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Review of energy efficiency initiatives and regulations for residential buildings in India

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ABSTRACT

Considering the importance of reducing energy consumption in building sector, objective of present study is to review codes, standards, regulations and energy efficiency initiatives in different countries to identify effective strategy for implementable energy efficiency measures for building regulations in India. A review of energy regulations of 17 countries including India is carried out covering regulation type, code structure, regulatory assessment, energy efficiency measures along with role of regulations in changing energy consumption trend in these countries. Also the initiatives taken in India on energy efficiency in building sector, National Building Code (NBC), Energy Conservation Building Code (ECBC), Indian Standard SP:41 modified Leadership in Energy and Environmental design (LEED) homes, Small Versatile Affordable Green Rating Integrated Habitat Assessment (GRIHA) for residential buildings to identify implementable energy measures for building regulations. A case study of building regulations of Hamirpur town with composite climate, located in north western Himalayan state of Himachal Pradesh, India is carried out to identify implementation problems for energy regulations at local level. It is found that energy efficiency measures are not followed strictly at local level although National codes or state regulations exist because of inappropriate regulation structure, ineffective enforcement and non-availability of detailed technical methodology. Building envelope, climatic and site conditions, building materials, water conservation, waste water recycling, heating, natural day lighting, cooling, ventilation are found to be important parameters for improving energy efficiency in buildings. The identified energy efficiency measures along with passive solar heating and cooling concepts are proposed to be included in SP: 7-2005 NBC and in building regulations for designing energy efficient residential buildings. The recommendations from this study will be useful for similar climate locations in India and worldwide. The outcome of study can also be used for global locations where the energy regulations do not exist or are not effective.

Contents

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1. Introduction

The residential buildings consume about 10% of world delivered energy which is increasing at the rate of 1.5% per year as per International Energy Agency [IEA] report [1].The electricity consumption accounts for 28% of the total energy use in non-Organization for Economic Cooperation and Development (non-OECD) countries which are continuously rising. In India, the residential building sector which is 79.9% of total housing stock [2], consumes about 21.98% of total energy (170,034 GWh) which is the second highest energy consuming sector after industrial sector [3]. The electricity consumption per capita in residential sector is 0.63 MWh generating a total of 1710.3 million metric ton of CO_2 emissions which is third highest after China and USA [3]. At present, per capita electricity consumption in India is lower than many countries but is expected to rise at fast pace in future due to rapid industrialization and economic growth [4]. The average energy consumption for various activities in India is 38% for cooling, 28% for lighting, 13% for refrigeration, and 7% for air conditioning [5]. The overall energy conservation potential in India is about 23% [6] and overall saving potential in domestic sector is 32% wherein households of rural and urban India have a saving potential of 40–50% and 15–20% respectively [7] as shown in Fig. 1.

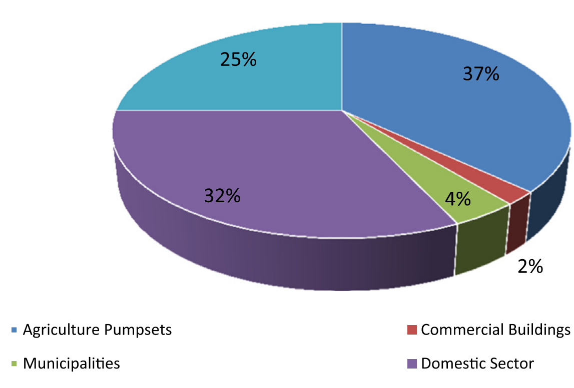

Fig.1. Energy saving potential in various sectors in India.

The residential sector in India is one of the biggest energy consumers with fast growing energy demand and significant energy saving potential. The growing energy needs of the country will bring a huge demand and supply gap in residential sector for which energy efficiency can be an effective tool to reduce this gap. This tool if included in the development regulations effectively can result in huge energy saving. The regulatory procedures for the development of buildings are governed by codes, standards and regulations which vary from each other in a significant way [8]. The main strategy is to develop effective energy regulations by incorporating energy saving measures in building regulations from the prevalent codes, standards and guidelines as adopted in different countries to achieve energy efficiency and reduce energy consumption in residential building sector. This will result in significant reduction in energy demand in a country.

In India, the building codes are proposed by concerned ministry/department and approved by parliament of India, whereas standards are developed by Bureau of Indian Standards (BIS) based on building research. The guidelines can be enacted by any private or government organisations whereas regulations are enacted by town planning department, housing boards, local self-governments of concerned states and approved by state legislative assembly.

Considering global regulatory practices and role of these regulations in changing energy consumption trends in different countries, the main objective of the present study is to identify the most effective regulations and implementable energy efficiency measures in terms of parameters and indicators from the world wide experience which can be incorporated in existing regulations from prevalent codes, standards and guidelines in India, so that the same can be effectively implemented.

The paper is organized as follows: an overview of energy efficiency regulations in various countries are compared and analysed in Section 2 in order to identify the most effective regulation structure and enforcement guidelines. Further various energy efficient initiatives for buildings in India are described in Section 3; energy efficiency standards in India are discussed in Section 4; a case study of Hamirpur town in India is presented in Section 5 followed by results and discussion in Section 6 and conclusion in Section 7 respectively.

Table 1
Comparison of energy efficiency codes of various countries worldwide [22–40].

Country	Energy regulation name	Regulation type	Regulation structure			Enforcement criteria									Regulatory assessment and Revision schedule	Energy efficiency measures							
			Scope	Prescription	Stringency#	Design compliance	Construction compliance	Post construction compliance	Audit before occupancy	Audit after occupancy	Penalty-refusal	Penalty-fine, punishment	Incentives	Capacity building		Heating and cooling	Design guidelines	Construction details methodology	Wall and ceiling insulation	Air sealing and ventilation	Lighting efficiency	Windows U-value and SHGC	Other installations
US	2012 International Residential Code (IRC)	SC	SF, MF	P	Mi	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N
Canada	National Energy Code of Canada for Buildings 2011	SC	SF, MF	P, TO, PR	Mi	Y	N	N	N	N	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
Mexico	2009 New Mexico Energy Conservation Code	SC	SF, MF	P, PR	M	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	N	N	Y	N	Y	Y	N
Brazil	Brazilian Energy Labelling Schemes for Residential Buildings (RTQ-R) 2010	PU	SF, MF	P, PR	V	Y	N	Y	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N
UK	Building Code on Conservation of Fuel and Power 2013-Part L	SC	SF, MF	PR, MO	M	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
France	RT2012	CC	SF, MF	PR	M	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
Germany	EnEV 2014	PC	SF, MF	PR	M	Y	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Italy	EU Energy Performance of Buildings Directive (EPBD) 2002/91/EC in 2005	PC	SF, MF	P, PR	M	Y	Y	N	N	Y	N	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y
Spain	2009 CET, Technical Building Code 2007	PC	SF, MF	P, PR	M	Y	Y	Y	N	N	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y
China	National Building Energy Standards	PC	SF, MF	P, PR	M	Y	Y	N	N	N	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y
India	State/city regulations in few states	PU	SF, MF	P, PR	Mi	Y	N	N	N	N	N	N	N	N	N	Y	Y	N	N	N	N	Y	N

Table 1 (*continued*)

Country	Energy regulation name	Regulation type	Regulation structure			Enforcement criteria									Regulatory assessment and Revision schedule	Energy efficiency measures							
			Scope	Prescription	Stringency#	Design compliance	Construction compliance	Post construction compliance	Audit before occupancy	Audit after occupancy	Penalty-refusal	Penalty-fine, punishment	Incentives	Capacity building		Heating and cooling	Design guidelines	Construction details methodology	Wall and ceiling insulation	Air sealing and ventilation	Lighting efficiency	Windows U-value and SHGC	Other installations
Japan	Energy Conservation Policy for Housing 2011	PU	SF, MF	P, PR	Mi	N	Y	N	N	N	N	N	Y	Y	N	Y	Y	Y	Y	Y	N	Y	N
South Korea	Building Design Criteria for Energy Saving (BDCES) 2008	PU	SF, MF	P, PR	M	Y	N	N	N	Y	Y	N	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
South Africa	South African National Standard SANS 0204: Energy Efficiency in Buildings 2011	PC	SF, MF	P, PR, MO	M	Y	Y	Y	Y	N	Y	N	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y
Australia	BCA 2010-6 Star NatHERS Rating for Buildings	SC	SF, MF	P, PR	M	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	N	N	Y
New Zealand	New Zealand Building Code (NZBC)-Clause H1	CC	SF, MF	P, PR	M	Y	Y	Y	N	N	N	Y	Y	N	Y	Y	Y	N	Y	N	Y	Y	N
Russia	Presidential Decree 2012, State Programme on Energy Savings 2010	PU	SF, MF	P, PR, MO	M	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N

SC – Substitute co-regulation, PU – Public, CC – Conditional co-regulation, PC – Prescribed co-regulation; SF – Single Family, MF – Multifamily; P – Prescriptive, PR – Performance, TO – Trade-off, MO – Model; Mi – Mixed (regulation is enforced mandatory in some parts of a country), M – Mandatory, V – Voluntary; Y – Yes, N – No

#Stringency- means that the regulations are enforced either Mixed or Mandatory or Voluntary in a country,

2. Overview of building regulations worldwide with focus on energy savings

2.1. Building regulations with focus on energy efficiency in different countries

Building regulations are mandatory standards for the design and construction of buildings to ensure safety and health of people including those with disabilities and to ensure energy efficiency [9]. These are means of regulating the development and are described in the master plan of the area. Considering the importance of energy efficiency in buildings, Building Energy Efficiency Codes (BEEC) are enforced parallel to building regulations in many countries under which various mandatory and voluntary measures are enforced to regulate the use of energy in buildings. These are also called Energy Codes, Energy Conservation Codes [11]. In Europe and North America, energy efficient designs were made mandatory in 1970s, whereas many other countries focused on this aspect from 1990s onwards [10]. In all cases, energy regulation is the outcome of provisions mentioned in prevalent standards developed beforehand [10,11]. Also green building rating systems have been developed to achieve energy efficiency through suitable guidelines [12–20] which form basis for formulation of energy codes. Different approaches are followed worldwide for the implementation of building regulations and energy codes. Earlier in USA, National Capital Planning Commission (NCPC) and Department of Energy (DOE) handled building regulations and energy codes separately. However, lately the energy codes of USA are based on standard of International Code Council (ICC) for residential buildings wherein the International Residential Code (IRC), is a comprehensive residential specific version of International Energy Conservation Code (IECC) including building regulations in it. However, in Australia and Canada, both building regulations and energy codes are regulated separately. In China and Indonesia building regulations and energy codes are developed and regulated together to form comprehensive energy regulations. This practice is recommended by International Energy Agency (IEA) [10] to be followed by different countries.

