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Towards climate-responsive and low-carbon development

Addressing the critical urban issues in Residential and Transport Sector in Uttarakhand

A Report On International Best Practices:

Energy Efficiency Practices And Policies In Cold Regions

Prepared For

G. B. Pant Institute of Himalayan Environment and Development
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March 2022

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Suggested Citation

Kansal, A., Das, N., Elangovan, R. & Garg, T. (2022). A Report on International Best Practices: Energy Efficiency Practices and Policies in Cold Regions. New Delhi: Alliance for an Energy Efficient Economy

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A Report On International Best Practices:

Energy Efficiency Practices And Policies In Cold Regions

Contents

List of Acronyms

HVAC	Heating Ventilation and Air conditioning
PV	Photovoltaic
EPBD	Energy Performance of Buildings Directive
GEF	Global Environment Facility
ULB	Urban local body
OSB	Oriented strand board
EPS	Expanded Polystyrene insulation
XPS	Extruded polystyrene insulation
ERV	Energy recovery ventilator
VOC	Volatile organic compounds
EV	Electric vehicle
LEED	Leadership in Energy and Environmental Design
CABR	China Academy of Building Research
PVC	Polyvinyl chloride
ACH	Air change per hour
EnEV	German Energy Saving Ordinance
A/V	Area to volume ratio
LED	Light-emitting diode
SEER	Seasonal energy efficiency ratio
AFUE	Annual fuel utilization efficiency
EPA	Environmental protection agency
IAQ	Indoor air quality
CFL	Compact fluorescent lamp
BEE	Bureau of Energy Efficiency

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The embodied energy and operational energy anticipated to be used in the increasing residential stock will expand the state's carbon footprint if the residential sector is not advanced through low-cost, sustainable, local, and affordable solutions while ensuring occupants' comfort.

01

INTRODUCTION

ABOUT THE PROJECT

Realizing that the increasing demand for energy and resources will put immense pressure on the Himalayan ecosystem, the Ministry of Environment, Forests & Climate Change (MoEF&CC) targeted addressing critical issues related to conservation and sustainable development in the region through the National Mission on Himalayan Studies (NMHS). This includes ten Himalayan states and only the hilly areas of two states. Among these, Uttarakhand is one of the most populated states and has the highest electricity demand of the Himalayan states under the jurisdiction of NMHS. As per the Uttarakhand state government statistics (MoSPI, 2015), the residential sector accounts for 24% of the total electricity consumption in the state. The monthly household electricity consumption in urban areas is expected to grow at a rate of 7% annually from the current consumption rate of 22.5 kWh/person (CSO, 2019). The combined effect of increasing population, urbanization and energy demand will put tremendous pressure on the already depleting natural resources in the state and threaten biodiversity and the Himalayan ecosystem.

The embodied energy and operational energy anticipated to be used in the increasing residential stock will expand the state's carbon footprint if the residential sector is not advanced through low-cost, sustainable, local, and affordable solutions while ensuring occupants' comfort. The residential sector's fragmented character with a lack of guidelines for climate-responsive design and low-carbon intensity construction has impeded past efforts to address the energy efficiency in this sector. Therefore, the project aims to characterize the residential sector in Uttarakhand's cold regions to provide a roadmap for improved thermal performance and energy efficiency and promote low-carbon development of upcoming residential stock in urban areas. The guidelines will also support India's and State's climate change commitment and other national priorities.

As per the Uttarakhand state government statistics (MoSPI, 2015), the residential sector accounts for

24%

of the total electricity consumption in the state.

1.1 NEED FOR THE STUDY

In the face of increased energy demand to achieve thermal comfort and concerns over decarbonization of the construction industry, residential buildings are receiving increasing perusal to be sustainable, energy-efficient, and at the same time provide a healthy indoor environment for their occupants. The existing policies and programs have not addressed energy efficiency in India's cold climate regions. The hour's need is to identify potential areas of a house that can be designed better to address the pressing issue of energy efficiency. This report aims to identify best practices in building design, construction and operation strategies practiced in different cold regions across the globe, which can be leveraged to develop a replicable set of measures that suits the local needs of Uttarakhand's cold region. This report presents a detailed analysis of various energy-efficiency practices in selected countries, with a primary focus on design strategies adopted to achieve energy efficiency, low carbon development, and thermal comfort in households.

1.2 APPROACH

The overall approach to review global best practices is presented below:

01 **Identify a list of counties** that match the conditions of cold regions of India, particularly Uttarakhand.

02 **Identify best** design/ construction practices, design guidelines, energy/building codes.

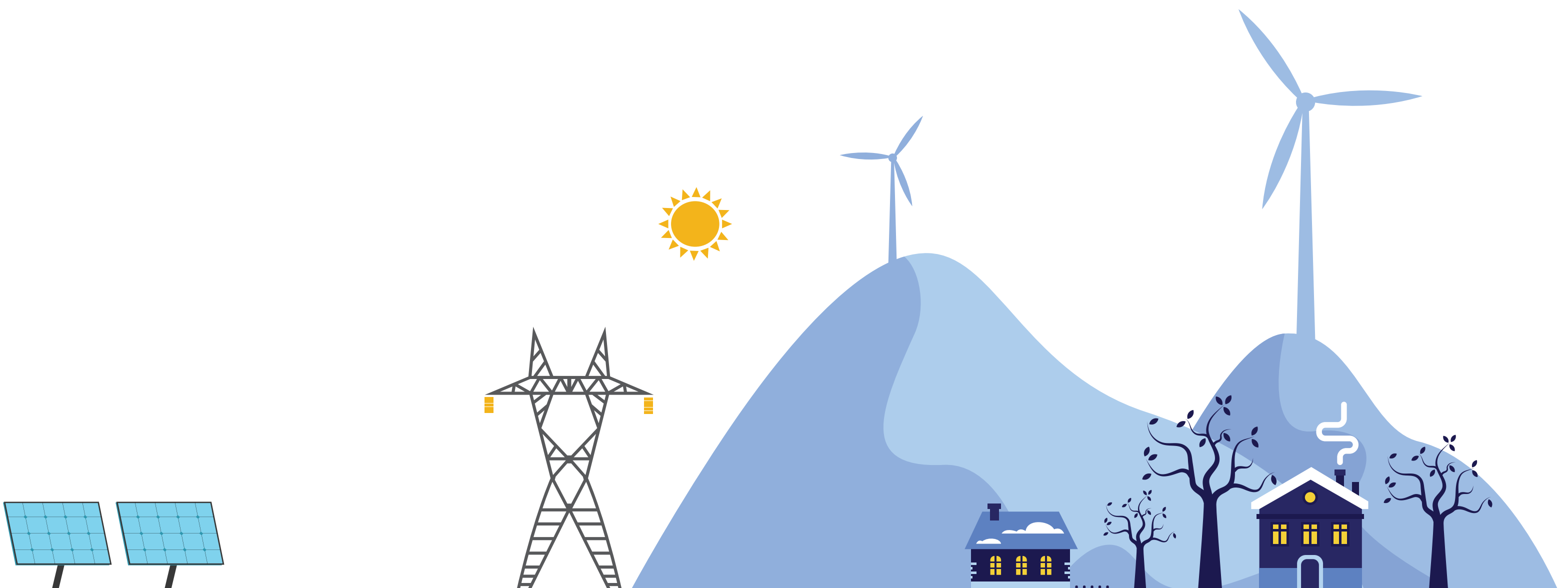
03 **Provide a summary** of the best practices in the context of Uttarakhand and how best they can fit into the current scenario of Uttarakhand.

1.3 KEY OBJECTIVES

The objectives of this report are two folds:

To understand the international practices in the housing sector which promote climate change mitigation and their feasibility in the selected regions.

To identify some basic building design, construction, and operation strategies practiced in selected countries (with a cold climate) that can apply to the Uttarakhand region.



02

BACKGROUND

The building sector's contribution to India's Gross Domestic Product (GDP) was 8.04% in 2014-15, and it is estimated to rise to 16.74% by 2025 (Commission & Delhi, 2010). Assuming an annual growth rate of 4.6%, India will add the built-up area (new construction) of approximately one billion square meters by 2050 (AEEE analysis). However, poor construction details and non-adoption of energy efficiency measures undermine the energy-saving potential both in demand and consumption. India must develop energy-efficiency strategies focused on the residential sector to limit the current unsustainable increase in energy demand.

Uttarakhand's annual residential electricity consumption per capita is 237 kWh/person/year; in contrast, the national average is 194 kWh/person/year (Economy, 2019). The energy consumption is bound to increase due to the decadal population growth rate of 20% since 1961 (Directorate of Economics and Statistics, 2016). In response, it will impact the supply and demand of energy to meet the growing population's daily needs, thereby making energy efficiency a critical early step in designing sustainable buildings.

The building sector's contribution to India's Gross Domestic Product (GDP) was

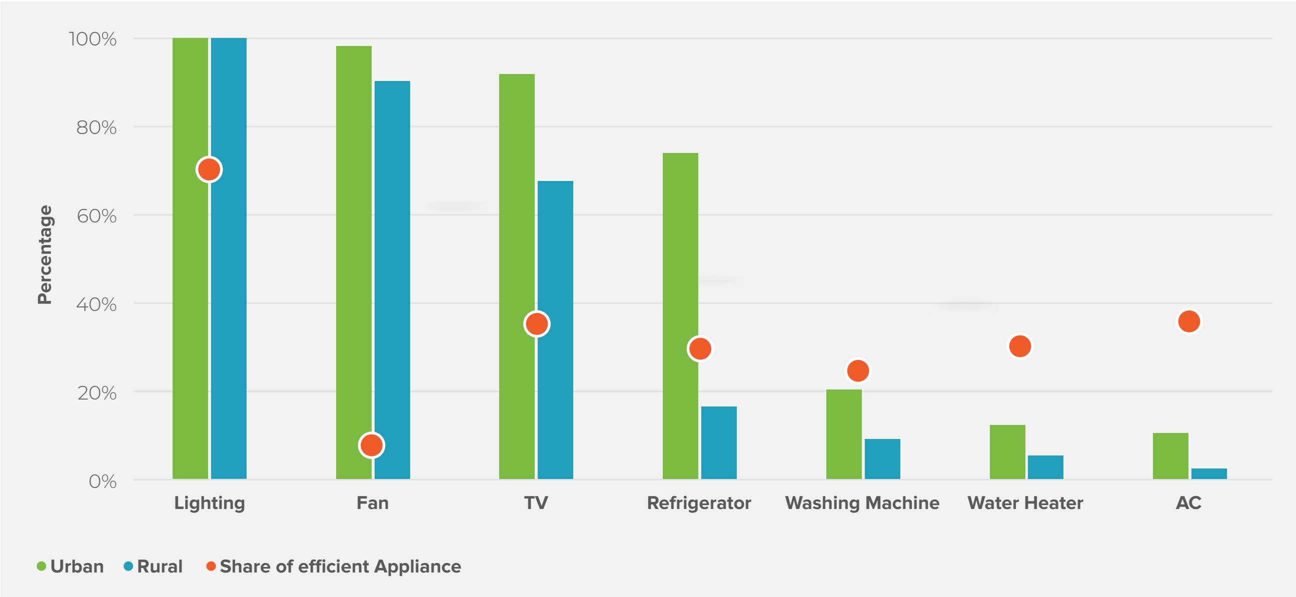
8.04% in 2014-15,

and it is estimated to rise to 16.74% by 2025 (Commission & Delhi, 2010).

2.1 ENERGY CONSUMPTION AND CARBON EMISSIONS IN INDIA

As a result of economic expansion and progress, industrialisation has increased energy supply and demand. Because of changing lifestyles and the growing demand for contemporary energy access, modernisation is predicted to quadruple the global energy supply from 2016 to 2030 (Danish et al., 2021) we examined the relationship between nuclear energy consumption and CO2 emissions in the context of the IPAT and Environmental Kuznets Curve (EKC. Despite its low per capita CO2 emissions, India is the world's third-highest CO2 emitter. Its electricity industry has a carbon intensity that is significantly above the global norm (India Energy outlook report 2021).

Figure 1: Percentage of Household using appliances in 2019.

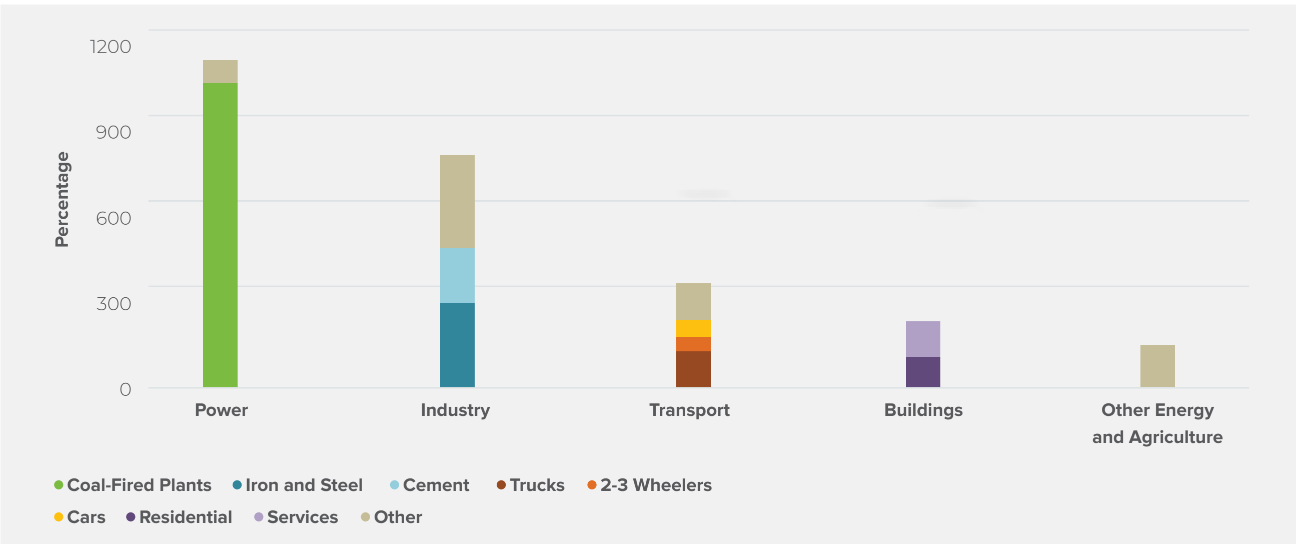


Source: (India energy outlook report (IEA), 2021)

According to (India energy outlook report (IEA), 2021) 66% of the country's households depend on firewood, crop residues, and cow dung as fuel for cooking. 85% of these households are in rural areas.

