annual rainfall is between 250 and 500 millimeters in the area of the sloping roof area. The average annual rainfall of over 500 mm is basically a steep slope. The figure shows that Ningqiang in southern Shaanxi area (perennial an average annual rainfall 1103.6 mm) roof pitch should be at the top of the steep slope zone (> 30°).

The slope presentation method: B/A or B/2A or C/cos alpha

The extension is equal to 1 over cosine of alpha is equal to the square root of A squared plus B squared over A

And then the dil factor is equal to the square root of 1 plus C squared.

The length of the sloping roof is equal to A×D

When S = 0, we are waiting for two slopes

![Slope roof schematic diagram.](image)

Furthermore, the slope of the roof is related to the type of waterproof material in roofing, the more the smaller seam of the waterproof material, the more likely it is to leak, so the slope will be higher. If the suitable slope of the small green tile is about 1:2, the corrugated tile is about 1:3, and the Hani grass slope is more than 1:1.

**Conclusion**

Based on common Ningqiang areas in southern Shaanxi, the add-on slope roofs of roof design and construction as the starting point, the investigation found that the local residents' spontaneous the problems in the construction activities. Through this professional scientific method of research, as well as the material for the market research, a large amount of data after contrast comparison, mainly for new build slope roof "selection", "structure", "grade", three aspects: put forward scientific and rational optimization. These optimizations will provide relevant assistance and guidance in the construction of "the add-on slope roofs" for local residents, especially in these three aspects. In the construction of the local houses in future, they may make the best possible energy saving, environmental protection, comfort and beauty.

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