The regulations have three components namely regulation structure, enforcement guidelines and enforcement and when all the three components are dealt together by public organisations these are called public regulations. However, the experience of countries like UK, USA, Australia etc. in adopting public regulations, shows that public regulations are ineffective, expensive, and the concerned institution remains burdened with permission work whereas construction assessment is rarely done, due to which these regulations are not much in practice [21] and being replaced by other regulations known as prescribed co-regulation, conditional co-regulation, substitute co-regulation and private regulation [21].

In prescribed regulation, the site enforcement is done by private organisations, whereas in conditional co-regulation, the enforcement guidelines are prepared jointly by both private organisations and public department whereas site enforcement is done only by private organisations. In substitutive regulations, both enforcement guidelines and site enforcement are done by private organisations and regulation structure is prepared by public department. In private regulations, all the responsibility including regulation structure is with private organisations.

A detailed comparative study of various energy regulations of different countries [22–36] is shown in Table 1 in order to understand the regulation structure, enforcement criteria, energy efficiency measures and performance contribution of each regulation towards energy efficiency. The early adopter countries of energy regulations namely: USA, UK, Germany, France, Canada, China, South Korea and Japan are found to be successful in effective implementation whereas Spain which was also early adopter has ineffective regulations. The late adopter countries like New Zealand, Australia, Italy, Mexico, Russia and South Africa showcased successful implementation whereas in Brazil and India the residential energy regulation is either voluntary or is not effective. In USA, 2012 International Residential Code (IRC) is adopted by 49 states, District of Columbia, Guam, Puerto Rico and the U.S. Virgin Islands whereas in India, Andhra Pradesh and Himachal Pradesh states have energy regulations for residential buildings.

2.2. Role of regulations in changing energy consumption trend

In order to understand the impact of studied regulations on residential building energy consumption, the energy consumption rate (henceforth called rate) in kiloton of oil equivalent (ktoe; 1 ktoe = 11,630,000 kWh)of different countries as per IEA database [39] for the period 1990–2012 is shown in Fig 2–4.

It is seen from Fig. 2 that in USA, the energy consumption since 1997 has decreased with the enforcement of ICC codes. In China, residential energy codes were implemented in early 1980s so the rate remained steady till 2001, increased from 2001 to 2007 due to tremendous economic growth and reduced due to stricter regulations under revised Energy Conservation Law of the People's Republic of China. The energy consumption in residential buildings in India is found rising at a constant rate which is at par with growth rate of the country.

Fig. 3 shows the rate is constant in France, UK, Germany, and Canada which may be due to enforcement of energy codes since 1970, 1976, 1977 and 1978 respectively. However, with the introduction of Energy Performance Building Directive (EPBD) 2002 regulations in France, UK, Germany, and National Energy Code of Canada for Buildings in Canada in 2012, the rate is reduced further. Similar trends are seen in case of Japan, as there existed energy regulations from 1979 onwards, but the rate is decreased with improved and stricter regulations introduced in 2011.

It is seen from figure4 that in Australia, with the strong enforcement of detailed regulations in 2003, the rising energy consumption became constant after 2003 and started growing at a lesser rate. The rate decreased drastically in Italy from 2005 onwards, when for the

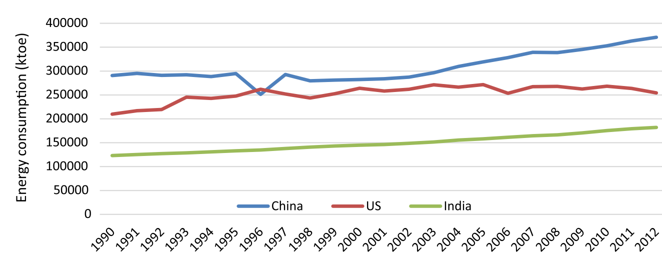

Fig. 2. Energy consumption in residential sector of China, USA and India (1990–2012).

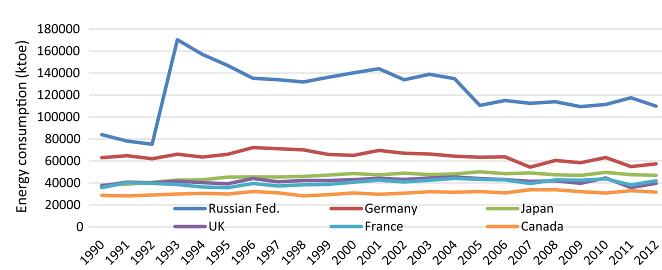

Fig. 3. Energy consumption in residential sector of Russian federation, Germany, Japan, UK, France and Canada (1990–2012).

first time the energy regulation was introduced. Similar trend is seen in Mexico from 2001 onwards, in South Africa from 2008 onwards, in New Zealand from 1992 onwards. Similarly the rate in Korea is decreased from 2008 onwards. In Spain, the rate has grown at a constant pace even though the codes were existing since 1980s. It was due to lack of regulatory assessment and revision schedule in the country. However in 2007 the rate was reduced with the introduction of EPBD regulations in which regulatory assessment and revision schedule was introduced. The rate is rising in Brazil as no mandatory energy regulations are enforced till date.

2.2.1. *Research studies on the effectiveness of energy regulations*

A study done by Yu, Evans and Delgado [37] showed that regulatory assessment is the most important measure for the success of any regulation. Also strong enforcement and high rate of compliance are critical for energy regulations.

Rachel Young [38] compared various country codes by calculating energy intensity per floor space of residential and commercial buildings in various countries. The IEA data was used to obtain data on energy consumption and floor space area of both buildings. The energy consumption/m^2 floor area was further normalized for heating and cooling degree days for various countries using ChartsBin-a web-based data visualization tool. The buildings in India were found to be less energy intensive in general wherein the energy intensity of residential buildings was found to be more than commercial buildings. The energy intensity of residential buildings in India was found to be more than countries like China, Brazil and Mexico. The study concludes that mandatory nature of codes, wide coverage of energy efficiency measures, proper evaluation and enforcement mechanisms such as incentives, refusals for noncompliance and fines and punishments plays a vital role in higher rate of success of the regulations.

Alexander Gusev [41] showed that in spite of much later introduction of energy efficiency code in Russia (in 2009) as compared to other developed countries, the efficiency could be achieved easily by developing a strong and effective regulatory structure developed based on the experience of early adopter countries. However, out of 89 targeted indicators from various sectors 49 could not be achieved due to failure of mandatory audits, lack of monitoring, lack of incentives and finance, voluntary nature of some norms etc.

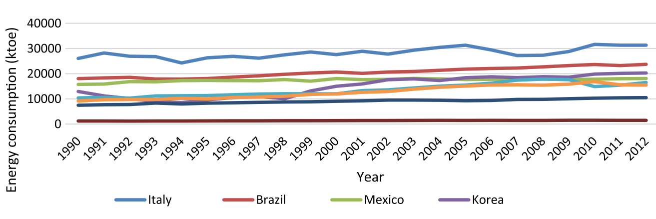

Fig. 4. Energy consumption in residential sector of Italy, Brazil, Mexico, Korea, South Africa, Spain, Australia and New Zealand (1990–2012).

Makramet al. [42] developed a method to find the intensity of regulations over a time in Germany and found that EnEv 2002 regulation was more effective than earlier regulations. The study shows that energy regulation is an effective tool to achieve energy efficiency and strongly affect the adoption of existing technologies.

The inferences for effective implementation of energy regulations based on the experiences in different countries are summarized in Table 2.

It is found from the above study that regulation type, regulation structure, enforcement criteria, regulatory assessment, revision schedule and details of energy efficiency measures are responsible for developing effectiveness of regulations. Thus regulation details summarized in Table 2 need to be introduced in the existing or proposed energy regulations of any country for effective implementation.

2.3. *Overview of regulatory procedures for residential buildings in India*

In order to utilize the experience of different countries in successful implementation of energy regulations, a study of existing regulations national, state and local level and related research studies for residential buildings in India are reviewed in this section.

2.3.1. *Provisions at national level*

The SP: 7-2005 National Building Code [43] is the model code in India for building industry which further provides provisions for building regulations. Prior to 1970 the development control of building industry was limited to building regulations at municipal level only. These regulations were found to be outdated so need was felt to develop standard guidelines for buildings to include modern materials and construction techniques. The first unified National Building Code (NBC) was enacted by combining relevant Indian standards in 1970 [44]. The aim was to unify building regulations of the country to make them performance oriented. NBC was further revised by Bureau of Indian Standards in 1983 and 2005 respectively [45,43]. NBC-2005 is divided into 11 parts which are further divided into 26 sections and contains administrative regulations, development control rules, general building requirements; fire safety requirements; conditions regarding materials, structural design, construction (including safety); and various building services. It covers diversified building industry which is mostly informal and provides basic information to the workforce. NBC regulates the building construction sector and is followed by building construction agencies, private developers, government departments, local bodies. NBC provides a basic framework to develop local regulations for specific regions and covers basic guidelines but energy efficiency aspects are not covered clearly although some provisions may indirectly lead to energy efficiency improvements. Therefore to address energy efficiency issues in building sector, a separate energy code known as Energy Conservation Building Code (ECBC) [46,47] was enacted in 2006 and revised in 2007 by the Indian Bureau of Energy

Table 2
Summary of inferences based on effective implementation of energy regulations by different countries.