Figure 2 provides a visual representation of the CO2 emissions from the Indian energy sector. Residential buildings constitute approx. 100 Mt CO2.

Figure 2: CO2 emissions from the Indian energy sector.



Source: (India energy outlook report (IEA), 2021)

2.2 PRACTICES TO PROMOTE ENERGY EFFICIENCY IN INDIA

Regions that experience cold climates follow certain energy-efficient construction practices. Trapping the sun's heat properly insulating buildings to retain internal heat with minimum heat loss are major design concerns. Building efficiency can be achieved by studying the site's macro and micro-climate applying bioclimatic and passive design principles to reduce energy loss and heating/ cooling energy demand while taking advantage of the local environment. A few design practices (Koenigsberger et al., 2013) recommended for the Indian cold climate include:

- **Site** – Buildings along the leeward and south slope allow for better access to solar radiation and minimize exposure to cold winds. In cold climates, the street orientation East-West allows maximum south sun.
- **Orientation and planform** – Compact buildings with small surface-to-volume ratios to reduce heat loss. Living spaces with glazing on the south and insulation on the north enhance thermal comfort.
- **Building Envelope** – False ceiling with internal insulation using thermocol, wool, or polyurethane foam. Sloping roof for quick drainage of rainwater and snow. Skylights on the top admit heat and light. High thermal mass in walls to delay heat loss. Sufficient vapor barrier in walls by using bitumen coating, polyethylene sheet, etc. Cavity wall on the north side. Maximum windows provided on the south are perfectly sealed and preferable double glazed. External surface walls should be dark in colour to absorb heat from the sun.
- **Passive Techniques**

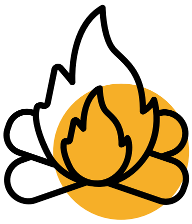
  A. Glazing – Maximise south glazing, minimize east and west glazing, use adjustable shading, use insulating low-E glass and sealed frames.

  B. Trombe wall - Thermally massive wall with vents provided at top and bottom. Solar radiation is absorbed during the day and stored as sensible heat. The air space between the glazing and the wall gets heated up and enters living spaces by convection through vents. Cool air from rooms replaces this air.

  C. Water wall – Thermal storage wall made up of drums of water stacked up behind glazing. Effective in reducing diurnal temperature swings.

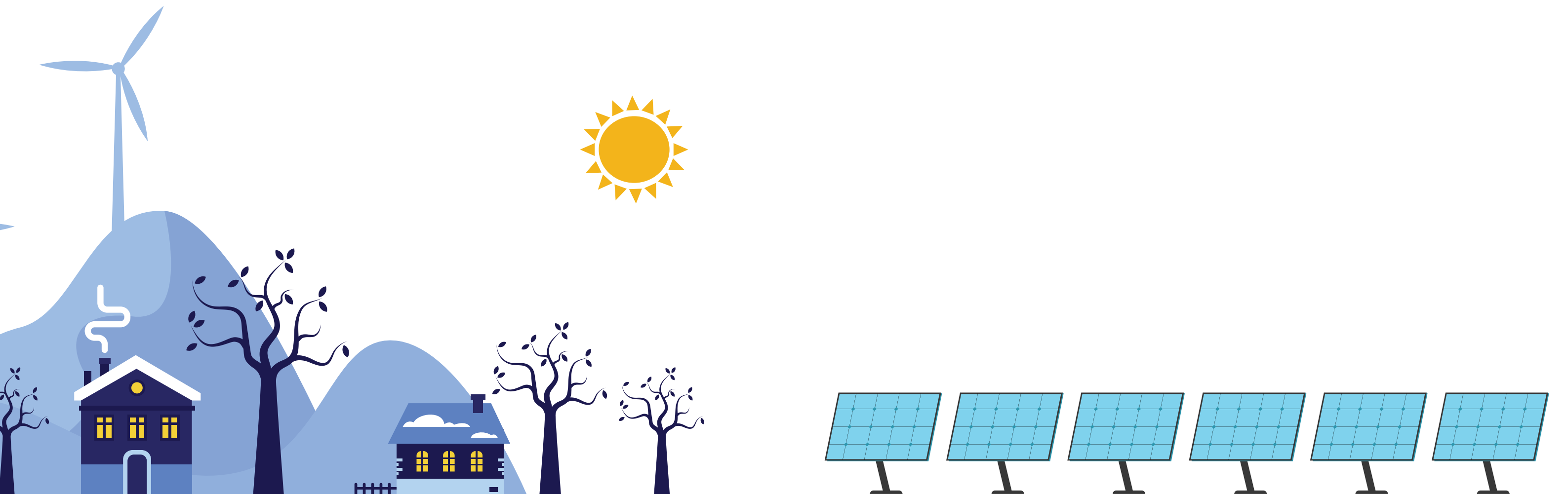
  D. Sunspace or Solarium – Solar radiation heats the solarium directly, heating the living space by convection and conduction through the mass wall.

It is found that energy efficiency measures are not followed strictly at the local level. However, National codes or state regulations exist because of inappropriate regulation structure, ineffective enforcement, and non-availability of detailed technical methodology (Chandel et al., 2016). Building envelope, climatic and site conditions, building materials, water conservation, wastewater recycling, heating, natural daylighting, cooling, ventilation, passive solar heating, and cooling are essential parameters for building energy efficiency.



According to (India energy outlook report (IEA), 2021)

66% of the country's households depend on firewood, crop residues, and cow dung as fuel for cooking.



> The embodied energy and operational energy anticipated to be used in the increasing residential stock will expand the state's carbon footprint if the residential sector is not advanced through low-cost, sustainable, local, and affordable solutions while ensuring occupants' comfort.

03

GAPS AND CHALLENGES IN THE CURRENT SCENARIO

National-level policy implementation is one of the most challenging tasks in the face of any country's government. We have identified the following barriers which can hinder the adoption of climate responsive and low carbon development guidelines for the residential buildings in the state of Uttarakhand, India:

1. **Administrative and Institutional Barrier:** Inter-ministerial coordination is necessary to execute work to monitor high-paced construction activities in a country as large as India. This requires people at different government levels to reach a consensus on implementation. The complex administrative structure of India can pose a challenge.

2. **Design and Technical Barrier:** Most of Uttarakhand's construction follows the conventional construction materials and practices using brick and RCC. With the recent shift from traditional to modern construction practices, the state's expertise in standard low-carbon traditional construction practices is reducing.

3. **Behavioral and lifestyle Barrier:** Homeowners' modest approach to adopting and implementing energy efficiency practices in their homes also creates a roadblock.

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As per the National Building Code(NBC, 2016), India is divided into five climate zones based on mean monthly maximum temperature (0C) and relative humidity (%).

04

CLIMATE CLASSIFICATION FOR COLD-CLIMATE

Climate has a crucial impact on the energy consumption of buildings. Climate classification is done according to several climate variables to understand regional climate characteristics. As per the National Building Code(NBC, 2016), India is divided into five climate zones based on mean monthly maximum temperature (0C) and relative humidity (%).On the other hand, the globally accepted Köppen-Geiger Climate classification is based on temperature and precipitation, encompassing the various climates and temperature ranges across the globe in a more holistic manner. To draw an anomaly between the temperatures of Uttarakhand and other similar areas, it becomes utmost essential to compare the world map using a uniform scale of measurement. Thus, to identify best practices for Uttarakhand, we have studied the Köppen Geiger Climate classification in detail to shortlist our zones of study.

- Upon imposing the Köppen Geiger Climate classification model on the Indian state of Uttarakhand, we identify 11 climate zones.

- These climate zones were compared to the rest of the world to identify countries showing similar climate conditions as Uttarakhand.

- For this report, we select from the following countries: Canada, China, Germany, Russia, and the United States.

- The residential energy efficiency landscape in the chosen countries has been thoroughly investigated. It will serve as the foundation for determining how to progress in Uttarakhand.

Figure 3: Köppen-Geiger Climate Classification map of Uttarakhand

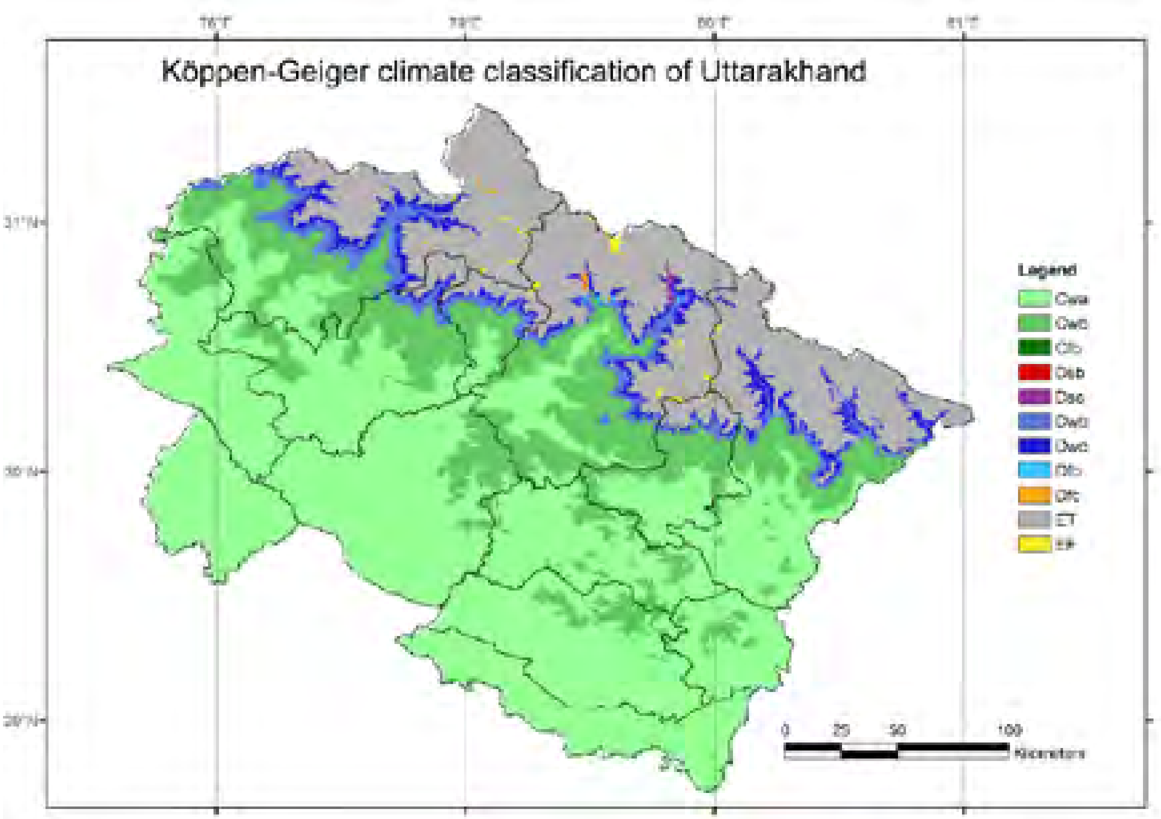
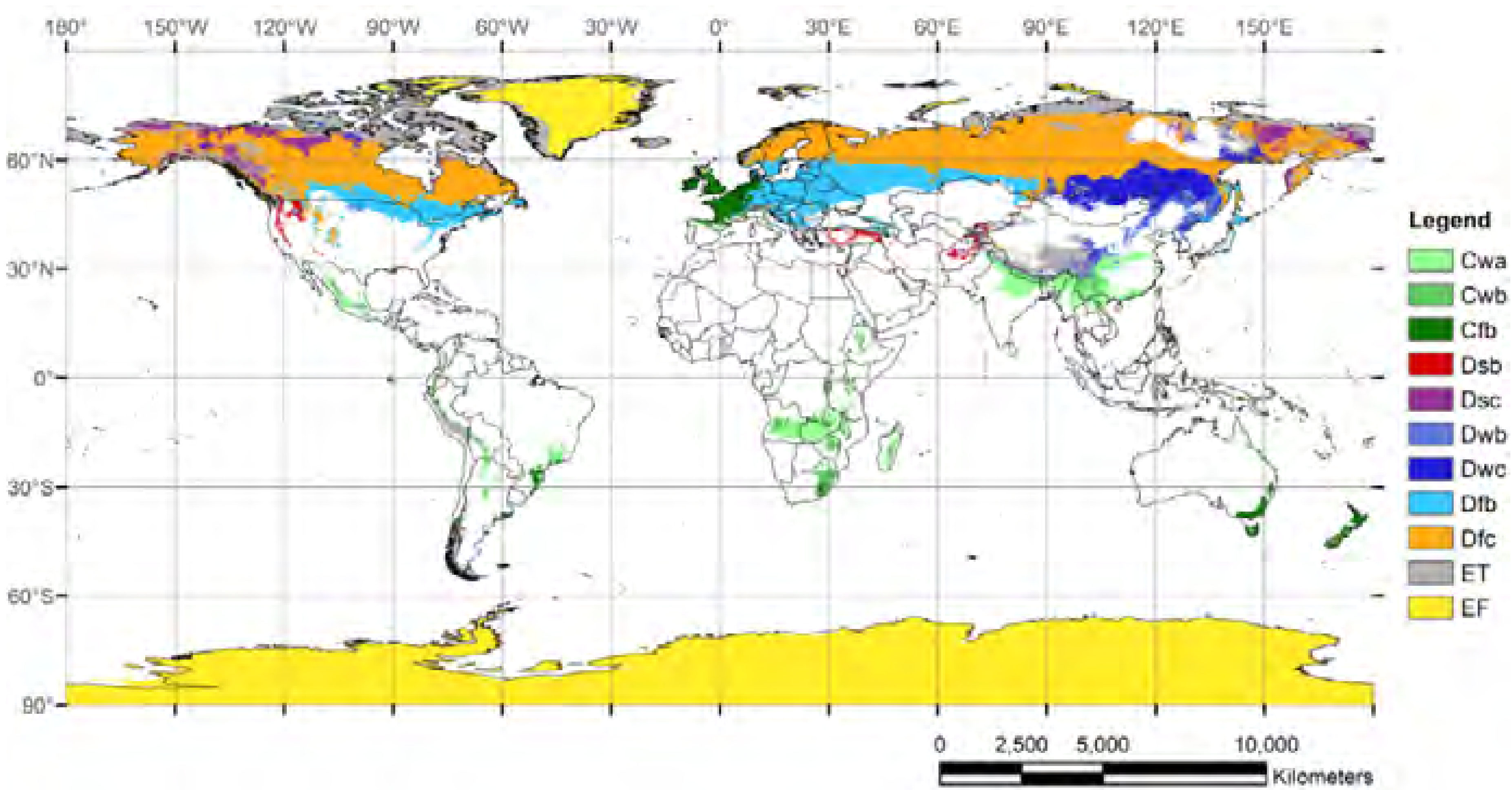


Figure 4: Uttarakhand climatic zones as per Köppen Geiger classification overlayed on the world



> To develop a wholesome understanding of the code implementation process in China, USA, Canada, Russia, and Germany, a step-wise detailed analysis of the following stages has been made: Code adoption, compliance, and enforcement mechanisms.

