Study on Green Energy-saving Strategies of Existing Building Roofs in Xi'an City of China

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Abstract. Taking existing residential buildings in Xi'an as the research object, this paper puts forward energy-saving transformation strategies from flat roof to slope, evaporative cooling structure of roof water storage, green roof and roof ventilation structure, aiming at providing technical model and transformation experience for existing residential buildings in hot summer and cold winter areas.

Key words: Xi'an area, energy-saving transformation, construction practices, green technology.

1. Introduction
Hot summer and cold winter areas are the areas where energy consumption is relatively serious in China. Due to the influence of climate, the energy consumption of air conditioning and heating in summer is increasing sharply in this area, and it will also increase substantially. Xi'an area is hot in summer and cold in winter. In the energy consumption of buildings, residential consumption is an important part. As one of the components of residential envelope structure, roof's heat gain and loss has a great impact on the energy consumption of the whole house. Therefore, studying the adaptation of residential roof to climate and discussing the strategies of roof energy-saving design will inevitably have a positive impact on the energy consumption of buildings in hot summer and cold winter areas, which is of great significance to the development of building systems in hot summer and cold winter areas.

2. Analysis of Roof Design Status in Hot Summer and Cold Winter Areas
Because of the extreme climate in summer and winter in Xi'an, the building envelope structure should not only meet the objectives of heat preservation and storage in winter, heat insulation in summer, heat preservation in winter at night and solar energy utilization in daytime, but also be solved by a single strategy and material. Residential roof, as one of the components of building skin which is greatly affected by external environment, should have the potential of "dynamic adjustment" according to climate change, which has been neglected for a long time in roof design. People are more willing to pay attention to the beautiful form of roof than others. The specific requirements of German urban planning departments on the impact of roofs on urban landscape can be seen from the detailed requirements for the construction of residential roofs in different situations.
Table 1. Requirements of German Urban Planning Department for Roof Impact on Urban Landscape

| Roof shape                                  | Residential area | Living Service Area | Mixing zone |
|---------------------------------------------|------------------|---------------------|-------------|
|                                             | Low Density     | Multi-storey        | High-density |
| Roof Shape of Major Buildings               | ●                | ●                   | ●           |
| Roof Shape of Affiliated Buildings          | ○                | ○                   | ○           |
| The Orientation of Housing Architecture     | ●                | ●                   | ○           |
| Slope of roof                               | ●                | ●                   | ○           |
| Roof materials and colours                  | ○                | ●                   | ○           |
| Additional building on roof                 | ○                | ●                   | ○           |
| Eaves face                                  | ●                | ●                   | ○           |
| Shape and size of awning                    | ○                | ○                   | ○           |
| Projecting part of roof                     | ○                | ○                   | ○           |

Legend: ● Absolute necessity ○ Hope to do so

3. Study on Climate Adaptability of Residential Roof in Xi’an

3.1. Flat Roof vs Slope Roof

From the structural point of view of flat roof and sloping roof, the analysis shows that the sloping roof has one more part in the structural design than the flat roof—the isolation air layer under the roof. The isolation air layer is the buffer between the outside surface of the roof and the ceiling of the room. It works together with the outside roof and ceiling ceiling, so that the average thermal resistance of the whole roof is obtained. The influence of the external environment on the room decreases accordingly. Therefore, sloping roofs should have better thermal comfort than flat roofs. The author has carried out field investigation on typical flat roofs and sloping roofs of Xi’an residential buildings, and carried out comparative experiments to verify the above analysis.

![Profile of general sloping roof and flat roof](image)

Legend: ● Test point location

It can be clearly seen from the experimental temperature curve that sloping roofs have better thermal insulation than ordinary flat roofs: the indoor temperature of sloping roofs has been lower than that of flat roofs for 24 hours from 8:30 a.m. to the same time the next day; and during the hottest period from 13:30 to 17:30, ordinary flat roofs have better thermal insulation. The indoor temperature of the roof keeps rising, but the indoor temperature under the sloping roof does not increase dramatically, but shows a relatively gentle growth trend, which makes the indoor environment better than the ordinary flat roof, and reflects the thermal performance superiority of the sloping roof over the flat roof in summer.
3.2. Flat Roof vs Flat to Slope Roof

The advantages of slope roof have led to many large-scale residential roof "flat-to-slope" projects in recent years. Through several years of exploration and practice, the use function of flat-to-slope has been greatly improved compared with flat roof, and satisfactory results have been achieved. The author has carried out field investigation and experiment on flat roof and flat roof of Xi'an residential buildings, and has understood the improvement effect of flat roof to slope roof on indoor temperature of top-floor residential buildings. The experimental results are as follows.

![Legend: • Test Point Location](image)

**Figure 2.** Section diagrams of common flat roof and flat-to-slope roof

After retrofitting the flat roof, the thermal performance of the retrofitted flat roof is better than that of the original flat roof. The performance difference between the sloping roof and the sloping roof is especially obvious: (1) From the point of view of rational analysis, the isolated air layer under the flat roof makes the roof increase. It is divided into buffer zones between the external environment and the use space, and the increase of the average thermal resistance caused by the interlayer air makes it difficult for the external heat to enter the use space under the roof, which improves the comfort of the room; (2) The experiment clearly shows that in 24 hours from 8:30 a.m. to the same time the next day, the indoor temperature of flat roof is always lower than that of ordinary flat roof; (3) In terms of the influence of outdoor environment on indoor temperature fluctuation, especially after 4 p.m., the indoor temperature under ordinary flat roof fluctuates greatly on the temperature curve due to the change of external environment, while the flat roof changes from noon to noon. After that, the highest temperature gradually declines, and there is no big fluctuation in the middle, forming a smooth temperature drop curve, which more clearly reflects the thermal insulation performance superiority of the flat roof to the ordinary flat roof.