S. no.	Regulation details	Inferences for effective implementation of energy regulations
1	Regulation type	Early adopter countries changed from public to prescribed, substitutive or conditional co-regulations for effective implementation
2	Code structure	
	Scope	Single as well as multifamily regulations are followed in all countries.
	Type	Introduce prescriptive regulations initially along with predetermined period of shift for performance based regulations.
	Stringency	Mandatory regulations are most effective whereas voluntary regulations are ineffective.
	Enforcement criteria	• Design compliance is most commonly followed by construction and post construction compliance in most countries. • Audit before and after occupancy, penalty in terms of fines and punishment improves the effectiveness of regulations. • Incentives in terms of tax rebate, soft loans etc. encourage adherence.
	Capacity building	• Awareness and education curriculum enhance the acceptance of regulations among society. • Professional training require to be imparted for understanding regulations by designers for better compliance.
3	Regulatory assessment and Revision schedule	Invite public participation and include latest research that results in revised effective and acceptable regulations.
4	Technical requirements	Technical details of energy regulations along with their explanation are found to be most effective.

Efficiency (BEE), which provides energy efficiency guidelines, both prescriptive and performance based for commercial buildings and multi-family residential buildings. ECBC does not cover small residential buildings whereas these buildings constitute a major part of residential building sector in the country [48,49]. As already discussed in previous sections, the Green rating systems namely Leadership in Energy and Environmental design (LEED) homes and Small Versatile Affordable Green Rating Integrated Habitat Assessment (SVAGRIHA) have also been introduced in India.

2.3.2. Provisions at state level

In India, land is the state subject [50] and its development is under the control of state government through related departments namely Town and Country Planning (TCP), Development authority, Improvement Trusts or urban local bodies. State government enacts the state Town and Country Planning (TCP) Act. The provisions of the ***Act*** are further elaborated in related rules based on which the development plans are formulated at city/town/local level. The national level codes namely NBC and ECBC are regarded as standards by state governments to follow completely or modify as per the needs.

2.3.3. Provisions at local level

The local level office of TCP department or urban local body develop separate development plans for regulating the building sector under which building regulations are defined and these regulations when enforced for the jurisdiction become mandatory by law and are considered as “code”. Building regulations so developed have the desired provisions of NBC which are taken either with or without modification as per their local suitability. Building regulations are mandatory by law for its urban areas jurisdiction only whereas rural areas are generally developed without any regulations. However, development plans for the region include urban fringe and surrounding rural areas which are to be included in the town in near future.

Thus, considering the mandatory nature of building regulations, energy efficiency can only be achieved in buildings if suitable energy efficiency measures are incorporated in building regulations which will result in significant reduction in energy demand. As mentioned above, only Himachal Pradesh and Andhra Pradesh states of India have introduced energy efficiency measures in state building regulations which are to be detailed in respective city level development plans.

2.4. Research related to building regulations in India

Various researchers have studied the relation of building regulations and energy efficiency in India. A study by TERI recommended improvements in existing building regulations by including energy efficiency in residential buildings in Bangalore through proper orientation, building envelope (fenestration, shading devices, roof insulation and wall insulation), indoor lighting and solar water heating. Further, structure of building regulations is recommended with mandatory and voluntary guidelines, from prescription to performance based regulations, capacity building of stakeholders, incentives for energy efficiency and dissemination using web tools and calculators [51].

Huang and Deringer [52] identifies the barriers in effective implementation of ECBC and NBC due to lack of clear implementable guidelines, lack of local infrastructure, supervision, monitoring, incentives, appropriate materials, equipment and widespread expertise.

Leadership in Energy and Environmental Design (LEED) [12] is a rating system developed in USA based on various energy efficiency provisions as mentioned in various USA energy standards like ASHRAE standards and ICC codes. For example, energy performance evaluation using simulation requires weather data which is available for most of locations in USA and other developed countries but may not be available for developing countries. Further the simulation software and procedures are better available in countries where these are developed and used which is not the case in most of the developing countries. The problem further aggravates when professional training is not provided by energy regulation enforcing agencies. The prescriptive requirements are the technical details which may not regulated properly in many countries such as U-value of materials, wood certification etc. Hence it becomes difficult to implement USA regulations, standards and rating systems such as LEED in countries like India where USA standards are not used.

Further it is also difficult to use any sustainable rating system due to varied nature of climates, regulation enforcement powers with varied nature state governments, lack of adequate related guidelines voluntary compliance of ECBC India [53–54].

Kumar and Pushplata [55,56] studied the building regulations of hill towns of Himalayan region for sustainability and environmental preservation and recommended performance and location specific regulations. In another study Kumar [57] recommended that development of building regulations for hill regions should consider vernacular architecture benefits like smaller buildings, local materials, better earthquake resistance, site development using cut and fill, slope stabilization and aesthetic quality. Further regulations at settlement level, cluster level and building level are also suggested. However, the study did not address newly enforced building regulation measures of energy efficiency as per revised HP Town Planning Rules [58–59] even though the same are notified beforehand.

Ramesh et al. [60] studied the impact of building envelope insulation, glazing (single or double) and onsite power generation on energy efficiency of residential buildings considering life cycle energy (embodied and operational) for 75 years. Tulsyan et.al [61] studied the impact of ECBC measures on energy saving of different buildings and found that building envelope can save up to 15% of total energy. It is found that the energy efficiency is a measure of how judiciously building uses energy. Reddy and Jagdish [62] identified various common and alternative building materials and calculated their embodied energy which is used further to calculate total embodied energy of a building for different slab types Debnath et al. [63] considered total embodied energy of building materials consumed in different storey residential buildings. Pinky and Palamiappan [64] studied life cycle energy analysis impact of a case study building considering embodied, operational and demolition energy and total life span of the building. Information on constructed energy efficient buildings in India has been compiled under Ministry of New and Renewable Energy (MNRE) project [65].

The important energy efficiency parameters identified from the various research studies are listed in Table 3.

It is found that embodied, operational and demolition energy needs to be considered and the energy use is dependent on building height in terms of number of floors, life span, envelope properties and climatic conditions. The electrical energy use can be minimized by the use of on-site photovoltaic generation, better HVAC systems and limiting the use of artificial light.

3. Energy efficiency initiatives for buildings in India

During 1990s, a number of studies were carried out to estimate the potential and cost effectiveness of energy efficiency and demand side management (DSM) in India [66]. However, first serious effort was made during 8th Five Year Plan (1992–1997) for

Table 3
Identification of Energy efficiency parameters for buildings based on research studies in India.

Parameters		[60]	[61]	[62]	[63]	[64]	[65]
Energy use	Embodied energy	✓	X	✓	✓	✓	✓
	Operational energy	✓	✓	X	X	✓	✓
	Demolition energy	X	X	X	X	X	✓
Life span of building		X	X	X	X	✓	X
Building height		✓	X	X	✓	X	X
Thermal properties	Walls	✓	✓	X	X	✓	X
	Roof	✓	X	X	X	✓	X
	Glazing-U Value, SHGC, VLT, shading coefficient	✓	✓	X	X	X	X
No. of glazing panes- single or double		✓	✓	X	X	X	✓
Climatic conditions		✓	✓	X	X	X	✓
On site Photovoltaic generation		✓	X	X	X	X	✓
HVAC -Coefficient of performance, economizer		X	✓	X	X	X	X
Artificial lighting (Lighting Power density)		X	✓	X	X	X	X
Solar water heaters		X	X	X	X	X	✓
Alternative design evaluation		X	X	X	X	X	✓
Behaviour of inhabitants		X	✓	X	X	X	✓

improving energy efficiency in industry and building sector [67]. India launched a website portal for information service on energy efficiency to public in 1999 [68] and energy efficiency awards were introduced for manufacturers of rated appliances and recently to residential buildings [69].

3.1. Initiatives for improving energy efficiency in buildings

The Ministry of Power is primarily responsible for the overall development of electrical energy through generation, transmission and distribution in the country which is focusing on demand side management and energy efficiency in buildings and industry [70]. Energy Conservation Act was introduced in 2001 during 9th Five Year Plan (1997–2002) [69,71] and Bureau of Energy Efficiency (BEE) was established in 2002 by the Ministry of Power. BEE identified energy intensive industries, commercial building as designated consumers and developed energy consumption norms however residential buildings were not covered for energy efficiency [46]. The 10th Five Year Plan (2002–07) addressed benchmarking of the hydrocarbon for climate change [72]. Ministry of Power revised the existing Electricity Act in 2003 [73] to regulate generation, transmission and distribution of electricity. This act focused on enhancing electricity quality and reliability to consumers through development of Central Electricity Authority as technical advisor and development of regulatory mechanism, demand side management through separate agency at state level called Regulatory Commissions, and the state electricity boards. In 2006, the Planning Commission of India declared an Integrated Energy Policy to integrate focus of ministries dealing with energy sector to address energy access to poorest and energy security to sustain the annual economic growth rate of the country to 8–9% till 2031. The policy recommended restructuring of BEE for energy efficiency related activities [74]. BEE promoted use of energy efficient appliances using energy labelling under National Energy Labelling Programme 2006 also called Standard and Labelling (S&L) Programme [75] under which initially frost free and direct cooled refrigerator, tubular fluorescent lamp and air conditioners were rated and presently ceiling fans, LPG stoves, colour televisions, storage water geysers, washing machines, motors are also covered. BEE also developed Energy Conservation Building Code (ECBC) 2006 and revised in 2007 [76,77]. Presently the research and development programme of BEE focuses on development of energy efficient windows, development of low cost insulation materials and development of simulation software [46].