05

INTERNATIONAL BEST PRACTICE

The following chapter has been presented in two parts, each of which will touch upon two individually relevant areas of learnings while formulating guidelines for cold climate regions of India. While Part I focuses on code/ policy implementation, Part II focuses on the energy-efficient construction practices used in real-time in the countries under the lens, namely, China, the United States of America, Canada, Russia, and Germany.

PART 1

This section highlights the various energy efficiency codes, regulations, guidelines, and labeling programs introduced for the residential building sector. The fundamental goal of these initiatives is to encourage low-carbon growth, passive design, energy conservation, and thermal comfort.

PART 2

This section highlights the energy efficiency practices implemented in the chosen countries and broadly covers these practices' essential and critical components. The energy efficiency practices are addressed in each country's energy efficiency code for buildings under HVAC, Building Envelope, and Renewable Energy sources and systems.

PART 1 POLICIES FOR RESIDENTIAL HOUSES IN COLD REGIONS

To develop a wholesome understanding of the code implementation process in China, USA, Canada, Russia, and Germany, a step-wise detailed analysis of the following stages has been made: Code adoption, compliance, and enforcement mechanisms.

- Code adoption talks about the different types and sizes of buildings that come under its purview and the different energy systems that the code touches upon.
- The compliance sections talk about the different compliance strategies followed by the country e.g., prescriptive or performance based
- Enforcement talks about the strategies a country is adopting to accelerate the widespread adoption of the code.

CANADA

The Canada has been undertaking energy efficiency measures for building construction since 1978. The currently used National Energy Code of Canada for Buildings (NECB) covers residential buildings greater than 600 m2 in size (IPEEC, 2016a). An additional code called the National Building Code of Canada (NBC) covers smaller buildings. The latest 2017 revision of the NECB code further raised the standards for compliance for all the new building construction by an additional 10-15% (G. of Canada, 2017) to help Canada achieve 'Net Zero Energy Ready (NZER)' buildings by 2030

ADOPTION

Type of buildings: The NECB and NCB to residential buildings, including single-family and multi-family dwellings.

Table 1: Residential Building size thresholds for code adoption and enforcement.

Type of Construction	Building size threshold
New Buildings	Mandatory for all new buildings in provinces which adopt the code (Threshold, if the individual state/ provincial jurisdictions determine any)
Existing Buildings or retrofits	Applies to retrofit projects based upon individual thresholds determined by the respective state/ provincial jurisdictions. No set thresholds followed country-wide.

Source: (G. of Canada, 2017)

The latest 2017 revision of the NECB code further raised the standards for compliance for all the new building construction by an additional 10-15% (G. of Canada, 2017)

To help Canada achieve 'Net Zero Energy Ready (NZER)' buildings by 2030

Energy systems covered: Building envelope, HVAC, service water heating, lighting, electric power, maintenance.

COMPLIANCE

The provincial/local government is responsible for undertaking all compliance-related activities and organizing on-site inspections during the design, construction, and pre-occupancy stages. There are two broad compliance strategies followed are

- **Prescriptive approach:** Calculated based on the U-factor within the building envelope components and individual building components.
- **Performance-based approach:** The performance-based solution provides a tailor-made solution to meet the minimum compliance requirements.

ENFORCEMENT

Market creation- Incentives, Penalties, and other mechanisms

- **Penalties for non-compliance include:** Refusal of a construction permit, Refusal of an occupancy permit, Publication of owner names if their project fails to comply

- **Incentives offered if the project goes beyond the minimum requirements include:** Subsidized loans and low-interest rates, recognition for good performance under the ENERGY STAR scores

Capacity Building and Training Programs

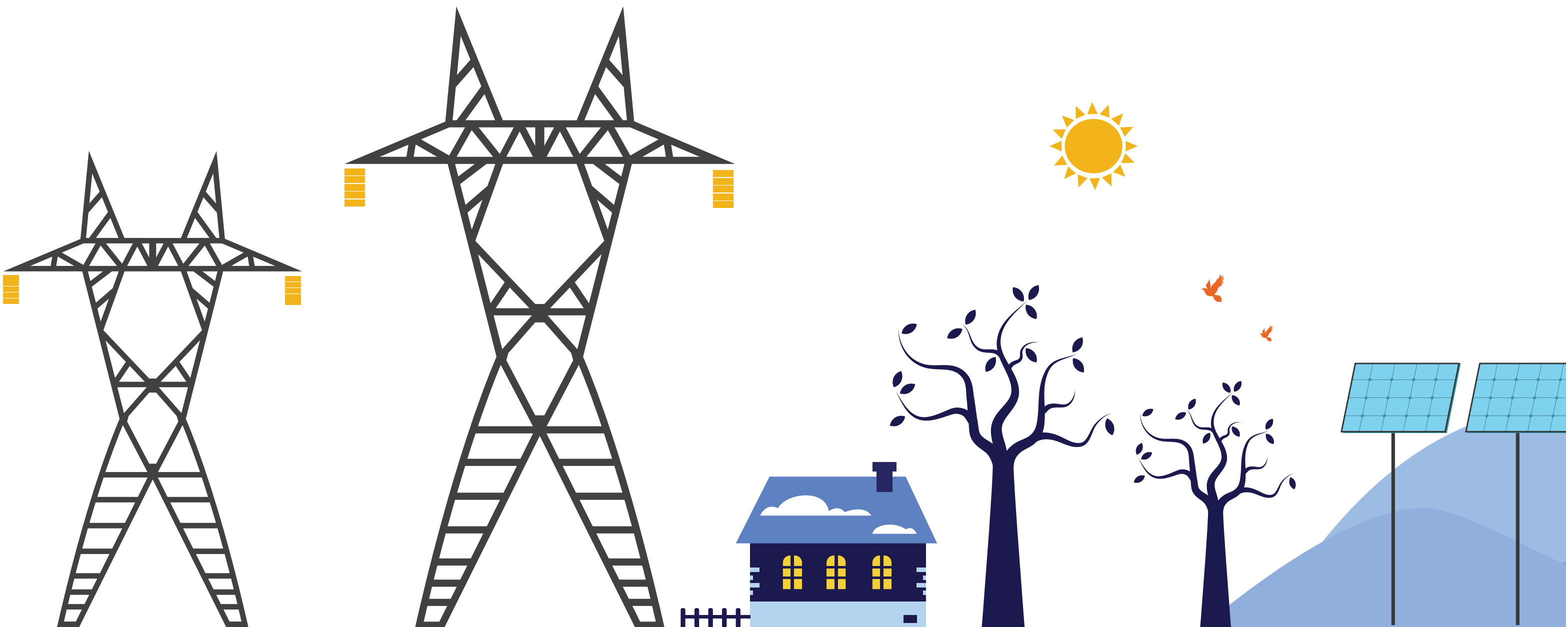
Natural Resources Canada (NRCan) provides training resources, case studies, databases and organizes online and offline training programs for design professionals and homeowners to learn in-depth about the model code implementation in their respective projects.

Energy Performance Certificates

Building projects all over the globe are moving towards attaining energy performance certificates. Most of these certification programs/schemes offered in Canada, such as SuperE, energy STAR, EnerGuide, are voluntary. No government-led subsidies are provided to lower the cost of applying for these certifications.

Table 2: National level initiatives in Canada.

Policy Instrument	Year of Implementation	Explanation
National Level Initiatives		
ENERGY STAR Certification	2001	Enable highly efficient skylights and windows as they are the prime source of up to 65% heat losses (N. R. Canada, 2020) for homes.
EnerGuide	2006	Places certified under this program are eligible for a green Home insurance refund of up to 15-25% (Enervision, 2020).
R-2000 Standard	2012	Buildings that exceed the energy efficiency by 50% compared to non-compliant new homes.
Passive House Canada (PHC)	2013	PHC compliant units consume up to 90% lesser energy (P. H. Canada, 2020) than conventional units.
Pan-Canadian Framework on Clean Growth and Climate Change	2016	A framework to collectively adopt energy-efficient construction technologies and meet the GHG reduction targets.



CHINA

In the 1980s, the Ministry of Urban and Rural Construction and Environmental Protection later renamed the Ministry of Housing and Urban-Rural Development (MOHURD) in 2008, was the first ministry to introduce building energy codes in China. Unlike most countries across the globe that prepare one comprehensive code applicable across the entire country, Chinese ministries prepare multiple building energy efficiency codes per the different climate and building types. China released its first building energy efficiency code JGJ 26-1986 for cold and severely cold climate zones in the late 1980s. The JGJ 26 has undergone three revisions ever since its inception. Each revision added 30% energy saving criteria compared to the previous version. Currently, the code targets a 75% reduction in the energy used by residential buildings in cold climates compared to the pre-1986 benchmarks (Xu et al., 2016).

ADOPTION

Type of buildings: The JGJ-26 applies to all new and existing residential buildings built in the country's cold and severely cold regions.

Table 3: Building size thresholds for China's energy efficiency code adoption and enforcement.

Type of Construction	Urban/Rural	Building size Threshold
New Buildings	National code for urban buildings	None (Threshold, if the individual state/territory jurisdictions determine any)
	National code for rural buildings	
Existing Buildings or retrofits	National code for urban buildings	None (Threshold, if the individual state/territory jurisdictions determine any)
	National code for rural buildings	

Source: (Evans & UMD, 2009)

Energy systems covered: Heating, cooling, natural ventilation, lighting, thermal bridging, design, the orientation of buildings, heat recovery, passive solar, passive cooling, shading, daylight requirements, and renewable energy sources (PV, solar, etc.)

COMPLIANCE

The local/city council is responsible for undertaking all compliance-related activities and organizing on-site inspections during the design and construction phase. There are two broad compliance strategies followed in China, namely

- **Prescriptive approach:** compliance is achieved if the building meets the criteria mentioned in the code
- **Performance-Based Approach:** The performance-based solution provides a tailor-made solution to meet the minimum compliance requirements. To test for compliance, one or a combination of the following methods can be used: Evidence of suitability, verification method, auditing report, comparison to deemed-to-satisfy.

The state/provincial/local governments conduct no post-occupancy compliance checks for any new residential project in China. The necessary information is collected only by the national-level government during the annual compliance assessment of each residence. The sample cities for each yearly compliance assessment are picked up at random by the MOHURD, and the selected cities are notified two weeks before the survey date.

ENFORCEMENT

Market creation - Incentives, Penalties, and other mechanisms

- **Penalties:** Refusal of a construction permit, Refusal of an occupancy permit, Fines, Loss of license, Publication of building owner names who fail to comply
- **Incentives:** Offered if the project goes beyond the minimum requirements include Tax Incentives in income, value-added tax, fixed asset tax, etc., Financial subsidies, Financing support

Capacity Building and Training Programs:

Capacity building programs are driven by the MOHURD and primarily target implementing institutions such as the state/local governments, third-party auditors, stakeholders, designs, engineers, material manufacturers, etc. Training programs are conducted every time a new version of any building energy code is published.

Performance Certificates:

Energy Performance Certificates are voluntary in China and can be issued for projects during the design and post-occupancy stages. These certificates can be issued by the Departments of Housing and Urban-Rural Development at the state/local levels.

Table 4: National level initiatives in China.

Policy Instrument	Year of Implementation	Explanation
National Laws related to building energy conservation		
Renewable Energy Law	2006	Residential units are promoted to use solar energy and solar photovoltaic power sources to meet water heating, room heating, and lighting demands.
Green Building Labelling	2006	A Three-Star Rating system based on the following criteria: Land, energy, and water efficiency, material efficiency, indoor environmental quality, and operational management.
Regulations and policies related to building energy conservation		
Private financing – Green credit policy	2007	Provides guidelines on the energy-efficient and environment-friendly activities that private banks must fund.
Financial Subsidy Funds for the Application of Solar Photovoltaic Buildings	2009	Building projects that use solar photovoltaic larger than 50kWp can get up to 50 million RMB subsidies.
Assessment Guidelines for Green Building Materials	2015	Energy-efficient building materials and technology must be promoted and readily available to implement energy-efficient codes.
Technical Guidelines for Passive Ultra-low Energy use Green Buildings	2015	China is conducting trial constructions in multiple residential projects to test passive ultra-low energy technologies to promote green building construction.

GERMANY

In 2002, the first edition of Germany's performance-based code called the Energy Saving Ordinance EnEV, later renamed the Energy Performance of Buildings Directive (EPBD), was established and enforced differently. The 2009 revision to the code introduced alterations in the building component thresholds such as reduced U-value for walls and windows, airtightness, HVAC systems, etc. The 2013 revision of the code further raised the standards for compliance for all the new building construction.

