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Review article

Energy efficiency in cold-climate houses: A comprehensive review of insulation materials, passive architecture, and heating systems

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ABSTRACT

This analysis examines energy-efficient strategies for residential buildings in cold and cold-temperate regions, with special emphasis on the Kashmir region, where winter temperatures can fall to −18 °C. It reviews recent research on thermal insulation materials, passive building design, and renewable heating systems, evaluating their thermal, environmental, and economic benefits. Passive design measures such as proper building orientation, airtight envelopes, thermal zoning, and solar glazing can reduce heating demand by up to 50%. Envelope improvements, including reflective glazing, shading devices, and better wall and roof insulation, can lower building energy use by 30%–50%. Adding thermal mass to walls and floors can also reduce heating and cooling loads by 30%–50%. Studies show that optimised floor slab thickness can cut total energy use by about 17% and heating demand by 27%. Insulation optimisation depends on climate and material type. Typical optimum thickness ranges from 3.4–8.2 cm for XPS systems and 3.6–8.2 cm for EPS systems, while advanced low-conductivity materials may need even less thickness. Multi-objective design methods combining envelope optimisation and ventilation strategies have achieved up to 28% lower energy use compared with conventional residential designs. Infiltration control in airtight buildings can prevent 30%–40% of heating losses caused by uncontrolled air leakage. Overall, the study highlights that combining traditional passive construction knowledge with modern insulation materials and renewable heating technologies can create climate-responsive, energy-efficient homes for mountainous cold regions. These integrated solutions can significantly reduce energy consumption, improve indoor thermal comfort, and support environmental sustainability.

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