Under 11th Five Year Plan (2007–12) various programmes were launched to reduce the energy consumption of the country [78]. A National Action Plan on Climate Change (NAPCC) was prepared in 2008 to achieve sustainable development in building sector considering environmental aspects especially reducing carbon emissions [79]. NAPCC considered use of climate friendly technologies and financial incentives for greenhouse gas emissions reduction. NAPCC has 8 missions out of which National mission for Enhanced Energy Efficiency (NMEEE) is important for building sector [80]. The mission focuses on encouraging use of energy efficient appliances, demand side management and developing fiscal instruments to promote energy efficiency. NMEEE targets included tax exemption for use of energy efficiency measures, up gradation of existing buildings for energy efficiency, efficient street lights and pumping sets. Super-Efficient Equipment Programme (SEEP) was launched recently by BEE under NMEEE which is focused on incentivized manufactures and sale of most efficient appliances in India.

BEE launched energy efficient lamp saving scheme in 2009 under which good quality subsidized compact florescent lamps were distributed to households to reduce the lighting demand [81]. The star rating for buildings was introduced in 2009 to rate a commercial building for its performance on a scale of 1–5 stars. In 2010 The Energy and Resource Institute (TERI), adopted a calculation tool for energy assessment of buildings and launched a toolkit named ittoolkitindia [82] that calculates energy needs of building and recommends active and passive energy efficiency measures. These schemes resulted in less demand of energy and reduction of investments for generation of electricity by government side.

3.2. Initiatives on use of renewable energy in buildings

Ministry of New and Renewable Energy (MNRE) is the nodal agency of government of India relating to promotion of new and renewable energy sources and is encouraging renewable energy use in buildings through following initiatives:

3.2.1. Passive solar building programme

MNRE provides financial support for training, education, demonstration activities to promote energy efficient building designs based on the principles of solar architecture [83]. The programme encourages development of energy efficient buildings using passive solar features that considers use of solar energy for heating, cooling and day lighting by proper orientation, use of appropriate materials, door windows sizing and designing, shading devices etc. Some states have constructed demonstration buildings but not much progress has been made. However, Himachal Pradesh is first state in the country to make passive design features mandatory in the construction of all its future buildings and constructed a number of passive solar designed buildings. The first author (SS Chandel) has co-ordinated the Solar House Action Plan of Government of Himachal Pradesh during 1993–2009 which resulted in construction of more than 200 buildings under this programme [84–86]. Chandel and Aggarwal [84] have studied the performance of a passive solar bank office building at Shimla in the state showing the improvement in energy efficiency and energy saving potential of a passive solar building. The evaluation of another passive solar building constructed in Mandi town by Chandel and Sarkar [87] have shown that the adaption of passive solar features leads to considerable improvement in energy efficiency, cost effectiveness and sustainability.

3.2.2. Green building initiative

MNRE has taken another initiative to promote green buildings in India through Green Rating Integrated Habitat Assessment (GRIHA) rating system [88] during 12th Five year Plan (2013–2018) under which incentives are provided for the construction of green buildings. Financial assistance is also provided for the installation of solar water heaters, solar lanterns, solar cookers and rooftop solar photovoltaic power generation systems by MNRE along with incentives to financial institutions for supporting installation of solar systems.

3.2.3. Solar city programme

100 cities are proposed to be supported for development as Solar Cities by MNRE [83] aimed at minimum of 10% reduction in projected demand for conventional energy by enhancing supply from renewable energy sources in the city and using energy efficiency measures. The basic aim is to motivate the local governments to adopt renewable energy technologies and energy efficiency measures by using solar, wind, biomass, small hydro, and waste to energy resources depending on the need and resource availability in a city.

4. Energy efficiency standards, guidelines and regulations in India

A detailed literature survey is carried out to understand the role of national level existing codes/ standards/guidelines in the development of energy efficient residential buildings.

4.1. Standards: SP41: Handbook of functional requirements of buildings

A need was felt for detailed manual for various provisions of National Building Code (NBC) 1983 related to thermal comfort, day lighting, shading devices, ventilation rate etc. The Central Building Research Institute (CBRI), Roorkee prepared a handbook which was adopted as Indian Standard code [89]. This handbook provides detailed information on climatology, heat insulation, ventilation and lighting in non-industrial buildings for the planning and functional design of buildings under Indian conditions based on Indian standards. It has four parts: Part 1 deals with basic climatic elements like air temperature, solar radiation, humidity, rainfall and wind and climatic zones of the country are described. Part 2 deals with heat insulation of buildings, such as dwelling, hospitals, schools and office buildings both for air-conditioned and non-air conditioned buildings. Part 3 gives detailed information on the requirements of ventilation and design guidelines for achieving desired ventilation rates in buildings. Part 4 deals with design methods for daylighting, artificial lighting and supplementary artificial lighting which would depend upon the type of buildings and the visual task being performed by the occupants.

The handbook provides general calculation methodology and fundamentals of various concepts but does not provide any specific energy efficiency guidelines for residential or any other buildings. This require to be introduced and elaborated in NBC so that these are followed in the country.

4.2. Energy Conservation Building Code (ECBC) 2007

ECBC is a voluntary standard [46] launched by BEE mainly for commercial buildings having load of 500 kW or to buildings having conditioned space of more than 1000 m^2. The adoption of a code vests with state governments as per their requirements. ECBC is implemented 22 states and 1 union territory (UT) out of 29 states and 7 union territories of India. Rajasthan, Odisha, Uttarakhand, Punjab, Karnataka, Andhra Pradesh and UT Puducherry have implemented ECBC without modifications, whereas Uttar Pradesh, Kerala, Chhattisgarh, Gujarat, Bihar, Tamil Nadu, Haryana, Maharashtra and West Bengal have amended the code to suit their climatic conditions. Himachal Pradesh, Assam, Tripura, Mizoram, Jharkhand, Goa and Madhya Pradesh are in the process of implementation after amendments. The main purpose of ECBC is to provide minimum requirements for the energy-efficient design and construction of buildings for various climatic conditions in India. Various parameters covered under ECBC are given in Table 4:

4.3. Rating systems

4.3.1. Modified Leadership in Energy and Environmental Design for homes

A green building rating system was introduced in India through Indian Green Building Council (IGBC) that modified the Leadership in Energy and Environmental Design (LEED) rating system of United States to suit Indian conditions [12]. It is the first dedicated rating system for residential buildings and is focused on existing materials, practices and technology. It is both prescriptive and performance based in nature and has certain prerequisites for qualification of building for rating. It rates individual residential unit and multi-dwelling residential units for 75 and 100 points respectively and provides rating criteria for both types of residential units [12]. Various energy efficiency measures provided are shown in Table 5:

4.3.2. Small Versatile Affordable Green Rating Integrated Habitat Assessment for residential buildings (SVAGRIHA)

A native rating system named Green Rating Integrated Habitat Assessment (GRIHA) is developed by The Energy and Resources Institute (TERI) in 2005 which was adopted as national rating system by Ministry of New and Renewable Energy, government of India in 2007 [88]. It has further been developed specially for residential buildings and is called SVAGRIHA. It recommends ECBC for the energy efficiency benchmarking and evaluates further improvements and gives points for enhancement over ECBC base case recommendations. It rates residential buildings on the basis of 50 energy efficiency points [13] and for five climatic classifications defined in NBC 2005 [43] as shown in Table 6 below:

The energy efficiency measures of SVAGRIHA are shown in Table 7 for a composite climate.

4.4. Guidelines

4.4.1. Handbook of energy conscious buildings

This handbook is an outcome of a project undertaken jointly by Indian Institute of Technology, Bombay and Solar Energy Centre of MNRE now known as National Institute of Solar Energy (NISE) and provides information on energy conscious building. It provides guidelines on the use of eco-friendly and less energy intensive materials, passive solar techniques, day lighting features, integration of renewable energy technologies in building design, conservation of water and waste water recycling, rainfall harvesting and use of energy-efficient appliances [90]. Specific guidelines are developed for residential buildings in different climates. The parameters suitable for hot and dry climate are given in Table 8.

4.5. Building regulations in India

Considering present state of provisions and effectiveness of energy regulations in various countries as discussed above, there is a lack of energy regulations in a number of countries and where such regulations exist, these are not much effective and face many barriers [52]. As already mentioned in Section 2, India does not have a national energy code for residential buildings. However, a few states namely Himachal Pradesh and Andhra Pradesh have included some energy efficiency provisions in their respective building regulations. Himachal Pradesh has constructed a number of energy efficient buildings under the 'Passive solar building programme'. Also the state of Himachal Pradesh is pioneer in introducing energy efficiency measures in building regulations. In order to understand the effectiveness of these provisions, a case

Table 4
Energy efficiency measures under Energy Conservation Building Code of India.

Sl. no.	Indicators and parameters	Provisions for residential buildings in composite climate
1.	Orientation	Site orientation as per climatic conditions
2.	Building envelope	As per prescriptive requirements given in 1.iv.d
	i. Fenestration Glazing material- U-factor & solar heat gain coefficient (SHGC)	
	ii. Air leakage	Maximum- Glazed external doors: 5.01/s m², others 2.0/s m²
	iii. Building envelope sealing	Joints, utility lines penetrations, site build fenestrations, assemblies, other openings.
	iv. Prescriptive requirements:	
	a) Roofs	Max. U value (assembly): 0.261, Min. R-Value (Insulation): 3.5
	b) Cool roofs	For slopes less than 20°: Min. solar reflectance 0.70, Min. emittance: 0.75
	c) Opaque walls	Max. *U* value (assembly): 0.44, Min. *R*-value (insulation): 2.1
	d) Vertical fenestrations	Max. *U* value: 3.3, Max. SHGC: 0.25 (WWR < 40%), 0.20 (WWR 40% –60%), Min. VLT (Visible Light Transmittance): 0.27 (WWR < 30%), 0.2 (WWR 30 %– 40%), 0.16 (WWR 40 %–50%), 0.13 (WWR 50% –60%)
	e) Skylights	Max. *U*-value: 11.24, Max. SHGC: 0.4 (0–2% skylight to roof ratio (SRR)): 0.25 (2.1–5% SRR)
3.	HVAC	
	i. Natural ventilation: Rate	Rates as per NBC 2005
	ii. Minimum equipment efficiency	Minimum (Coefficient of performance) COP, Min. (Integrated part load value) IPLV, power consumption ratings AC units.
	iii. Controls	Use of time clock, temperature, cooling tower controls.
	iv. Piping & ductwork	Min R- Value insulation for piping, cooling system & ductwork.
	v. System balancing	
	vi. Condenser	
	vii. Economizers	
4.	Service hot water and pumping	
	i. Solar water heaters	
	a. Capacity	Min 1/5th of total capacity
	b. Equipment efficiency	As per IS codes
	c. Piping insulation	Min R-value 0.74 (above 60°, 0.35 (40 – 60°)
5.	Lighting	
	i. Lighting controls	Automatic control (Min. building area 500 m²), occupancy sensors, space control area requirements, outdoor controls, exit signs.
	ii. Light power density Power consumption standard (Watts/ m²).	Interior lighting: • Multifamily residential: 7.5 W/m² (Building Area method) or Space Function method for various activities. Exterior lighting: • Building entrance with canopy:13 W/m² • Building exit: 60 W/linear m of door width • Building façade: 2 W/ m² of vertical façade
	iii. Use of energy efficient lamps	Min. 60 lm/W efficacy (outdoor)
6.	Electrical power	
	i. Efficient motors	Use of efficient motors in equipment
	ii. Power correction factor	0.95–1 power factor for 3 phase having > 100 A supply.
	iii. Power distribution system	Proper sizing of cables: max. 1% power losses

study is presented in Section 5 for Hamirpur town located in a composite climate zone.