In 2002, the first edition of Germany's performance-based code called the Energy Saving Ordinance EnEV, later renamed the **Energy Performance of Buildings Directive (EPBD), was established and enforced differently.**

ADOPTION

Type of buildings: The EPBD in Germany applies to residential buildings, including single-family and multi-family dwellings.

Table 5: Building size thresholds for code adoption and enforcement in Germany.

Type of Construction	Building size threshold
New Buildings	All new buildings which use mechanical heating/ cooling systems
Existing Buildings or retrofits	All retrofit projects and expansion projects of more than 50 sq m

Source: (Network, 2018)

Energy systems covered: Building envelope, HVAC, service water heating, lighting, electric power, renewable energy, maintenance.

COMPLIANCE

The state/local government is responsible for undertaking all compliance-related activities and organizing on-site inspections during the design, construction, and pre-occupancy stages. There are two broad compliance strategies followed EPBD in Germany, namely

- **Prescriptive solution:** Provides a list of rules to assure easy compliance and enforcement
- **Performance-Based Solution:** The performance-based solution provides a tailor-made solution to meet the minimum compliance requirements. To test for compliance, one or a combination of the following methods can be used: Evidence of suitability, verification method, auditing report, comparison to deemed-to-satisfy.

ENFORCEMENT

Market creation- Incentives, Penalties, and other mechanisms

- **Penalties for non-compliance include:** Refusal of a construction permit, Suspension or loss of license, Fines
- **Incentives offered if the project goes beyond the minimum requirements include:** Subsidized loans and low-interest rates via government-owned banks

Capacity Building and Training Programs:

The German Energy Agency (GEA) documents evidence and techniques, maintains an online database, and organizes events to enhance engineers, architects, artisans, etc.

Table 6: National level initiatives in Germany.

Policy Instrument	Year of Implementation	Implementation Process
CO_2 Rehabilitation Pro-gramme – KfW Programme	1996	It offers financial aid to both new and retrofit construction projects to build environmentally friendly homes.
Market Incentive Programme Renewable Energies (MAP)	2000	It is an initiative to provide financial aid to projects which opt for small-scale renewable heat energy systems in their design.
Energy Efficiency Ordinance of Germany (EnEV)	2002	To accelerate thermal comfort, every new residential construction must meet the energy consumption values set for heating, cooling, domestic hot water, airtightness, thermal bridging, and ventilation.
German Heating Cost Ordinance	2009	The German Heating Cost Ordinance had made metering and pricing of district heating mandatory to monitor the actual energy consumption of heating appliances and hot water in buildings that constitute two or more residential units.
Efficiency House Plus	2011	This concept encourages people to generate their energy to meet daily demands. The excess energy produced is fed back into the public grid, stored in a battery, used for electro-mobility purposes, or directly sent out to the immediate neighborhood areas for use.
Energy Performance Certificates (EPCs)	2014	EPCs are awarded to construction projects based upon the total energy during a term of 1 year.

RUSSIA

Energy efficiency building codes in Russia were introduced in 1955 and propagated efficient building envelopes to minimize heat losses. The Russian government institutes designed these codes' collaborated effort, non-governmental organizations such as Engineer Associations, and private industry stakeholders. These building codes underwent multiple revisions over the years, with the energy-saving stringency increased by almost 20% with each revising compared to the preceding version of the code. The latest version of the code dated 2012 is the SP 50.13330.2012 - Thermal Performance of Buildings. It is mandatory for all new constructions in Russia except certain states like Moscow, which have their codes.

Energy efficiency building codes in Russia were introduced in 1955 and propagated **efficient building envelopes to minimize heat losses.**

ADOPTION

Type of buildings: The SP 50.13330.2012 applies to all residences, including one-family and multi-family dwellings.

Table 7: Building size thresholds for code adoption and enforcement in Russia.

Type of Construction	Building size threshold
New Buildings	Mandatory for all new buildings except buildings that require heating for less than five days per week or three months per year. It does not apply to temporary structures also which are built to stand for less than two years.
Existing Buildings or Retrofits	It is mandatory for all retrofit building projects except buildings that require heating for less than five days per week or three months per year.

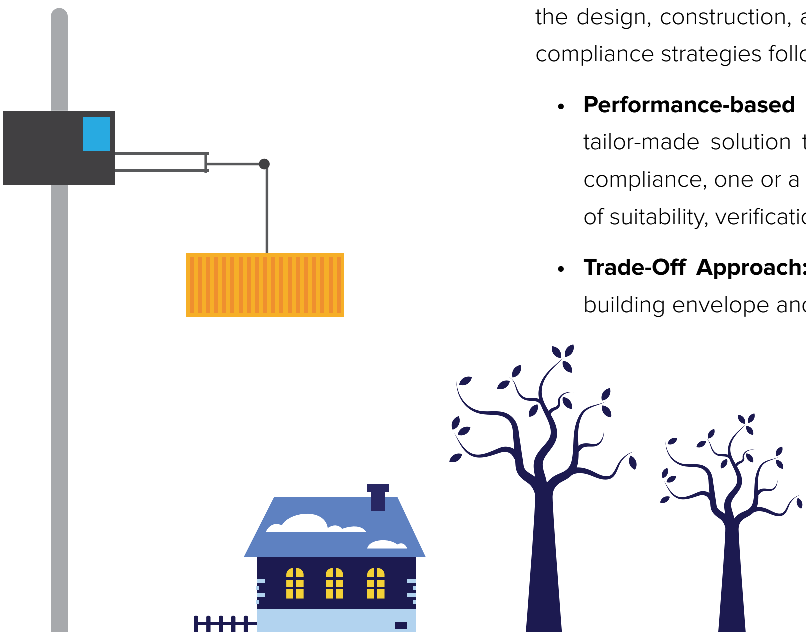
Source: (Matrosov et al., 1997)

Energy systems: Building envelope, HVAC, service water heating, lighting, electric power, maintenance.

COMPLIANCE

The state and local (varies based on different states) governments are responsible for undertaking all compliance-related activities and organizing on-site inspections during the design, construction, and pre-occupancy stages of a project. There are two broad compliance strategies followed are:

- **Performance-based approach:** The performance-based solution provides a tailor-made solution to meet the minimum compliance requirements. To test for compliance, one or a combination of the following methods can be used: Evidence of suitability, verification method, auditing report, comparison to deemed-to-satisfy.
- **Trade-Off Approach:** Calculated based on the U-factor by trade-offs within the building envelope and individual building components.



ENFORCEMENT

Market creation - Incentives, Penalties, and other mechanisms

- **Penalties for non-compliance include:** Refusal of a construction permit, Fines
- **Incentives offered if the project goes beyond the minimum requirements include:** Subsidized loans and low-interest rates for buildings with a green rating

Energy Performance Certificates

As far as energy performance certificates are concerned, all new buildings must obtain an occupancy certificate from the state authorities.

Table 8: National level initiatives in Russia.

Policy Instrument	Year of Implementation	Explanation
Global Environment Facility (GEF) Project to Boost Urban Housing Energy Efficiency	2010	Improves the energy efficiency of houses in Russia by addressing financial, legislative, and technical barriers people face to achieve energy efficiency in existing design.
European Bank for Reconstruction and Development (EBRD) Sustainable Energy program	2011	Supports energy efficiency in residential buildings by granting homeowners and housing associations financial assistance opting for energy-efficient construction or refurbishment.

USA

The first building energy codes in the United States of America were developed in 1974 in response to the 1973 energy crisis and published by the American Society for Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 90-75. To support the implementation of ASHRAE, a Department of Energy (DOE) was set up to determine the potential energy savings of commercial and high-rise residential buildings. Following the widespread adoption and implementation of the ASHRAE in the retail building sector across the country, the International Code Council (ICC) developed the International Energy Conservation Code (IECC) in 1998 – A residential energy model code.

ADOPTION

95% of the country's land area except **for California, Washington, and Florida, which develop their energy codes outside ASHRAE and ICC.**

The IECC is a mandatory code adopted and used in 48 states across the country, which constitute almost 95% of the country's land area except for California, Washington, and Florida, which develop their energy codes outside ASHRAE and ICC.

Type of buildings: IECC applies to residential buildings such as - detached single and two-family dwellings, multiple single-family dwellings, apartments up to 3 stories in height, dormitories, boarding houses, convents, small residential care facilities, assisted livening facilities, hotels and motels, mixed occupancy.

Table 9: Building size thresholds for IECC adoption and enforcement in USA.

Type of Construction	Building size threshold
New Buildings	Mandatory for all new buildings except buildings that require heating for less than five days per week or three months per year. It does not apply to temporary structures also which are built to stand for less than two years.
Existing Buildings or Retrofits	It is mandatory for all retrofit building projects except buildings that require heating for less than five days per week or three months per year.

Source: (Matrosov et al., 1997)

Energy systems: Envelope, HVAC, Service water heating, Lighting, Electric power, & Maintenance.

COMPLIANCE

The local/city council is responsible for undertaking all compliance-related activities and organizing on-site inspections during the design and construction phase. There are three broad compliance strategies followed by the IECC in the US, namely

- **Prescriptive (no Trade-Off) solution:** Calculated based on the R-value. Compliance is achieved if the building meets the criteria mentioned in the code.
- **Prescriptive (Trade-Off) solution:** Calculated based on the U-factor by trade-offs within the building envelope and individual building components.
- **Whole Building Performance/Simulated Performance:** Calculated based on the Energy Rating Index (ERI Factor), independent of prescriptive requirement. The building has to be tested for compliance and demonstrate an ERI value prescribed threshold for the particular climate zone in which it is located. Also, the annual energy cost of the project must be less than or equal to the benchmark.

ENFORCEMENT

Market creation - Incentives and Penalties

- Penalties for non-compliance include Refusal of a construction permit, Refusal of an occupancy permit, Fines, e.g., jurisdictions have increased the fine schedule for resubmission over the past few years to impose stringency and to ensure an IECC compliance in the first submission, suspension, or loss of license
- Incentives offered if the project goes beyond the minimum requirements include

  Lower interest rates for construction

  Special recognition of the building design under the Ratings and Labelling Program

  Renovation budgets under the Property Assessed Clean Energy (PACE) program

Capacity Building and Training Programs

The US DOE offers multiple training programs and technical assistance resources to help stakeholders implement code. Most training programs are offered online, while some in-person training sessions are also provided for code officials. The Building Energy Codes Program (BECP) provides publications, resource guides, and training material accessible to all members.

National Level Initiatives

The USA offers its states the authority to establish their energy efficiency codes/standards and implement them to ensure the region's highest-performing buildings. The country's climatic conditions are diverse; each state implements a code that suits its annual climatic condition and local material and technology market. The table below shows some additional codes, standards, labeling programs, and energy efficiency initiatives in the USA to ensure efficient residential constructions.

Table 10: Other initiatives to promote sustainable residential construction in USA

State-wise EE Residential Policy	Year of Implementation	Implementation Process
An example of a State-specific residential building energy codes		
Residential Energy Code with amendments 2012 – Montana (PNNL, 2009)	1972	**ADOPTION:** • The Montana State Building Codes Bureau enforces the Residential (five or more dwellings) Energy code. It allows a window of 90 days for the local jurisdictions to adopt and implement the code. • Mandatory code for all new and significant retrofit residential buildings in the state. The code is revised every three years. **COMPLIANCE:** • To obtain the occupancy certificate, the projects must exceed the energy conservation provisions mentioned in the code by at least 20% to get the occupancy certificate. • The code specifies requirements concerning the U- & R-values of the building envelope and mechanical equipment efficiency. • The builder provides a labeling sticker for the—building depicting its efficiency, which is mandatorily placed inside the electrical panel of the building. • Compliance can be demonstrated by either of the following methods: prescriptive or trade-off. • Compliance Tools used: COMcheck and REScheck **ENFORCEMENT:** • The design must submit its plans and specifications prepared by the engineer or architect to the state-designated authorities to receive approval. Around the same time, many other states within the USA, namely Oregon, South Dakota, New York, Ohio, Nebraska, adopted building energy codes and revised them to suit the local needs and demands.
Energy Star Certified Homes	1992	Energy Star certification ensures better quality, performance, and comfort for the inhabitant, clubbed with a minimum energy-saving potential of 10%
Home Energy Rating System (HERS) Index	2006	The HERS rating system analyses the energy efficiency and performance-based upon a 150-point scale. Homes scoring 150 are highly energy-intensive, and homes achieving a 0 can be categorized as zero energy homes.
DOE Zero Energy Ready Home	2013	To promote self-sustainable buildings which produce enough energy to meet their daily demand. Also, the overall building energy demand can be lowered to half the standard building requirement through careful design.