3.3. Experimental conclusions

It can be clearly seen from the comparative experiments that the sloping roof and the reformed flat roof have better thermal insulation performance than the original flat roof. The indoor temperature of the ordinary flat roof is much more affected by the external environment than that of the sloping roof and the flat roof. Slope roofs and flat roofs are better than ordinary flat roofs to ensure the comfort of the room, which reflects the thermal performance advantages of the two relative to ordinary flat roofs.

4. Climate Adaptability Design Strategy of Residential Roof in Xi'an Area

4.1. Strategies of Roof Leveling to Slope Conversion

The basic principle of heat insulation of flat roof is that the new air isolation layer under the slope roof makes the additional roof part become a buffer between the external environment and the use space. At the same time, because of the above-mentioned air layer, the average thermal resistance of the whole roof is increased, which makes the heat exchange between the outside and the inside of the room more difficult. In summer, the transmission of sunlight radiation heat to the indoor is blocked. In winter, the loss of indoor heat through the roof is reduced, and the comfort of the room is improved.
4.2. Evaporative Cooling Strategy for Roof Water Storage

Storing water on the roof in summer and then cooling it by evaporation can reduce the solar radiation from the roof by using the reflectivity of the water surface to the sunlight. At the same time, the water surface itself absorbs a lot of heat of vaporization in the process of evaporation. Most of these heat is absorbed from the solar radiation absorbed by the roof, which greatly reduces the heat transferred into the room through the roof and correspondingly reduces the inner part of the roof. Surface temperature.

The structural practices are summarized as follows: (1) Water depth and roof slope: the appropriate water depth is 150-200 mm. In order to ensure the uniformity of roof water storage depth, the slope of water storage roof should not be greater than 0.5%. Waterproof layer method: Best for rigid waterproof roof, also can be used for coiled waterproof roof. When using rigid waterproof layer, the partitioned seams should be made according to the regulations. (3) Water storage area division: In order to facilitate zonal overhaul and avoid excessive storms, water storage roof should be divided into several water storage areas, and the side length of each area should not exceed 10 m. The storage area is made of turbidity and condensate, and water holes are left on the wall to connect the water layers of each storage area. However, the two sides of the deformation joint should be designed as disconnected storage areas.

4.3. Green Roof Strategy

The structure level of green roof is generally composed of planting soil, drainage layer, isolation layer, insulation layer, waterproof layer and base layer. The isolation layer is located between the planting soil and the thermal insulation layer, which can prevent the soil from entering the thermal insulation layer, and also prevent the plant from rooting into the thermal insulation layer, thus playing a protective role. In addition, in hot summer and cold winter areas, the sunshine radiation is very severe in summer. Strong sunshine can easily cause burns on the leaves of roof plants. Therefore, plant varieties with good heat tolerance should be selected. The authors put forward suggestions for the selection of plant systems for roof greening in hot summer and cold winter areas.

|                      | Grassland roof greening                                                                 | Community roof greening                              |
|----------------------|----------------------------------------------------------------------------------------|-------------------------------------------------------|
| resistance           | Strong comprehensive resistance, including drought resistance, barren resistance, cold resistance, heat resistance, strong wind resistance, strong light resistance, etc. | Various plant species with different resistance can be applied. Species with strong resistance |
|                      | Less pests and diseases, or stronger resistance to pests and diseases                    | Less pests and diseases, or stronger resistance to pests and diseases |
| Morphologic          | Perennial herbs predominate, while evergreen plants are preferred.                     | Trees, shrubs, vines and herbs can be used.            |
| requirements         | The height is less than 1.5 meters, mainly on the ground.                              | Highly demanding, no more than 5 meters                |
|                      | Root system is shallow, root penetration is not strong                                  | Ornamental strong                                     |
|                      | Strong ground coverage                                                                  | Root penetration is not strong                         |
|                      | Less dead leaves, easy to remove                                                        | Slow growth, less defoliation and easy removal         |

4.4. Roof Ventilation Strategy

Ventilated roof shows its superiority especially in hot summer. As the roof changes from a solid structure to a structure with ventilated air interlayer, the air layer under the overhead slab plays the same role as the air layer under the flat roof, which makes the heat exchange inside and outside the roof difficult and
improves the actual average thermal resistance of the roof. Consider the design of adjustable opening
and closing device in the air duct of the overhead layer. Opening in summer and closing in winter can
achieve the dual purpose of heat insulation in summer and winter, and make the ventilated roof more
flexible to adapt to the climate of Xi'an.

5. Conclusion
As the fifth elevation of the city, the roof has tremendous development space and potential value. Green
roof combines rainwater and flood management, pollution control and ecological landscape design. It
helps to reduce urban heat island effect, improve carbon and oxygen balance, achieve energy saving and
emission reduction, and fully embodies the concept of harmonious coexistence between man and nature.
In the process of building sponge city system at present, green roof plays a significant role, which helps
to reduce the burden of follow-up technology. In the process of design and simulation, relevant analysis
software should be used for scientific calculation and analysis, and problem feedback and field
adjustment should be done well, so as to realize the feasibility and stability of the system.

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