5. Case study in a composite climate: Hamirpur town, India

5.1. Present status

As both standards and guidelines are not implemented directly so the study of building regulations at local location in a state is essential to know the energy efficiency measures adopted for the development of residential buildings. The reason for taking up this case study is that composite climate is the most dominant climate in large parts of India besides the energy regulations are already enforced in Hamirpur through existing regulations. The outcome of study can be used for global locations which have no energy regulations or existing regulations are not effective.

Hamirpur town (latitude 31.63°N and longitude 76.52°E) is located in the state of Himachal Pradesh in the north-western Himalayan region of the country. The elevation of the state ranges from 450 m to 6500 m above mean sea level and is divided into two broad climatic zones: composite and cold as per NBC classification [43] and Hamirpur is located in the composite climate.

The development plan follows building regulations of Hamirpur town [91] and is implemented by Town and Country Planning (TCP) department of the state. However, these building regulations are basic in nature and does not address energy efficiency measures. Due to varied climatic conditions, the architectural features in the buildings are unique and energy needs of inhabitants are also different throughout the year. In 1994, considering the energy use in buildings, a Solar House Action Plan for Himachal Pradesh was implemented in the state regulating that all the govt. and semi govt. building shall have passive solar features with day lighting features so as to reduce the dependence on conventional energy sources and electricity [85]. Under the plan, the state government has modified the existing building regulations enacted under the Himachal Pradesh Town and Country Planning (HPTCP) Act to include passive solar and energy conservation measures in all types of buildings [58,59]. In spite of inclusion of passive solar building design concepts in HPTCP Act in 2009, the building regulations under the development plan for Hamirpur has not been modified. The regulations have not been revised so far to include various provisions of the revised act of 2009 and revised rules of 2014. Thus, there is no specific adherence for energy efficiency in buildings including residential buildings although there is a mandatory provision to have rain water harvesting systems in all buildings as a water conservation measure. MNRE has declared Hamirpur as a solar city which is among one of first 100 solar cities to be developed in India [83] as such the energy efficiency measures need to be addressed in building regulations. It is found that neither study area nor the state has any energy efficiency code for residential buildings.

5.2. Energy consumption pattern

It is important to understand the energy consumption pattern of the study area so as to suggest any modifications in the building regulations. Electricity is the main source of energy in Himachal Pradesh which is used mostly for heating, cooling and lighting. Hamirpur with sub humid subtropical climate with harsh summers and winters from April–August and December–March respectively for which electricity is used for both heating and cooling of the building. The exact statistics for energy use for study area could not be presented due to lack of secondary data. However, it can be seen from electricity sale and purchase statistics of the state that demand is more in winters than in summers as more electricity is sold to surrounding states in summer and rarely in winters. Also frequent electricity cuts are observed during winters due to shortage of electricity and overloading. It is observed that inhabitants prefer to sleep on the terraces during summers and

Table 5
Energy efficiency measures in modified LEED homes, IGBC.

Sl. no	Indicator and parameter	Provisions for residential buildings Individual residential unit	Multi-dwelling residential units
1.	Local building regulations	Mandatory	Mandatory
2.	2.1 Rain water harvesting	Mandatory	Mandatory
	i. Rainwater harvesting system to capture rain from roof & non-roof areas		
	a. > 50%	2 points	2 points
	b. > 75%	4 points	4 points
	ii. Water efficient plumbing fixtures using less water		
	a. < 25% less	2 points	2 points
	b. < 35% less	4 points	4 points
	2.2 Water conserving landscape:	Mandatory	Mandatory
	i. Min 15% area landscaped.	1 point	1 point
	ii. Draught tolerant species in % area:	2 points	2 points
	a. > 20% area	Not applicable	2 points
	b. > 40% area	Not applicable	1 point
	iii. Reducing turf area		
	a. < 20% area		
	b. < 40% area		
	2.3 Waste water treatment & reuse: treated water use		
	a. > 50%	1 point	1 point
	b. > 95%	2 points	2 points
3.	3.1 Heat island effect-non roof: shaded/softscaped area		
	a. > 50% area	2 points	1 point
	b. > 75% area	4 points	2 points
	3.2 Heat island effect- roof: use high reflectance & emittance materials or vegetation		
	a. > 50% area	2 points	2 points
	b. > 75% area	4 points	4 points
4.	Orientation	Use of simulation	
5.	5.1 SHGC	2 points	2 points
	i. WWR < 20%: 0.38		
	ii. WWR: 20 –30%: 0.32		
	iii. WWR: > 30%: 0.27		
	5.2 Glazing U- Value	1 point	1 point
	i. WWR: < 30%: 3.3		
	ii. WWR: > 30%: 2.8		
	5.3 Wall assembly *U*-vlue: 1.8	1 point	2 points
	5.4 Roof assembly *U*-value: 0.5	1 point	2 point
6.	Lighting		
	i. Lighting power density reduction		
	a. > 20%	1 point	1 point
	b. > 30%	2 points	2 points
	ii. Lighting controls	Not mandatory	1 point
7.	7.1 Air-conditioning systems: star rating		
	i. Unitary: Min 3 star or Central system efficiency:		
	a. > 10%	1 point	1 point
	b. > 20%	2 points	2 points
	7.2 Space heating system	Mandatory	Mandatory
	a. Unitary heat pump with min. COP efficiency as 2.5 and use of non-electric heating system	Mandatory	Mandatory
	b. Min. thermal efficiency: 70%		
8.	Solar water heating system		
	i. Hot water supply to total hot water demand	> 50%: 2 point > 95%: 4 points	> 25%: 2 points > 50%: 4 points
9.	CFC-free equipment Energy saving measures in appliances and other equipment	Mandatory to Use any four BEE 4-star rated equipment from Ceiling Fans, Electric geysers, Refrigerators, Television, Washing machines, Pumps and Motors, Other rated appliances	Mandatory to use any two from BEE 4-star rated Pumps, BEE 4-star rated Motors, Intelligent elevators, Efficient parking garage exhaust system, Other energy efficient equipment.
10.	10.1 Energy performance & enhancement:		
	i. Percentage energy cost savings	1–10 point for 3% –30% savings	1–10 point for 2% –20% savings
	10.2 Use on-site renewable energy sources:	Mandatory	Not mandatory
	i. Min. 5% generation	> 5%: 2 points > 10%: 4 points > 15%: 6 points	> 2.5%: 2 points > 5%: 4 points > 7.5%: 6 points
	ii. Generation % of total energy use		
11.	Distributed power generation	Not applicable	hybrid distributed power generation sets using non fossil fuels for 15% of total load (2 points)
12.	Energy metering	Not applicable	Install energy meter for any three: • external lighting • municipal water • grey water • landscaping water • chilled water
13.	13.1 Salvaged materials reuse		
	i. Reused Cost percentage	> 2.5%: 1 point > 5% : 2 points	> 1%: 2 points > 2% : 4 points
	ii. Materials with recycled content		
	a. > 10%	1 point	1 point
	b. > 20%	2 points	2 points
	13.2 Local materials	Mandatory	Mandatory
	i. 50% materials to be manufactured within 400 km	1 point	1 point
	ii. Percentage of local materials	2 points	2 points
	a. > 25%		
	b. > 50%	Mandatory	Mandatory
		2 points	2 points
	13.3 Rapidly renewable building materials & certified wood:	4 points	4 points
	i. Min 50% materials		
	ii. > 50%		
	iii. > 75%		
14.	Day lighting:		
	i. Prescriptive: % area desirable glazing factor Bedroom & others: 1, Study room: 2, Kitchen: 1	Mandatory	Mandatory
	a. Min 50%	4 points	4 points

Table 5 (*continued*)

Sl. no	Indicator and parameter	Provisions for residential buildings Individual residential unit	Multi-dwelling residential units
	b. > 75%	Mandatory 4 points	Mandatory 4 points
	ii. Simulation: % area with 108 lx on 21 September at 12 noon		
	c. Min 50%		
	d. > 75%		
15.	15.1 Fresh air ventilation		
	i. Min. open able area: Living spaces: 10%, Kitchen: 8%, Bathrooms: 4%	Mandatory	Mandatory
	ii. Enhancement using area for Living spaces; 13%, Kitchen: 10%, Bathrooms: 5%	2 points	2 points
	15.2 Air conditioned buildings ventilation. Opening for :		
	i. 5 cfm per person	Mandatory	Mandatory
	ii. 6.5 cfm per person	2 points	2 points
	15.3 Cross ventilation		
	i. No obstruction till 2 m from opening	Mandatory	Mandatory
	ii. Min ventilated area from min. two orientations:		
	a. > 50%	2 points	2 points
	b. > 75%	4 points	4 points
16.	Low VOC materials, paints & adhesives		
	i. 100% area with low or no VOC paints and coatings	1 point	1 point
	ii. Within specified Limits for adhesives and coatings	1 point	1 point