SUMMARY REVIEW

Figure 5: **Comparative Analysis of Energy Efficient Policies in 5 countries**

ACTIONS			COUNTRIES – COLD CLIMATE REGION ANALYSIS					
			CANADA	CHINA	GERMANY	RUSSIA	USA	INDIA
ADOPTION	Building size	*Mandatory for all new buildings*	Existing	Existing	Partially Existing	Partially Existing	Existing	Not Existing
		Mandatory for up-gradation/ retrofitting in all existing buildings	Existing	Existing	Partially Existing	Partially Existing	Partially Existing	Not Existing
	Energy Systems	*Building Envelope*	Existing	Not Existing	Existing	Existing	Existing	Existing
		Heating	Existing	Existing	Existing	Existing	Existing	Not Existing
		Ventilation	Existing	Existing	Existing	Existing	Existing	Existing
		Lighting	Existing	Existing	Existing	Existing	Existing	Existing
		Maintenance	Existing	Existing	Existing	Existing	Existing	Not Existing
		Thermal Bridging	Not Existing	Existing	Not Existing	Not Existing	Not Existing	Not Existing
		Orientation	Not Existing	Existing	Not Existing	Not Existing	Not Existing	Existing
		Renewable energy	Not Existing	Existing	Existing	Not Existing	Not Existing	Partially Existing
	Fixed Code revision timeline		Partially Existing	Partially Existing	Existing	Not Existing	Existing	Not Existing
COMPLIANCE	Strategy	*Prescriptive with trade-off*	Existing	Existing	Existing	Existing	Existing	Not Existing
		Prescriptive without trade-off	Not Existing	Partially Existing	Partially Existing	Not Existing	Existing	Not Existing
		Performance-based	Existing	Existing	Existing	Existing	Existing	Not Existing
	Role of local govt.	*Design stage*	Existing	Existing	Existing	Existing	Existing	Existing
		Construction Stage	Existing	Existing	Existing	Not Existing	Existing	Existing
		Occupancy stage	Existing	Existing	Existing	Existing	Existing	Not Existing
	Role of 3rd party	*Design stage*	Not Existing	Existing	Partially Existing	Existing	Partially Existing	Existing
		Construction Stage	Partially Existing	Existing	Partially Existing	Existing	Partially Existing	Existing
		Occupancy stage	Partially Existing	Existing	Partially Existing	Existing	Partially Existing	Not Existing
	Existing tools/ software for code compliance		Existing	Existing	Existing	Existing	Existing	Not Existing
ENFORCEMENT	Incentives		Existing	Existing	Existing	Existing	Existing	Not Existing
	Penalties		Existing	Existing	Existing	Existing	Existing	Not Existing
	Capacity building and training programs		Existing	Existing	Existing	Existing	Existing	Partially Existing
	Building Material Testing and Energy performance Certificates		Existing	Existing	Existing	Existing	Existing	Partially Existing

Legend	Existing	Partially Existing	Not Existing

When evaluating a country's performance against another, it is not a simple comparison, which is why there can't be a one-size-fits-all approach to policymaking and implementation. The summary table above shows that despite a well-formulated code/policy implementation strategy in place in the selected countries, not all of them choose to implement each step (adoption, compliance, enforcement) to achieve energy efficiency in their homes. Thus, a framework must be crafted to suit the energy efficiency demands existing in India based upon its transformation potential and carefully assessed timeline. One key learning from the above analysis is that adopting codes is a step-wise process, where stringency for adoption is only increased with time and proper capacity buildings and training of concerned professionals.

PART 2 ENERGY EFFICIENCY PRACTICES

The energy efficiency practices are addressed in each country's energy efficiency code for buildings under heating, cooling, natural ventilation, lighting, thermal bridging, passive solar, passive heating, renewable energy sources, etc. These practices are supported with examples of materials and innovative technologies that help achieve the targeted thermal performance output in each of the five countries.

CANADA

Passive House is recognized internationally as the proven best way to build for residential buildings' comfort, affordability, and energy efficiency through all stages of design, construction, and liveability (Schmitt, 2021). The Passive House Institute (PHI) specifies significant quality criteria for the Passive House Standard to support building owners and planners in realizing their projects. Projects labeled as "certified passive house" meet these quality criteria. Two examples are chosen, which resemble the existing Housing type and climate severity in Uttarakhand's cold region.

A. Passive house in Whistler, Canada

Developed in the Resort Municipality of Whistler, the apartment building consists of 24 units on four floors over a single level of parking built and certified to Passive House standards. There are a mix of 1 bed and two-bedroom rental companies with a common laundry area. The gross floor area is 1,659 m2 achieving an FSR of 1.14. The building was constructed in 2019 by Integra Architecture. The primary energy demand is 145 kWh/m2 per year for heating, hot water, auxiliary, and household electricity. (Database, 2019)

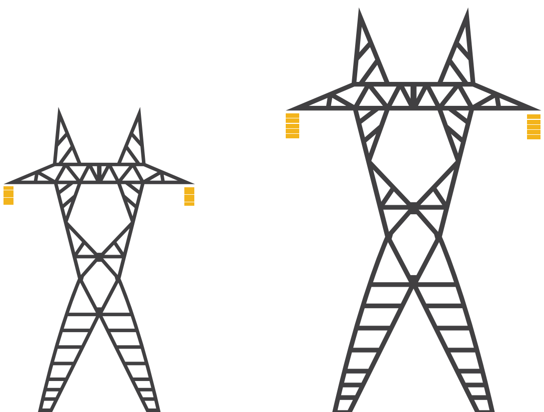
Figure 6: Views of Passive house in Whistler, Canada. Source: (Database, 2019)

Table 11: The key features of the passive house in Whistler, Canada. Source: (Database, 2019)

S. No.	Heading	Energy Efficiency Practices
1	Baseline	Meets all the requirements of passive house certified homes
2	Building Envelope	Meets all the Insulation requirements of the National Energy Code of Canada for Buildings 2011
	a) Walls	Gypsum Board; U-value: 0.124 W/m^2K
	b) Insulation	Fiberglass batt insulation; Cellulose insulation
	c) Roof	Two layers of Gypsum board; Rockwool Batt Insulation; OSB and Plywood Sheathing; U-value: 0.058 W/m^2K
	d) Basement Ceiling/ floor slab	EPS; Reinforced concrete suspended slab; mono-glass spray foam; U-value: 0.08 W/m^2K
	e) Windows	Solid Pine, Exterior insulation, Aluminium cladding; U-value: 0.53 W/m^2K, g-value: 53%
	f) Air sealing	0.15 ach; n50
	g) Thermal Bridging	OSB Sheathing (prefab) blown in Cellulose insulation
3	Ventilation	The ERV is 84% efficient with a rotary heat exchanger.
4	HVAC	District Energy System with heat transfer with sewage through a 2-pipe closed-loop system; modular heat pumps arranged in banks; electrical baseboards provide supplemental heat. Heating demand – 13 kWh/m^2 per year.
	a) Duct system	It is centralized in the attic space, with ducts extending over the corridor before branching down into shafts to serve the units.
5	Domestic Hot Water System	Combination of the District Energy System with heat transfer with sewage through 2-pipe closed-loop system and the building's modular heat pumps arranged in banks. Hot water distributes on the first-floor level before branching up to serve the stack of units.
6	Lighting	Daylighting - horizontal solar shades that extend south are used to block high solar angles, and reflective interior blinds block low solar angles.
7	Indoor Air quality	Low VOC materials
8	Other energy-efficient features	EV stations facility for car parking; bicycle storage unit; Prefabricated wood panels with 3% wood waste. Dense-packed cellulose insulation with 85% post-consumer recycled newspapers.

Source: (Database, 2019)

Recently Apartment housing is becoming common in Uttarakhand. For example, features like providing insulation in walls, floor, windows, and roofs, adhering to U-values according to guidelines, maintaining the required air changes to reduce heat loss, reducing thermal bridging by giving insulation and sheathing, and using recyclable building materials can be implemented for upcoming or renovating apartment projects.



B. Passive house in Montreal, Canada

The Ozalee Passive house is a refurbished family house in Montreal that aims for Passivhaus and LEED Platinum certifications. Many features have been included, like water harvesting, waste material recycling, local and low VOC material, permaculture design, and many more. This is a detached house for one family, built-in 2015 by architect Lucie Langlois. The built-up area is 264 m2. The primary energy demand is 112 kWh/m2 per year for heating, hot water, auxiliary, and household electricity. (Database, 2015)

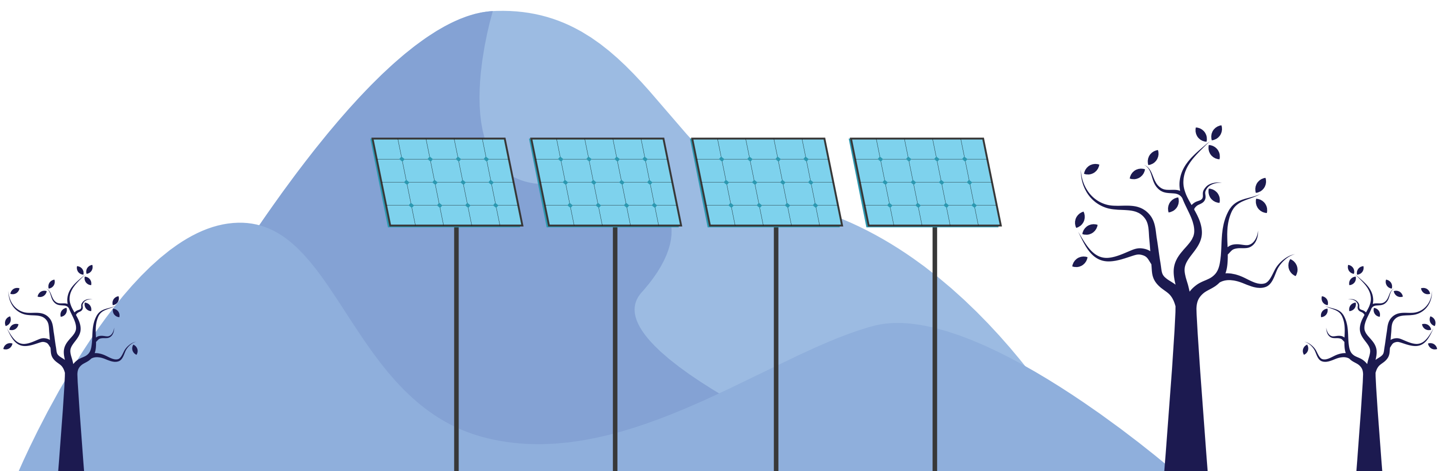
Figure 7: Views of Ozalee Passive house in Montreal, Canada. Source: (Database, 2015)

Table 12: The key features of the Ozalee Passive house in Canada.

Sl. No.	Heading	Energy Efficiency Practices
1	Baseline	Meets all the requirements of Passivhaus and LEED platinum certification
2	Building Envelope	Meets all the Insulation requirements of the National Energy Code of Canada for Buildings 2011
	A) Walls	Gypsum Board, technical cavity, plywood, wood fiber panel, U-value: 0.09 W/m^2K
	B) Insulation	Dense packed cellulose 400 mm thick,
	C) Roof	Gypsum Board, technical cavity, wood fibreboard with aluminum foil inside as vapor and air barrier, wooden roof trusses, loose cellulose insulation, ventilation space; U-value: 0.051 W/m^2K
	D) Basement Ceiling / floor slab	100 mm concrete, EPS insulation board 150 mm; U-value: 0.183 W/m^2K
	E) Windows	Wooden frame with aluminium profile outside; Triple glazing with Low-E coating and argon filling; u-value- 0.53 W/m^2K, g value – 53%.
	F) Air sealing	0.38 ach; n50
	G) Thermal Bridging	SIGA tape as air and moisture barrier, weatherproof membrane
3	Ventilation	geothermal heat exchanger; 83% efficiency
4	HVAC	Electrical supply air heating; 3 heated electrical walls; heating demand – 14 kWh/m^2 per year
5	Water Efficiency	Low flow faucet, shower, and toilet
	A) Domestic Hot Water System	Electric water heater; capacity – 280 liters
6	Lighting	Large Glass windows facilitate natural lighting during the day
7	Indoor Air quality	Low VOC materials
8	Other features	Rainwater harvesting underground tank, greywater recycling, use of local materials, on-site reuse (lumbers, pavers, solid wood walls)

Source: (Database, 2015)

From the reconnaissance surveys done in various urban cities of Uttarakhand; Detached single-family houses are being built with flat roofs for rainwater harvesting. From this example of the Ozalee Passive house, the features like providing insulation in walls, floor, windows, and ceilings, adhering to U-values and G-value according to guidelines, maintaining the required air changes to reduce heat loss, reducing thermal bridging by giving insulation, weatherproof membrane and adhesives/tapes, using local reusable building materials, and installing geothermal heat exchanger can be implemented.



CHINA

Buildings using climate-responsive technologies adjust proactively to climate changes with a high-efficiency resource utilization for environmental protection. With increasing demands for environmental-friendly buildings, various climate-responsive technologies have been adopted in diversified climates in China. Climate-responsive technologies provide the utmost comfort for building occupants indoors with control of environment physics influenced by four dominant climatic features, i.e., temperature, humidity, sunlight, and ventilation (Mao et al., 2018)the present study to explore the regional suitability of climate-responsive technologies was conducted with expert knowledge-based investigation in five kinds of climate regions in China, including severe cold region, cold region, hot summer & cold winter region, hot summer & warm winter region and temperate region. 71 climate-responsive technologies were identified for controlling climate physical features (i.e., temperature, humidity, sunlight, and ventilation.

A. Passive house in Beijing, China

The project is located in a cold area and is the first certified passive house with the plus standard in China. It was constructed in 2017 in a 423 m2 area by the WFR Architects group. The most crucial point for energy consumption is the building's heat loss during the heating season. There are two model residential units on the first floor: a single apartment and a three-room apartment. (Database, 2017)

Figure 8: Views of Passive house in Beijing, China. Source: (Database, 2017)

Table 13: The key features of the passive house in Beijing, China.

Sl. No.	Heading		Energy Efficiency Practices
1	Baseline		Meets all the requirements of Passive house plus certified homes
2	Building Envelope		Meets all the Insulation requirements of Design Standard for Energy Efficiency of Residential Buildings in Severe Cold and Cold Zones, 2010 and CABR 2008
	A)	Walls	20 cm aerated concrete; U-value: 0.127 W/m^2K
	B)	Insulation	25 cm EPS insulation
	C)	Roof	Lightweight concrete with XPS and EPS insulation; U-value: 0.083 W/m^2K
	D)	Basement ceiling / floor slab	31 mm screed, 120 mm RCC, 140mm XPS insulation, 100mm concrete; U-value: 0.235 W/m^2K
	E)	Windows	PVC window frames, triple glazing with argon to prevent heat transfer, U-value: 0.652 W/m^2K, g value – 50%
	F)	Air sealing	0.2 ach, n50
	G)	Thermal Bridging	88% moisture recovery rate
3	Ventilation		Passive heat recovery system
4	HVAC		Air heat pump system, heating demand 5 kWh/m^2 per year
	A)	Duct system	Integrated into envelope
5	Domestic Hot Water System		Air-water heat pump system; Thermo-solar on the roof and hot water tank.
6	Renewable energy system		The photovoltaic system on the roof generates 110 kWh/m^2 per year

Source: (Database, 2017)

From the reconnaissance surveys done as a part of the project inception across various urban cities of Uttarakhand, the government is building apartments for mass housing. From this example of Passive House, the features like providing insulation in walls, floor, windows, and roofs, adhering to U-values and G-value according to guidelines, maintaining the required air changes to reduce heat loss, reducing thermal bridging by using moisture recovery materials along walls and windows, passive heat recovery system, and photovoltaic for generating electricity can be implemented.