Table 6
Classification of climatic zones in India [43]

S. no.	Climatic zone	Mean monthly maximum temperature (0C)	Mean monthly relative humidity (%)
1.	Hot-dry	Above 30	Below 55
2.	Warm-humid	Above 30	Above 55
		Above 25	Above 75
3.	Temperate	Between 25 and 30	Below 75
4.	Cold	Below 25	All values
5.	Composite	A zone that does not have any of above season for more than six months.	

prefer walking in open spaces till late night rather than occupying houses in the evening till late night hours. Fans are used in almost all houses for all occupancy hours in rooms to achieve comfort from heat. The reason for such exorbitant use of fans is that there is no other option available and also the fans consume low energy. In winters, the heating systems are used only for an average 1–2 h whereas in some houses, heaters are not used during other periods due to other alternatives such as basking in sun, use of heavy clothing, reducing ventilation rate by closing doors and windows and use of quilts in night hours. The heating accounts for a major portion of total energy consumption. So in case heating system is used for all hours when temperature is below thermal comfort range, the energy consumption percentage for heating will become very high so strategies for heating the building will become most important. This shows that the present practice of building design and construction is not climatic responsive and fails to provide thermal comfort in winter or summer seasons. Due to lack of adequate design strategies, the energy consumption in buildings can be reduced significantly if passive solar features and other energy efficiency measures are used. However, the classification of existing residential buildings, their energy consumption pattern and various solar passive and energy efficiency measures using alternative cost effective construction will be identified for incorporation in building regulations for the composite climate in a follow-up study.

6. Results and discussion

The comparative study of energy regulations in different countries shows that the code structure, enforcement criteria, energy efficiency measures and performance assessment, previous regulations and their nature, and integrated approach of code development are important considerations for successful implementation of any energy regulation. The provision of building regulations helps in adopting latest research and technological developments towards implementation. Thus the regulation details must be introduced in the existing or proposed energy regulations of any country for effective implementation.

The provisions mentioned in various Indian codes, standards and guidelines and relevant research work in India have been identified for incorporation in building regulations. The identified parameters and indicators related to energy efficiency are summarized in Table 9.The parameters covered during temporary phase of construction like workforce safety, provision of infrastructure to workforce are not included in this list as they have negligible impact on energy consumption throughout building life cycle.

It is found that the main identified indicators are building envelope, site conditions and building materials which can be expressed through building and surroundings physical characteristics.

6.1. Building envelope

Building envelope is the most effective indicator which includes fenestration properties, wall–window ratio (WWR), wall and roof materials properties, air leakage/envelope sealing, natural ventilation, orientation, building configuration, day lit area, shape and height of building. These are simple design decisions to be taken within the site which can further be detailed by considering the impact of surroundings of a building like urban geometry, solar obstruction, height/width ratio of nearby buildings, outdoor surface albedo and trees.

Proper adherence to these parameters will provide adequate day lighting, ventilation, heating and cooling and results in energy efficient building adhering to the climatic conditions.

6.2. Site conditions

Site is an important indicator for hilly regions and includes topography, vegetation, distance between buildings (open spaces) and their treatments. However, considering the same might affect immediate neighbour's decision e.g. sloped land may require cutting of land that might affect building already constructed on the upper hills. Similarly distance between buildings is resultant of setbacks left by both buildings owners.

6.3. Building materials

Building material is an indicator for which local materials, embodied energy, paints and cost effectiveness is important. Reuse of salvaged materials and rapidly renewable building materials and certified wood needs to be encouraged. Water and waste water indicator has to be considered keeping in view its impact on direct energy use of building.

Table 7
Various energy efficiency measures in SVAGRIHA for composite climate [13].

Sl. no.	Indicators and parameters	Provisions for composite climate evaluation
1	Reduce hard paved surface & maintain native vegetation cover	
	i. Min. 50% soft paved area and/or shaded	2 points
	ii. Protect existing trees	1 point
	iii. Same number of trees before and after construction	2 points
	iv. All new native trees	1 point
2	Passive architectural design and systems	
	i. Low-energy or passive heating/cooling measures, any two from solar chimney/wind tower, courtyards, water bodies for evaporation, rduced solar access, building/site planning to increase cross ventilation, earth berming, thermal mass, dense vegetation cover, cavity walls, terrace garden/green roof, roof insulation using clay pots, design as per site slopes, light shelves, internal buffer spaces distribution, cool roofs, geothermal cooling/heating, ventilators	2 points
	ii. Use of active systems	2 points
3	Fenestration:	
	i. Reducing direct heat gain:	
	a. > 30%	1 point
	a. > 45%	2 points
	a. > 60%	3 points
	ii. Maximizing daylight	Mandatory
	a. Min 25% shall be day lit	1 point
	b. > 25%	2 points
	c. > 50%	3 points
	d. > 75%	
	iii. General considerations:	
	a. Orientation	Maximum openings with least insolation
	b. Shading devices	Adequate shading
	c. Window area	Max. 60% WWR
	d. SHGC	low-SHGC glass
	e. VLT	10% –60%
4	Efficient artificial lighting system: LPD lower than ECBC	2 points
5	Building envelope thermal efficiency	
	i. External heat gain: LPD values for different locations (e.g. Chandigarh)	
	a. < 135 W/m2	1 point
	b. < 110 W/m2	2 points
	ii. General considerations:	
	a. SHGC of glass	Lower SHGC
	b. *U*-value of glass/walls/roof	Lower *U*-value
	c. LPD and Equipment Power Density (EPD) levels	More efficient equipment
	d. Building occupancy	Optimum
6	Energy efficient appliances: Star rated air-conditioners, fans, water geyser:	
	i. BEE 3 star	2 points
	ii. BEE–5 star	3 points
7	Use of renewable energy on site	2 points
	i. Electricity generation using PV (min. capacity) as per built up area	Mandatory
	a. 100–500: 1 kW	1 point
	b. 500–1000: 2 kW	2 points
	c. 1000–1500: 2.5 kW	
	d. 1500–2000: 3 kW	
	e. 2000–2500: 3.5 kW	
	ii. Solar water heater capacity: min hot water demand (100 l/day for residence)	
	a. 50%	
	b. 50–75%	
	c. 75–100%	
8	Water demand reduction	
	i. Low water flow fixtures: reduce water demand by	
	a. 25%	1 point
	b. 33%	2 points
	c. 50%	3 points
	ii. Planting native trees: reduce water demand by	
	a. 25%	1 point
	b. 50%	2 points
9	Rainwater harvesting	
	i. Harvesting 75% water demand for 2 days (210 l/person)	3 points
	ii. Ground water recharge with filtration	1 point
10	Generate resource from waste: Zero waste generation	2 points
11	Reduce embodied energy	
	i. Use of PPC (Pozzolana Portland Cement) over OPC (Ordinary Portland Cement)	Mandatory
	ii. Use of 100% PPC than OPC	2 points
	iii. Use of low embodied materials: reduce embodied energy by	
	a. > 5%	1 point
	b. > 10%	2 points
12	Use of low-energy materials in interiors	
	i. Min. 70% interior area	Mandatory
	ii. Min. 70% flooring	1 point
	iii. Min. 70% other internal finishes	2 points
	iv. Low VOC and lead free paints	1 point
13	Adoption of green Lifestyle: Built up restricted 12.5 m^2 –50 m^2 per person	1 point
14	Innovation	2 points

Table 8
Energy efficiency measures for residential buildings in hot and dry climate [90].

Sl. no.	**Indicators and parameters**	**Provisions for residential buildings in hot and dry climate**	
		For conditioned buildings	**For non-conditioned buildings**
1.	Building envelope		
	i. Site orientation	No effect	North–south
	ii. Building configuration		
	a. Surface area to volume ratio (S/V ratio)	Decrease exposed surface area	Decrease exposed surface area
	b. Building shape	Compact	Compact
	c. Buffer spaces	Increase buffer spaces	Increase buffer spaces
	iii. Fenestrations		
	a. Openings arrangement	Double glazing & reflective coated glass	Single reflective coated
	b. Shading to windows area	50% is better	50% is better
	iv. Building components		
	a. Roof	PUF insulated RCC roof	Polyurethane foam insulation in RCC roofs
	b. Walls	Wall insulation: Thermocol, Siporex	Concrete block wall with no insulation
	v. External colour	White or cream	White or cream
2.	General recommendations for Passive Heating i. Glazed windows ii. Thermal storage mass iii. Thermal storage wall: Trombe wall, water wall, Trans wall, iv. Roof top collectors v. Solarium	• Energy efficient equipment to reduce internal heat gains. • Lowering Set point • Air exchanges: lower air change per hour (*ach*) is better • Scheduling of air exchanges:	• Energy efficient equipment to reduce internal heat gains. • Air exchanges: 9 *ach* is better
3.	General recommendations for Passive cooling i. Ventilation cooling ii. Wind tower iii. Induced ventilation iv. Nocturnal cooling v. Evaporative cooling vi. Passive downdraft Evaporative cooling vii. Earth berming		
4.	General recommendations for Day lighting	Use of windows, skylights, light pipes	
5.	Building materials		
	i. Embodied energy	Use of materials having less embodied energy	
	ii. Innovative building materials	Increase thermal resistance, thermal capacity &surface reflectivity	
	iii. Cost effectiveness	Among alternatives	

6.4. Other indicators

It is found that energy efficiency is also dependent on the analysis of building for which parameters such as operation energy use, demolition energy, life span of building, climatic conditions and behaviour of inhabitants are important. These are generally covered in regulations but their specific impact is required to be further studied.