B. Passive house in Xinjiang, China.

'Xingfubao' Passive House Pilot-Project is the first realized PH building in Urumqi City in northwest China with a freezing winter climate. The project covers a treated floor area of 4317 m2 with two underground floors and six overground floors. 'Xingfubao' Passive House building consists of shops on the first underground floor, restaurants on the ground floor, and offices and dwellings on the rest of the floors. It was built in 2013 by Christian Hennecke, Culture bridge Architects, and Wang Wei, Xinjiang Architectural Design Institute. It has 24 residential units. The primary energy demand is 191 kWh/m2 per year for heating, hot water, auxiliary, and household electricity. (Database, 2013)

Figure 9: Views of Passive house in Xinjiang, China. Source: (Database, 2013)

Table 14: The key features of the 'Xingfubao' Passive House.

Sl. No.	Heading	Energy Efficiency Practices
1	Baseline	Meets all the requirements of Passive house plus certified homes
2	Building Envelope	Meets all the Insulation requirements of Design Standard for Energy Efficiency of Residential Buildings in Severe Cold and Cold Zones, 2010 and CABR 2008
	A) Walls	20 cm brick wall; u-value – 0.111 W/m^2K
	B) Insulation	30 cm insulation curtain wall facade elements
	C) Roof	120 mm concrete with 300 mm XPS insulation; 8 mm PE film; U-value – 0.126 W/m^2K
	D) Basement ceiling / floor slab	80 mm screed, 40 mm soundproofing layer, 300mm EPS insulation, 100mm concrete; U-value – 0.117 W/m^2K
	E) Windows	PVC window frames with insulation in the air chambers of polyurethane; u-value – 0.58 W/m^2K, g value – 50%
	F) Air sealing	0.2 ach, n50
	G) Thermal Bridging	88% moisture recovery rate hFRG; insulation in the air chambers of polyurethane.
3	Ventilation	Eight ventilation units with heat and humidity recovery system
4	HVAC	Gas Boiler, heating demand 19 kWh/m^2 per year
	A) Duct system	Integrated into envelope
5	Domestic Hot Water System	Solar thermal vacuum tube collectors are installed on the roof. There are 24-panel sets, altogether 103.2 m^2.
6	Renewable energy system	Solar thermal vacuum tube collectors

Source: (Database, 2013)

From the reconnaissance surveys done in Uttarakhand's urban cities, residences with commercial space on the ground floor and living space on the first floor can be commonly seen. From this example of mixed development, the features like providing insulation in walls, floor, windows, and roofs, adhering to U-values and G-value according to guidelines, maintaining the required air changes to reduce heat loss, reducing thermal bridging by using moisture recovery materials along walls and windows, heat and humidity recovery system, and Solar tube collectors for hot water requirement can be implemented.

GERMANY

Dena is Germany's energy efficiency center, renewable energy sources, and intelligent energy systems. As the "Agency for the Applied Energy Transition," they contribute to attaining energy and climate policy objectives. High-rise and terraced houses, villas, and farms consume energy as efficiently as possible (Dena, 2015). Sound insulation, glazing, photovoltaics, solar thermal installations, or heat pumps. Here are two examples depicting the energy-efficient features and design practices. These examples have similar building profiles and are present in the same climate severity as Uttarakhand.

A. Residential units in Bremen, Germany

There are 1-2 residential units with efficiency house class 40. It was constructed in the year 2014. The living space is 150 m2. The primary energy demand is 33 kWh/m2 per year, which is 66% below the recommended EvEV 2009 standard, and the final energy requirement is 13.70 kWh/m2 per year. This residential unit has a transmission heat loss of 0.22 W/m2K, which is 45% below the recommended EvEV 2009 standard (Dena Efficient houses database, 2014)

Figure 10: Views of the residential units in Bremen, Germany. Source: (Dena Efficient houses data base, 2014)

Figure 11: Energy consumption class of the residential units in Bremen, Germany. Source : (Dena Efficient houses database, 2014)

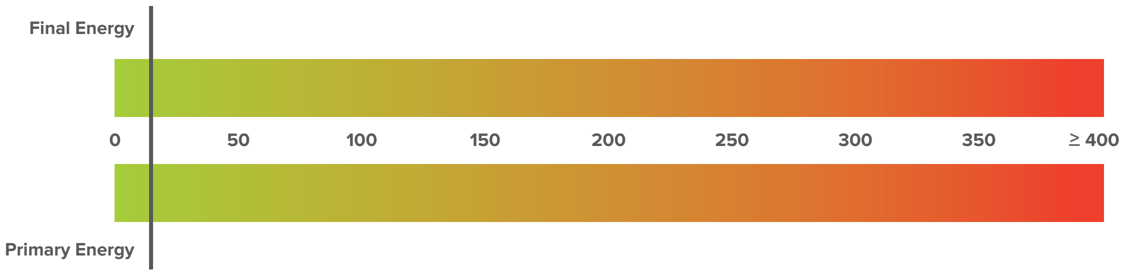


Table 15: The key features of the residential unit in Eberswalde, Germany.

Sl. No.	Heading	Energy Efficiency Practices
1	Baseline	Follows all the compliance of EnEV code 2009; Energy performance certificate
2	Building Envelope	Compact building A/V ratio – 0.76
	A) Walls	Light masonry; U-value: 0.13 W/m^2K
	B) Insulation	20 cm thick insulation, rigid foam panels such as polystyrene
	C) Roof	Sloping roof; mineral wool; U-value: 0.1 W/m^2K; 30 cm thick
	D) Attic	Mineral wool; U-value: 0.3 W/m^2K; 20 cm thick
	E) Windows	Single window; 3-pane heat protection glazing; U-value 0.67 W/m^2K; double casement
	F) Air sealing	1.5 ach per hour n50
3	Ventilation	Central apartment supply and exhaust air system
4	HVAC	Heat recovery system; heat pump, a geothermal system with 80% efficiency
5	Domestic Hot Water System	Central water heating with the solar thermal system.
6	Indoor Air quality	2 kg/m^2 per year CO^2 emissions
7	Renewable energy system	Photovoltaics with a capacity of 10.8 kWp generating 10,000 kWh/year

Source: (Dena Efficient houses database, 2014)

Residential units with pitched roofs integrated with solar panels are becoming common in Uttarakhand. From this example of an energy-efficient residence, the features like providing insulation in walls, floor, windows, and roofs, adhering to U-values according to guidelines, heat protection glazing, maintaining the required air changes to reduce heat loss, heat recovery systems, efficient appliances, and lighting, and using photovoltaics to generate electricity; can be implemented for upcoming projects.

B. Residential units in Bräuningshof, Germany

There are 1-2 residential units with efficiency house class 40. It was constructed in the year 2008. The living space is 160 m2. The primary energy demand is 14 kWh/m2 per year, which is 87% below the recommended EvEV 2009 standard, and the final energy requirement is 19.34 kWh/m2 per year. This residential unit has a transmission heat loss of 0.15 W/m2K, which is 72% below the recommended EvEV 2009 standard (Dena Efficient houses database, 2014)

Figure 12: Views of the Residential units in Bräuningshof, Germany. Source: (Dena Efficient houses data base, 2014)

Figure 13: Energy consumption class of the residential units in Bräuningshof, Germany. Source: (Dena Efficient houses database, 2014)

Table 16: The key features of the residential unit in Bräuningshof, Germany. Source: (Dena Efficient houses database, 2014)

Sl. No.	Heading	Energy Efficiency Practices
1	Baseline	Follows all the compliance of EnEV code 2009; Energy performance certificate
2	Building Envelope	Compact building A/V ratio – 0.66
	A) Walls	Prefabricated house wood construction; u-value – 0.10 W/m²K; 39 cm thick
	B) Insulation	20 cm thick insulation, rigid foam panels such as polystyrene
	C) Roof	Sloping roof; between the rafter insulation; u-value – 0.1 W/m²K; 40 cm thick
	D) Attic	Concrete; u-value – 0.10 W/m²K; 50 cm thick
	E) Windows	Single window; 3-pane heat protection glazing; u-value 0.73 W/m²K; passive house certified frame
	F) Air sealing	1.5 ach per hour n50
3	Ventilation	Central apartment supply and exhaust air system
4	HVAC	Heat recovery system; heat pump, geothermal system with annual performance factor 4. 92% efficiency; wood pellet stove system
5	Domestic Hot Water System	Central water heating with flat plate solar collector integrated into the roof; volume – 1000 liters.
6	Renewable energy system	Flat plate solar collector for hot water

Residential units with pitched roofs integrated with solar heaters for hot water are becoming common in Uttarakhand. From this example of an energy-efficient residence, the features like providing insulation in walls, floor, windows, and roofs, adhering to U-values according to guidelines, heat protection glazing, maintaining the required air changes to reduce heat loss, heat recovery systems, efficient appliances and lighting, and using photovoltaics to generate electricity; can be implemented for upcoming projects.

RUSSIA

The critical aspect of designing in Russia is its climate, making it impossible to develop a common strategy for sustainable design methodology. There are seven climatic zones in the country. Here are the main principles of "sustainable architectural design" for low-rise residential buildings, acceptable and typical for modern Russia (Zhogoleva & Teryagova, 2017).

1. The method of planning transformations - integration of dwelling into natural, social and industrial environment, gradual spatial development, achieving an optimum balance of closed, open, and semi-open spaces.
2. Reference to regional and national traditions of residential house construction
3. The use of environmentally friendly, local building materials and design concepts
4. Energy-efficient architectural design

We have chosen two examples to showcase these strategies. The selected examples are relatable to the project context.

- **The Clever House in Nizhny Novgorod, Russia -** A unique facility has been created – a demo house in which the world's latest technology achievements in the field of energy efficiency and the use of alternative energy sources are put on display. In June 2012, a two-story house with a total area of 240 m2 was built without access to public energy utilities, as its electricity is produced from renewable resources (Green Building Council Russia, 2012).

Figure 14: View of the Celver House in Nizhny Novgorod, Russia. Source: (Green Building Council Russia, 2012)

Table 17: The key features of the clever house in Nizhny Novgorod, Russia.

Sl. No.	Heading	Energy Efficiency Practices
1	Baseline	Building envelope construction and heat losses as per SNiP code 2012.
2	Building Envelope	Meets all requirements as per Building envelope construction and heat losses as per SNiP code 2012.
	a) Walls	Brick panel 300 mm with air film; U-value: 0.356 W/m^{2}K
	b) Insulation	fibered glass, continuous basalt fiber, expanded clay
	c) Roof	Metal and timber structure; 200 mm, air gap in attic
	d) Floor	Timber floor 200 mm; U-value: 0.377 W/m^{2}K
	e) Windows	Argon-filled Triple glazing windows
	f) Air sealing	0.6 ach, n50
3	Ventilation	Heat recovery ventilation,
4	HVAC	Heat pumps; heating demand – 2.3 kW
	a) Duct system	All systems are not hidden away but displayed for public
5	Domestic Hot Water System	Solar water heater system 2.5 kW
6	Lighting	LED lighting, light tubes for indoor lighting,
7	Renewable energy system	Solar modules for electrical power generation; solar vacuum tube technology; 1 kW PV system; micro-wind turbine 1.5 kW,
8	Other features	micro-generation wind turbines using magnetic levitation and a pellet boiler; automated monitoring and control systems.

Source: (Green Building Council Russia, 2012)

A demonstration project is part of the project deliverable in Uttarakhand. From this example of a demonstration project, an energy-efficient residence, features like providing insulation in walls, floor, windows, and roofs, adhering to U-values according to guidelines, heat protection glazing, maintaining the required air changes to reduce heat loss, heat recovery systems, efficient lighting, can be implemented for upcoming projects.