The above identified measures require being included in NBC and subsequently in building regulations, as NBC is conceived as backbone for building regulations. It is also seen that in spite of NBC revision in 2005, no provisions from SP41, energy efficient passive solar measures were included in revision despite the fact that these were already developed or are in practice before this revision. Similarly Solar House Action Plan for Himachal Pradesh and MNRE passive solar building programme showcased many success stories as per climatic conditions but detailed climate specific energy efficiency measures are not included. The energy efficiency cannot be achieved without considering passive solar passive measures and other energy saving measures as per climatic conditions as suggested in various codes and standards.

It is seen through case study of Hamirpur that the most of the residential buildings are naturally ventilated and non-air conditioned for which the energy efficiency can be achieved by careful selection of building envelope and through solar passive measures. There are a number of climate specific measures given in reviewed codes and standards as identified in Table 9 which will be incorporated in building regulations of Hamirpur after careful evaluation for its cost effectiveness.

Table 9
Identified indicators and parameters for energy efficiency measures in standards, guidelines and regulations for buildings in India.

Indicator	Parameter	ECBC	NBC	SP:41	LEED Homes	SVAGRIHA	HECB	Research work
Building envelope	Fenestration properties	✓	X	✓	✓	✓	✓	✓
	Wall–Window Ratio (WWR)	✓	✓	✓	✓	✓	✓	X
	Wall materials properties	✓	X	✓	✓	✓	✓	✓
	Roof materials properties	✓	X	✓	✓	✓	✓	✓
	Air leakage/envelope sealing	✓	X	X	X	X	X	X
	Natural ventilation	✓	✓	✓	✓	✓	✓	X
	Orientation	✓	✓	✓	✓	✓	✓	✓
	Building configuration/alternative design evaluation	X	✓	✓	X	✓	✓	✓
	Height of building	X	✓	✓	X	X	X	✓
	Day lit area	X	✓	✓	✓	✓	✓	X
	Shape	X	X	✓	X	X	✓	X
Site conditions	Topography	X	X	X	X	✓	✓	X
	Distance between buildings	X	✓	X	X	X	✓	X
	Treatment of open spaces/heat island effect-non-roof	X	X	X	✓	✓	✓	X
	Vegetation	X	X	X	X	✓	✓	X
Water and waste water	Rain water harvesting	X	✓	X	✓	✓	X	X
	Water efficient plumbing fixtures	X	X	X	✓	✓	X	X
	Water conserving landscape	X	X	X	✓	✓	X	X
	Waste water treatment and reuse	X	X	X	✓	X	X	X
Building materials	Reuse of salvaged materials	X	X	X	✓	✓	X	X
	Local materials	X	X	X	✓	X	X	X
	Rapidly renewable building materials and certified wood	X	X	X	✓	X	X	X
	Embodied energy	X	X	X	X	✓	✓	✓
	Paints	X	X	X	✓	✓	✓	X
	Cost effectiveness of materials	X	X	X	X	X	✓	X
Energy use applications	Artificial light consumption	✓	X	X	✓	✓	✓	✓
	HVAC-efficiency	✓	X	X	✓	X	X	✓
	Use of electric power	✓	X	X	X	X	X	X
	Solar water heaters	✓	X	X	✓	✓	✓	✓
	Renewable energy generation	✓	X	X	✓	✓	✓	✓
	Solar passive additional elements	X	✓	X	X	✓	✓	X
	Space heating system	X	X	X	✓	X	✓	✓
	Appliances	X	X	X	✓	✓	✓	X
	Efficient power distribution system	✓	✓	X	✓	X	X	X
	Occupancy/green lifestyle/Innovations	X	X	X	✓	✓	X	X
Energy efficiency analysis	Operation energy use and statistics	✓	X	X	✓	✓	X	✓
	Demolition energy	X	X	X	X	X	X	✓
	Life span of building	X	X	X	X	X	X	✓
	Climatic conditions–weather characteristics	✓	✓	✓	✓	✓	✓	✓
	Behaviour of inhabitants	X	X	X	X	X	X	✓

X – Not listed; ✓ – listed

7. Conclusions

This paper reviews codes, standards, regulations and energy efficiency initiatives worldwide in order to incorporate identified energy efficiency alternatives for Building Regulation in India. A case study of building regulations of Hamirpur town in a composite climate in the north western Himalayan state of India is critically examined for energy efficiency provisions. Based on the study the following conclusions are drawn:

1. It is found that energy efficiency is not always dependent on the existence of energy codes in a country rather it is the regulation mandatory structure and enforcement strategy that results in achieving higher energy efficiency in residential buildings. The regulatory assessment and revision of codes improves the quality of codes and increases the success rate.
2. The experience of implementing energy regulations in different countries worldwide shows that the code structure, enforcement criteria, energy efficiency measures and performance assessment, previous regulations, their nature, and integrated approach of code development are important considerations for successful implementation of any energy regulation.
3. The provision of building regulations helps in adopting latest research and technological developments in implementation.
4. The regulation details must be introduced in the existing or proposed energy regulations of any country for effective implementation. It is seen that at initial stage of adoption of energy regulations, prescriptive regulations need to be implemented along with pre-notified date of shift towards performance regulations. However adequate environment for this shift must be created such as developing professional curriculum, online resources, training, awareness campaigns and regulating the industrial sector.
5. The enforcement of a national code in different countries can combine all local regulations, allows for regulation biasness for wider acceptance and effective implementation.
6. An integrated energy efficiency approach for buildings is required for the country in which energy efficiency becomes a part of National Building Code and building regulations rather than enforcing different codes by various agencies.
7. Building envelope, building materials, climate and site conditions are most important parameters for energy efficiency needed to be developed in order to integrate them into the National Building Code (NBC) and building regulations. Energy conservation measures as identified in ECBC, SVAGRIHA and other rating systems along with passive solar design features need to be included and elaborated further in NBC for the development of energy efficient building regulations for various climatic zones of India namely hot-dry, warm-humid, temperate, cold and composite.
8. The preliminary case study of Hamirpur highlighted that the energy efficiency measures are not included in local building regulations and detailed guidelines are missing even though the same are well defined in codes and standards. A detailed follow up research study is proposed in which the energy performance classification of existing regulated buildings shall be done. This will result in developing optimal energy efficiency regulations to be included in existing building regulations.
9. It is found that energy efficiency cannot be achieved without considering passive solar measures. Adequate passive solar features and energy efficiency measures can reduce significantly energy consumption in composite and other climates.
10. Energy efficiency analysis requires to be included in NBC with detailed elaborations. Such analysis requires data on embodied energy index of building materials, operational energy use, demolition energy use, life span of building, climatic conditions and social behaviour.
11. Site specific studies in different countries with focus on climatic regions are follow up research areas for providing further

inputs for the strict implementation of energy regulations and conservation measures in buildings.