The homeowner Sergey Vishnyakov created an Energy-efficient house in Russia's Ural region - The project. The individual country house was designed considering the climatic conditions of this built-up area, its function, and orientation to the cardinal points. One of the house's first major distinctive features in energy efficiency is the building configuration – a two-storied home with mansard and octagon in the layout. The general building volume is close to the dome, being the most efficient structure (Sharovarova et al., 2017)

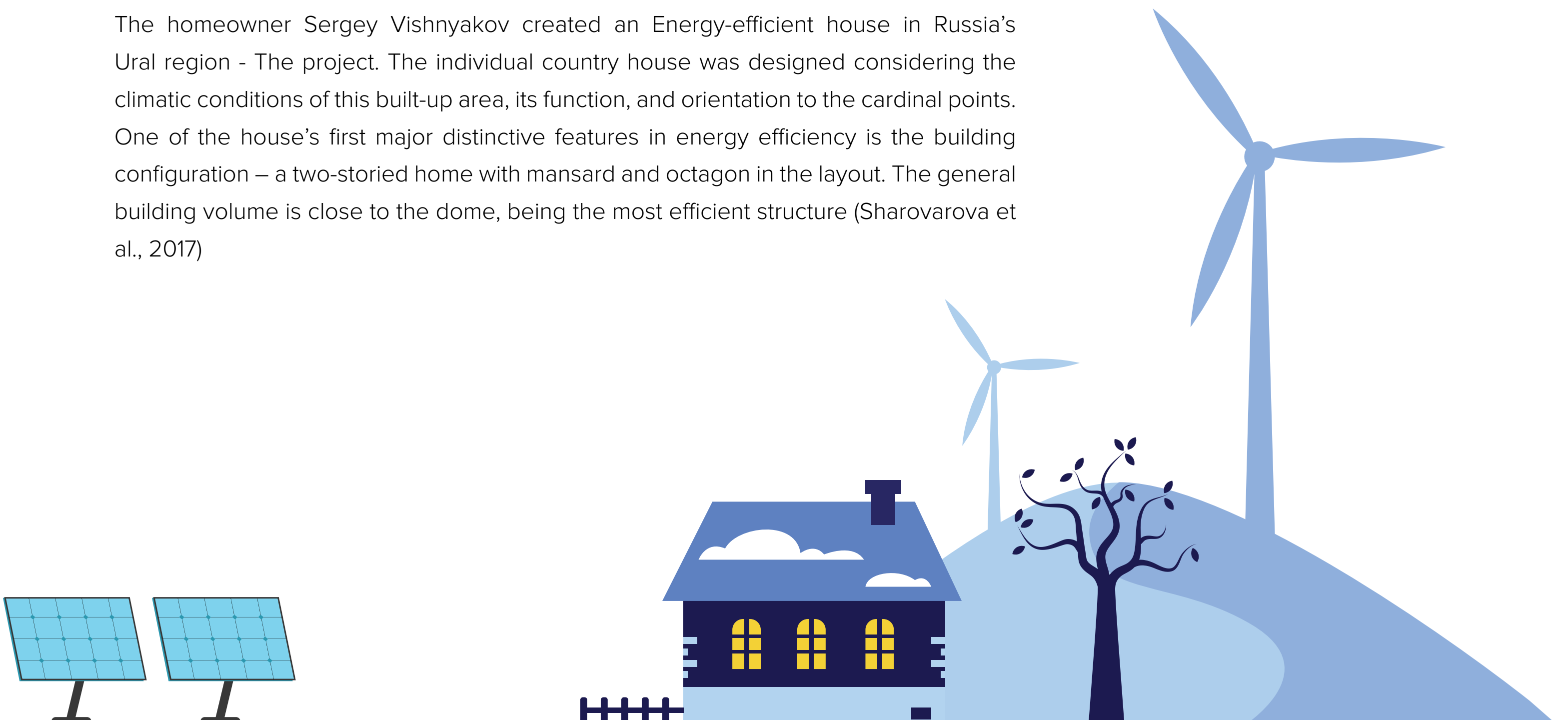


Figure 15: Views of the Energy-efficient house in the Ural region, Russia. Source: (Sharovarova et al., 2017)

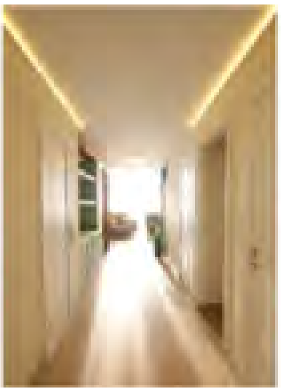




Table 18: The key features of the individual house in the Ural region in Russia. Source: (Sharovarova et al., 2017)

Sl. No.	Heading	Energy Efficiency Practices
1	Baseline	Building envelope construction and heat losses as per SNiP code 2012.
2	Building Envelope	Meets all requirements per Building envelope construction and heat losses per SNiP code 2012.
	A) Walls	Wooden frames, wooden facade board, and air gap between insulation and facade covering; u-value – 0.39 W/m²K
	B) Insulation	250 mm thick glass mineral wool insulation,
	C) Roof	Light steel and wooden structures of frame roof; insulation slab made of flax fibers
	D) Floor	RCC floors; mats and slabs from continuous basalt fiber;
	E) Windows	Triple-pane windows are made of low-emissivity glass and with argon flushing. u-value – 0.56 W/m²K
	F) Air sealing	0.5 ach; n50
	G) Thermal Bridging	facade thermo-panels - polyurethane foam
3	Ventilation	energy-saving supply and exhaust units with recuperative heat exchangers are integrated to create an optimal and comfortable microclimate in rooms
4	HVAC	Electric Boiler, Woodburning stove as stand by heating source; Heat pump,
	A) Duct system	Wall integrated
5	Domestic Hot Water System	Combination of Vacuum solar collectors and Electric heating units embedded into the boiler
6	Renewable energy system	Geothermal heat exchanger, PV panels for lighting and domestic needs;
7	Other features	Greenhouse on the south side of the house which allows reducing energy consumption for heating; external air supply for combustion with preheating in the geothermal heat exchanger;

All the residences have stand-alone heating systems or wood-burning stoves in Uttarakhand. From this example of an energy-efficient home, the features like providing insulation in walls, floor, windows, and roofs, adhering to U-values according to guidelines, efficient glazing, maintaining the required air changes to reduce heat loss, Geothermal heat pump systems with exhaust units, PV panels for lighting and domestic needs can be implemented for upcoming projects.

USA

The US Department of Energy's Building America program comprises public-private partnerships that conduct systems research to improve overall housing performance, increase housing durability and comfort, reduce energy use, and increase energy security for America's homeowners. (Pacific Northwest National Laboratory & Oak Ridge National Laboratory, 2010) Examples from these and other cold-climate builders illustrate best construction practices in the US. These examples are chosen in context with the project regarding upcoming row housing schemes by govt and detached private residences.

A. DOE Zero Energy Ready home at Wheat Ridge, Colorado.

Perrin's Row townhomes rise three stories above the street level in this 26-unit urban infill project along a busy corridor in the Denver suburb of Wheat Ridge (Northwest National Laboratory, 2015). The townhomes were built to the US Department of Energy's Zero Energy Ready Home program's rigorous energy efficiency requirements. The two-bedroom, two-bath, 136 m2 dwellings are expected to save their homeowners nearly Rs. Fifty-two thousand per year in energy bills and should achieve Home Energy Rating System (HERS) scores of 54 without solar energy systems or 28 when the 3.0-kW solar photovoltaic system is installed on the roof of each unit.

Figure 16: New Town Builders' Perrin's Row townhomes. Source: (Northwest National Laboratory, 2015)

Figure 17: HERS Index rating of New Town Builders' Perrin's Row townhomes. Source: (Northwest National Laboratory, 2015)

Table 19: Key features of New Town Builders' Perrin's Row townhomes.

Sl. No.	Heading	Energy Efficiency Practices
1	Baseline	Meets all the requirements of ENERGY STAR certified homes
2	Building Envelope	Meets all the Insulation requirements of the 2012 International Energy Conservation Code
	A) Walls	2 x 6 framed walls built with advanced framing techniques create a well-insulated thermal envelope with an R-value of R-23 by maximizing the space within the wall available for insulation while reducing both thermal bridging and lumber use.
	B) Insulation	Blown Fiberglass – a material manufactured from recycled glass bottles fills the advanced framed homes' wall cavities.
	C) Roof	3 feet ice and water shield; waterproof underlayment; 30-year asphalt shingles; metal drip edge
	D) Attic	i) vented attics that are insulated with R-50 of blown fiberglass insulation. ii) Truss heel heights are raised to 14 inches to maximize the insulation depths to the top plate's outside edge. iii) The packed containers are air sealed to reduce air infiltration at one of the homes' most leak-prone areas.
	E) Windows	Double-pane; argon-filled; vinyl-framed; low-e; U=0.30; SHGC=0.30
	F) Air sealing	2.48 ACH 50.
	G) Thermal Bridging	The fluid-applied (black asphalt emulsion coating) weather-resistant barrier ensures a continuous barrier against exterior bulk moisture while the vapor permeability allows two-way drying.
3	Ventilation	Fresh Air Ventilation; exhaust fans
4	HVAC	92 AFUE furnace; 13 SEER AC.
	A) Duct system	Located within the home's thermal boundary
5	Water Efficiency	water-saving plumbing fixtures, hot water recirculation pump; smart controls; drought-tolerant plants; drip irrigation.
	A) Domestic Hot Water System	Meets all the EPA's hot water distribution requirements; WaterSense program; 95% efficient tankless water heater. Intelligent Recirculation loop technology.
6	Lighting	well-placed efficient expanses of windows to provide natural light while reducing electronic lighting. 100% CFL lighting to minimize overall energy use.
7	Appliances	ENERGY STAR appliances – Refrigerator and Dishwasher
8	Indoor Air quality	Meets all the requirements of the US Environmental Protection Agency's Indoor airPLUS. Low-VOC paints, low-formaldehyde wood products, fresh air ventilation, sealed and cleaned air ducts, and a passive radon mitigation system.
9	Renewable energy system	A 3.0-kW solar photovoltaic system is included in each townhome provides homeowners with substantial financial savings on their utility bills.
10	Other features	i) The project was constructed to accommodate 100-pound-per-square-foot snow loads and wind resistance for 100 miles per hour gusts. ii) Energy management system - an internet-based live monitoring system that tracks solar system production and the home's overall electric consumption.

Source: (Northwest National Laboratory, 2015)

Recently the government has been building affordable row housing in Uttarakhand for middle-income and higher-income groups. From this example of energy-efficient row houses, the features like providing insulation in walls, floor, windows, and roofs, adhering to U-values according to guidelines, installing double pane Low-E glazing, maintaining the required air changes to reduce heat loss, low VOC products to maintain IAQ, and using Solar photovoltaic system to save utility bills can be implemented for upcoming projects.

B. DOE Zero Energy Ready home at Durango, Colorado.

Mantell Hecathorn (Northwest National Laboratory, 2015) built a certified house to ENERGY STAR and Built Green Colorado. This 357 m2 home at Shenandoah Circle is the builder's first DOE Zero Energy Ready Home. The award-winning home achieved a Home Energy Rating System (HERS) score of 50 without PV or 21 when a 6.3-kW PV system was added. The solar electric system should cut annual utility bills.

Figure 18: Home in Durango built by Mantell-Hecathorn builders.

Source: (Northwest National Laboratory, 2015)

Table 20: Keys features of the Home in Durango built by Mantell-Hecathorn builders.

Sl. No.	Heading	Energy Efficiency Practices
1	Baseline	Meets all the requirements of ENERGY STAR certified homes
2	Building Envelope	Meets all the Insulation requirements of the 2012 International Energy Conservation Code
	A) Walls	2x6; 24" on centre; 2 stud corners; ladder blocking; foam-insulated headers; 2" closed-cell spray foam (R-13); 3.5" blown-in fiberglass; coated OSB sheathing; 2" exterior high-density rigid foam (R-10); rain screen; stucco and stone.
	B) Insulation	Blown Fiberglass – a material manufactured from recycled glass bottles fills the advanced framed homes' wall cavities.
	C) Roof	Standing seam metal; ice and water shield at valleys; breathable underlayment
	D) Attic	Vented; 16" raised heel trusses; spray foam sealed baffles; baffles; 24" loose-fill fiberglass at the attic floor (R65); 7" closed-cell spray foam; unfaced fiberglass batts at the vaulted ceiling (R-30); all penetrations sealed with caulk or spray foam.
	E) Windows	Triple-pane; aluminium-clad; low-e; U=0.24; SHGC=0.38
	F) Air sealing	1.11 ACH 50.
	G) Thermal Bridging	There is a 15-mil, sealed radon vapor barrier membrane, then 4 inches (R-20) of rigid foam.
3	Ventilation	Continuous HRV (Heat Recovery Ventilator); MERV 13 filter.
4	HVAC	Rigid metal ducting; 96 % efficient propane furnace; 13 SEER AC.
	A) Duct system	All ducting is R-8 insulated, mastic-sealed rigid metal ducting that is installed in conditioned space, except some return ducts, which are encapsulated in 2 inches of closed-cell spray foam and buried in blown-in fiberglass in the attic.
5	Water Efficiency	water-saving plumbing fixtures, hot water recirculation pump; smart controls; drought-tolerant plants; drip irrigation.
	A) Domestic Hot Water System	i. Meets all the hot water distribution requirements of the EPA's WaterSense program ii. 95% efficient electric tank with recirculating pump
6	Lighting	80% LED, 20% CFL.
7	Appliances	ENERGY STAR appliances – Refrigerator and Dishwasher
8	Indoor Air quality	Meets all the requirements of US Environmental Protection Agency's Indoor airPLUS; No formaldehyde; low-VOCs.
9	Renewable energy system	A 6.3 kW solar photovoltaic system in each townhome provides homeowners with substantial financial savings on their utility bills.
10	Other features	pre-wired for electric car charging; iPad-based controller for HVAC.

Source: (Northwest National Laboratory, 2015)

According to the reconnaissance survey carried out in Uttarakhand, we found many detached residences with pitched roofs. From this example of a detached energy-efficient house, the features like providing insulation in walls, floor, windows, and ceilings, adhering to U-values according to guidelines, vented attics, installing triple-pane Low-E glazing, maintaining the required air changes to reduce heat loss, low VOC products to maintain IAQ, and using Solar photovoltaic system to save utility bills can be implemented for upcoming projects.

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When evaluating a country’s performance against another, it is not a simple comparison, which is why there can’t be a one-size-fits-all approach to policymaking and implementation.

06

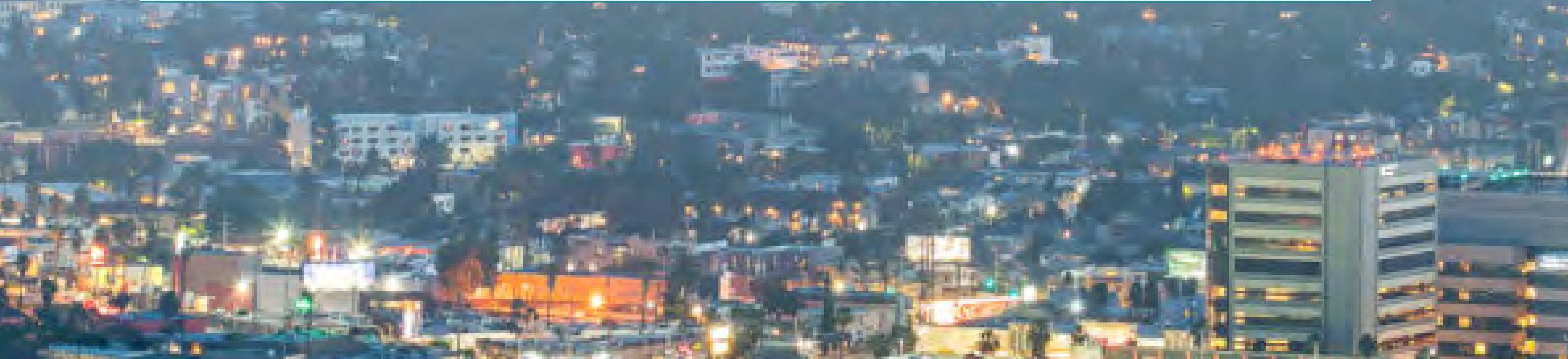
LEARNINGS AND RECOMMENDATIONS

PART 1 LEARNING

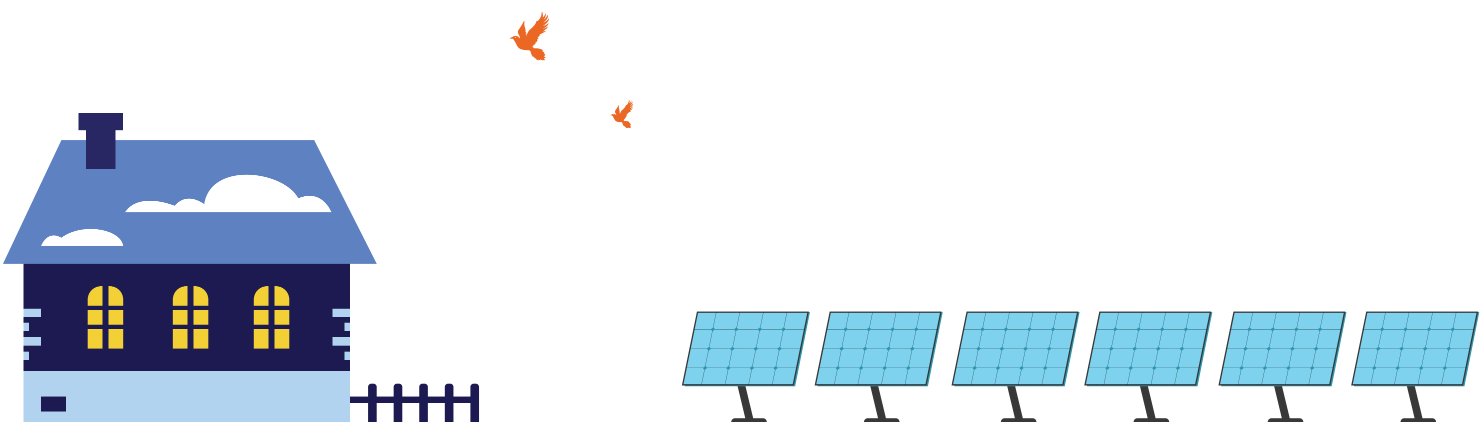
When evaluating a country's performance against another, it is not a simple comparison, which is why there can't be a one-size-fits-all approach to policymaking and implementation. A framework must be crafted to suit India's demands and local market based upon its transformation potential and carefully assessed timeline. While designing the framework, the following must be kept in mind:

Table 21: Opportunities for integration of energy efficiency in building codes/ guidelines

Opportunities	Relevant Recommendations	Relevant Stakeholders
The residential construction segment within Uttarakhand sees most pucca houses used by the inhabitant all year long. In Germany, buildings meant to be used for less than four months yearly or temporary facilities for less than two years are not covered under the Building Energy Code. However, they can voluntarily choose to adopt the code. A similar case exists in Uttarakhand, where people prefer to move into their summer homes during peak winter, leaving their homes empty between November and March.	**Recommendation 1:** Establish guidelines defining building size thresholds • All new construction (to be used for more than six months in a year) should mandatorily adopt the Building Energy Efficiency Guidelines • All Existing construction and new construction (to be used less than four months in a year) can voluntarily adopt the guidelines	• Town and Country Planning Office (TCPO) • Urban Local Body • Ministry of Urban Development (MoUD) • Mussoorie Dehradun Development Authority (MDDA)
Cold climate regions have high energy requirements to meet their space heating demand during peak winter and the energy needed to meet basic cooking, lighting, and water heating requirements.	**Recommendation 2:** Establish guidelines defining energy system requirements • Define and draft acceptable thresholds for different energy systems used in a typical household. e.g., Building envelope, lighting, heating systems, maintenance schedules, renewables, etc. • Simple structured guidelines will help ease the adoption and implementation of the required energy systems.	• Town and Country Planning Office (TCPO) • Urban Local Body • Ministry of Urban Development (MoUD) • Mussoorie Dehradun Development Authority (MDDA) • Uttarakhand Power Corporation Limited (UPCL) • Uttarakhand Renewable Energy Development Agency (UREDA)



Opportunities	Relevant Recommendations	Relevant Stakeholders
Compliance checks are necessary at multiple stages of a project – design, construction, post-construction, and post-occupancy, all of which intend to determine that the building meets the set criteria under the code/policy/guideline. India lacks the infrastructure to support compliance checks for each building. Learning from China's case, the government conducts annual compliance assessments where sample cities are picked up at random and given a two-week notification period. It helps make the homeowner accountable for following the imposed guidelines/code/policies and checking the building's operational capacity.	**Recommendation 3:** Develop a standard compliance check procedure to ensure energy-efficient building construction and operation.	• Urban Local Body • Mussoorie Dehradun Development Authority (MDDA) • Urban Development Directorate (UDD)
For the large-scale implementation of any energy efficiency and low carbon development initiative, the national government, in coherence with the state government and ULBs, must ensure regular training programs for design industry professionals. People must repeat their training every time the guidelines undergo revision, a general practice followed in China.	**Recommendation 4:** Introducing capacity building and training programs for professionals • Design and material optimization for better performance • Guidelines use, adoption, and compliance requirements • Passive design measures to enhance user comfort	• Urban Local Body • Mussoorie Dehradun Development Authority (MDDA)



PART 2 LEARNING

The intention to study various demonstration projects across the globe was to find out how different countries have benchmarked their energy systems as a part of their energy efficiency codes/guidelines. Understanding these benchmarks is critical to define thresholds for the context of Uttarakhand in India for easy translation of guidelines to the commoner. Nonetheless, it also ensures easy adoption and a self-compliance check for the user, thereby making the implementation process accessible.

Table 22: Learnings from the case studies studied across the selected countries.

Sl. No.	Interventions	Recommendations
1	Building Envelope	• Compact house with a small surface to volume ratio generally ranging between 0.66 to 0.76 as observed in Germany. • Use local construction materials available in Uttarakhand to add thermal mass to the external walls to reduce heat loss. • Keeping the U-value range between 0.4 to 0.1 W/m2K for external walls, 0.12 to 0.05 W/m2K for roof, 0.7 to 0.2 W/m2K for windows, 0.3 to 0.08 W/m2K for floors. • Use vapor and moisture barriers like adhesive tapes to seal doors and windows. Thermal bridging, a common phenomenon in a cold climate, must be avoided using a weatherproof membrane, which helps in 2-way drying interior and exterior moisture. • Use of buffer space between living and outside areas to reduce heat loss. • Ventilated attic spaces to reduce moisture build-up.
2	Orientation	• Location of buildings in southern slope to maximize solar radiation. • Location of living spaces towards the south to maximize sum exposure to capture heat. • Use triple-pane Low-E large windows on the southern side and small windows on the northern side.
3	Shading	Adjustable shading to maximize solar radiation during winters.
4	Insulation	Proper insulation must be used in roofs, walls, attics, and floors depending on the climate and design demand severity. Insulation materials like EPS, Fibreglass, glass wool, cellulose should be provided with thickness ranging between 20 to 40 cm using, etc.
5	Daylighting	Adequate daylighting can be achieved using skylight in roofs and clerestory fixed windows.
6	Ventilation	Maintaining the required air changes to reduce heat loss in a building. The air changes per hour at 50-pascal pressure ranges between 0.15 to 2.4 ach.
7	Heating system	• Both active and passive can be combined to achieve a comfortable environment. • Passive heating systems include a solarium, Trombe wall, water wall, air vents in the attic, and heat produced from cooking and cattle/people • Active systems include using a heat pump, solar thermal collectors, stand-alone heating systems, heat recovery systems that can be used per requirement.

8	Renewable energy systems	Use solar PV systems for electricity and domestic hot water and reduce utility bills. The domestic hot water system like solar collectors should be based on capacity and space available on site.
9	Appliance	Use BEE star-labeled appliances like refrigerators, Television, geyser, washing machine, dryer, solar water heaters, etc., to ensure reduction in energy consumption and annual savings.
10	Water efficiency	• Low flow fixtures and flush to be used in washrooms. • Rainwater harvesting can be incorporated.

> This study highlights that energy efficiency should be addressed at multiple levels while designing a new house and operating an existing one. The insights gathered from the energy efficiency landscape of different countries across the globe reveal that while there are significant opportunities for energy efficiency improvements, at the same time, the cost of inaction is equally substantial.

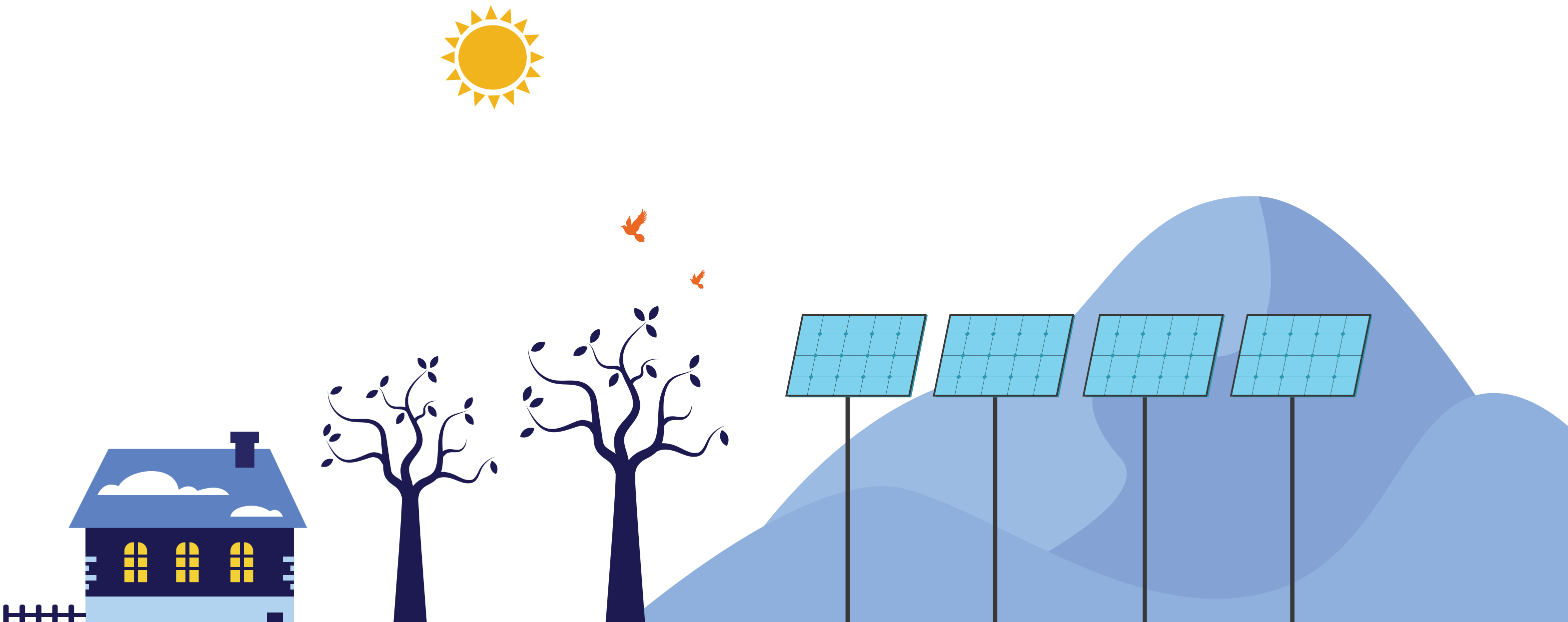
07

DISCUSSION AND WAY FORWARD

The existing and envisaged building stock will collectively contribute to Uttarakhand's high carbon footprint if low-cost, sustainable, local, and affordable solutions are not implemented rapidly. This study highlights that energy efficiency should be addressed at multiple levels while designing a new house and operating an existing one. The insights gathered from the energy efficiency landscape of different countries across the globe reveal that while there are significant opportunities for energy efficiency improvements, at the same time, the cost of inaction is equally substantial.

We have mentioned some pain points in the code implementation system in Section 3 above, which will hinder the implementation of cold-climate guidelines within India at administrative, institutional, technical, design, and social levels. Examples illustrated above show that while full compliance with building codes may present challenges, simply adhering to code is often insufficient. Effective code implementations require procedures, schedules, timelines, and regular checks, all of which define the crux of the implementation framework: adoption, compliance, and enforcement. Administrative capacity to manage the entire procedure from planning to maintenance of a building still poses a threat in a country as vast and developing as India. However, it is not entirely undoable. We can start with a systematic approach that requires minimal administration interference by keeping the codes voluntary. By planning capacity building training workshops for officials involved in the building construction and approval process, we can increase the stringency of the regulation and transition to the mandatory phase. On the other hand, technical barriers can be well tackled by defining the energy systems dominant in India by setting appropriate benchmarks for each of them.

Moving forward, the learnings must be kept in mind while drafting energy efficiency guidelines for the cold region of Uttarakhand. Upon preparing a draft of the guidelines for the Indian context, it can be valuable to engage in brief consultations with stakeholders (architects, developers, and builders) to gain an external perspective that ensures easy adoption, compliance, and enforcement of the final guidelines. The intention here is to reduce as many steps as possible in the implementation process so that mass-scale adoption by different user groups of the society can be achieved quickly. Additionally, the results presented will be helpful in the testing and validation of different scenarios through modes of simulation. Once the parameters and energy systems given in this study have been tested for the Indian cold region, the acceptable parameters can thus be translated into guidelines directly.



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