References

[1] International Energy Agency. World energy outlook. OECD/IEA; 2013 (online) 〈http://www.iea.org/publications/freepublications/publication/WEO2013_Executive_Summary_English.pdf〉 (accessed 22.01.15).
[2] CensusInfo 2011. Housing, household amenities and assets database (ver. 2.0). Census of India; 2011. Ministry of Home Affairs. Government of India.
[3] International Energy Agency. Statistics database; 2010. (online) 〈http://www.iea.org/statistics/statisticssearch/report/?country=INDIAandproduct=electricityandheat-andyear=2010〉 (accessed 05.06.13).
[4] Ministry of Statistics and Programme Implementation. Statistical year book – India Government of India; 2014 (online) 〈http://mospi.nic.in/Mospi_New/upload/SYB2014/ch16.html〉 (accessed 10.10.14).
[5] The World Bank. Residential Consumption of Electricity in India. World Bank publications; July 2008, (online) 〈http://www.moef.nic.in/downloads/public-information/Residentialpowerconsumption. pdf〉 (accessed 20.08.12).
[6] Deloitte. Securing tomorrows energy today: policy and regulations long term energy security. IEC; 2013 (Online) 〈http://www.indiaenergycongress.in/iec/Energy%20security%20Background%20Paper%20-%20020213.pdf〉 (accessed 19.09.13).
[7] Energy Management Group. State-wise electricity consumption and conservation potential in India. National Productivity Council; 2009 (online) 〈http://www.emt-india.net/eca2009/14Dec2009/CombinedSummaryReport.pdf〉 (accessed 10.01.13).
[8] Zoning, The free dictionary. (online) 〈http://legal-dictionary.thefreedictionary.com/Zoning〉 (accessed 12.09.14).
[9] Department of Communities and Local Government. Planning Portal. Government of United Kingdom. (online). 〈http://www.planningportal.gov.uk〉 (accessed 12.12.12).
[10] Loustsen J. Energy efficiency requirements in building codes. Energy efficiency policies for new buildings. IEA Information Paper. International Energy Agency; 2008.
[11] Liu F, Meyer AS, Hogan J. Mainstreaming building energy efficiency codes in developing countries: global experience and lessons from early adapters. Washington, DC. The World Bank Working Paper no. 204. World Bank Publications; 2010.
[12] Indian Green Building Council. IGBC green homes rating system; 2012 (online) 〈http://igbc.in/site/mmbase/attachments/342261/IGBC_Green_Homes-_Abridged_Reference_Guide_(Version_2.0)_-_April_2012.pdf;jsessio nid=9A8651C8F48B9AA8C8065FDFAE8C6D90〉 (accessed 14.07.11).
[13] Association for Development and Research of Sustainable Habitats (ADaRSH). SVA Green Rating Integrated Habitat Assessment (SVAGRIHA) (online) 〈http://www.grihaindia.org/index.php?option=com_contentandview=articleandid=86〉 (accessed 14.07.11).
[14] Building Research Establishment Ltd. Pre-assessment estimator- v 1.0. BREEAM UK NC; 2014 (online) 〈http://www.breeam.org/filelibrary/Pre-Assessment%20Estimators/BREEAM-UK-NC-2014-Pre_Assessment-Estimator-v1.0.xls〉 Centre of Environmental Technology Limited. HK BEAM (Residential): An environmental assessment for new residential buildings (Version 3/99): Kowloon, Hong Kong; 1999 (accessed 31.01.15).
[15] Green Building Council Australia. Green star rating tools; 2014. (Online) 〈https://www.gbca.org.au/green-star/rating-tools/〉 (accessed 22.01.15).
[16] Institute of Building Environment and Energy Conservation, CASBEE for Homes (Detached House): technical Manual: Japan; 2007 (online) 〈http://ibec.or.jp/CASBEE/english/download/CASBEE-H(DH)e_2007manual.pdf〉 (accessed 15.01.15).
[17] Rinker ME. Energy assessment & building energy performance options of green globes for new construction. College of Design. Construction and Planning. University of Florida. (online) 〈http://www.thegbi.org/content/misc/White_Paper_for_Green_Globes_New_Construction_Energy_Section.pdf〉 (accessed 17.01.15).
[18] Building and Construction Authority, Green mark for new residential buildings- Version RB/4.1: Singapore Government. (online) 〈http://www.bca.gov.sg/greenmark/others/gm_resi_v4.1_R.pdf〉 (accessed 18.01.15).
[19] Sanchez MC, Brown RE, Webber C, Homan GK. Savings estimates for the United States Environmental Protection Agency's ENERGY STAR voluntary product labeling program. Energy Policy 2008;36(6):2098–108.
[20] Passive House Institute. Passipedia – the passive house resource. Germany (online) 〈http://www.passipedia.org/〉 (accessed 14.01.15).
[21] Heijden Van der, Jeroen. International comparative analysis of building regulations: an analytical tool. Int. J. Law Built Environ. 2013;1(1):9–25.
[22] International Code Council. International Residential Code (IRC): USA; 2012.
[23] National Research Council Canada. National Energy Code of Canada for Buildings; 2011.
[24] Regulation and Licensing Department. New Mexico energy conservation code; 2009.
[25] InstitutoNacional de Metrologia, Normalizaçao e Qualidade Industrial. RegulamentoTécnico da Qualidade Para o Nível de EficiênciaEnergéticaEdificaçõesResidenciais (RTQ-R). Portaria n. 18, de 16 de janeiro de 2012; INMETRO: Rio de Janeiro, Brazil; 2012 (in Portuguese).
[26] HM Government. Approved Document L1A: Conservation of fuel and power in new dwellings; 2013 edition. March 2014 (online) 〈http://www.planningportal.gov.uk/uploads/br/BR_PDF_AD_L2A_2013.pdf〉 (accessed 01.07.15).
[27] F., 2011. RT 2012 : unsurcoût de construction de 15–20% [WWW Document]. lemoniteur.fr. URL 〈http://www.lemoniteur.fr/190- metiers/article/actualite/775575-rt-2012-unsurcout-de-construction-de-15-20〉 (accessed 01.06.14).
[28] Energieeinsparverordnung, EnEV; 2014.
[29] EU Energy Performance of Buildings Directive (EPBD); 2002.
[30] Technical Building Code 2007 (Royal Decree 314/2006 of 17 March 2006).
[31] Energy Conservation Policy for Housing; 2011.
[32] Building Design Criteria for Energy Saving (BDCES): South Korea; 2008.
[33] South African National Standard SANS 0204: Energy Efficiency in Buildings; 2011.
[34] BCA 2010-6 Star NatHERS Rating for Buildings: Australia.
[35] New Zealand Building Code (NZBC)-Clause H1.
[36] Presidential Decree 2012, State Programme on Energy Savings: Russia; 2010.
[37] Yu S, Evans M, Delgado A. Energy code enforcement and compliance evaluation: comparative lessons learned from the US and China, and opportunities for India. ACEEE 2014 Summer Study on Energy Efficiency in Buildings.
[38] Rachel Young. Global approaches: a comparison of building energy codes in 15 countries. ACEEE 2014 Summer Study on Energy Efficiency in Buildings; 2014.
[39] GBPN database.
[40] IEA database.
[41] Gusev A. Comparison of energy efficiency measures in Russia to those implemented by developed countries (including IEA measures). German Institute for International and Security Affairs (SWP) (online) 〈http://www.europarl.europa.eu/meetdocs/2009_2014/documents/d-ru/dv/dru_20131017_11_/dru_20131017_11_en.pdf〉 (accessed 01.07.15).
[42] El-Shagi, Makram and Michelsen, Claus and Rosenschon, Sebastian, Regulation, Innovation and technology diffusion: evidence from building energy efficiency standards in Germany (March 2014). DIW Berlin Discussion Paper no. 1371. Available at SSRN: http://ssrn.com/abstract=2432978%20or%20http://dx.doi.org/10.2139/ssrn.2432978.
[43] Bureau of Indian Standards (BIS). SP7: National Building Code (NBC)-2005. New Delhi; 2005 (online) 〈https://law.resource.org/pub/in/bis/S03/is.sp.7.2005.pdf〉 (accessed 31.01.15).
[44] Indian Standards Institution (ISI). National Building Code (NBC) – 1970. The Institution. New Delhi; 1974.
[45] Bureau of Indian Standards (BIS). National Building Code (NBC) – 1983. The Institution. New Delhi; 1983.
[46] Bureau of Energy Efficiency. Energy Conservation Building Code (ECBC). Ministry of Power. Government of India; 2006.
[47] Bureau of Energy Efficiency. Energy Conservation Building Code (ECBC). Ministry of Power. Government of India; 2007 (online) 〈http://www.eco3.org/ecbc〉 (accessed 14.07.14).
[48] Bureau of Energy Efficiency (BEE). Government of India. (online) 〈http://www.beeindia.in/〉 (accessed 10.11.11).
[49] Ministry of Home Affairs. Houselisting and housing census data highlights – 2011. Government of India; 2011.
[50] Ministry of Law and Justice. Land Acquisition Act – 1984 (modified), Government of India; 1985 (online) 〈http://www.dolr.nic.in/hyperlink/acq.htm〉 (accessed 30.01.15).
[51] MajumdarMili, SastryMinni. Development of Building Regulations and Guidelines to Achieve Energy Efficiency in Bangalore City. TERI; 2010 (online) 〈http://www.teriin.org/ResUpdate/reep/reep_overview.pdf〉 (accessed 12th June 2013).
[52] Huang J, Deringer J. Status of energy efficient building codes in Asia. Asia Business Council. Hong Kong SAR; 2007: p. 6–9.
[53] Komurlu R, Arditi D, Gurgun AP. Applicability of LEED's energy and atmosphere category in three developing countries. Energy Build 2014;84:690–7.
[54] Komurlu R, Arditi D, Gurgun AP. Energy and atmosphere standards for sustainable design and construction in different countries. Energy Build 2015;90:156–65.
[55] Kumar Pushplata A. Building regulations for environmental protection in Indian hill towns. Int J Sustain Built Environ 2013;2(2):224–31.
[56] Kumar Pushplata A. Building regulations for hill towns of India. HBRC J 2014 Available online 18 July 2014.
[57] Kumar A. Vernacular practices: as a basis for formulating building regulations for hilly areas. Int J Sustain Built Environ 2013;2(2):183–92.
[58] Department of Town Planning. Himachal Pradesh Town and Country Planning (Amendment) Rules – 2009 (Solar Passive Design). Government of Himachal Pradesh; 2009.
[59] Department of Town Planning, Himachal Pradesh Town and Country Planning Rules – 2014, Govt. of Himachal Pradesh; 2014 〈http://admis.hp.nic.in/himachal/tcp/pdf/TCPRules2014_Dec2014_A1b.pdf〉 (accessed 31.01.15).
[60] Ramesh T, Prakash R, Shukla KK. Life cycle approach in evaluating energy performance of residential buildings in Indian context. Energy Build 2012;54:259–65.
[61] Tulsyan A, Dhaka S, Mathur J, Yadav JV. Potential of energy savings through implementation of Energy Conservation Building Code in Jaipur city, India. Energy Build 2013;58:123–30.
[62] Reddy BVV, Jagadish KS. Embodied energy of common and alternative building materials and technologies. Energy Build 2003;35:129–37.
[63] Debnath A, Singh SV, Singh YP. Comparative assessment of energy requirements for different types of residential buildings in India. Energy Build 1995;23:141–6.

[64] Pd L, Palaniappan S. A case study on life cycle energy use of residential building in Southern India. Energy Build 2014;80:247–59.
[65] Majumdar M (Ed.). Energy-efficient Buildings in India. TERI Press; 2001.
[66] S. Nadel, V. Kothari S. Gopinath. Opportunities for Improving End-Use Electricity Efficiency in India. American Council for an Energy-Efficient Economy. Washington DC; 1991.
[67] Planning Commission. 8th Five Year Plan (1992–97). Government of India. New Delhi; 1992 (online) 〈http://planningcommission.gov.in/plans/planrel/fiveyr/8th/default.htm〉 (accessed 16.01.15).
[68] The Energy and Resources Institute (TERI). Energy efficiency information portal. (online) 〈http://www.teriin.org/index.php?option=com_ongoingandtask=about_projectandpcode=2006LC23〉 (accessed 05.05.12).
[69] UNDP India. Energy efficiency improvements in commercial buildings. Global Environment Facility Project Document (online) 〈http://www.undp.org/content/dam/india/docs/energy_efficiency_improvements_in_commercial_buildings_project_document.pdf〉 (accessed 10.12.14).
[70] Planning Commission. 9th Five Year Plan (1997–2002). Government of India. New Delhi; 1997 (online) 〈http://planningcommission.nic.in/plans/planrel/fiveyr/9th/vol1/v1c1-2.htm〉 (accessed 16.01.15).
[71] Ministry of Power. Energy Conservation Act. Government of India. New Delhi; 2001 (online) 〈http://www.creda.in/sites/default/files/page-document/Energy%20Conservation%20Act%202001.pdf#overlay-context=energy-conservation-act-2001%26%3Fq%3Denergy-conservation-act-2001%26〉 (accessed 16.01.15).
[72] Planning Commission. 10th Five Year Plan (2002–07). Government of India. New Delhi, 2002 〈http://planningcommission.nic.in/plans/planrel/fiveyr/10th/volume2/10th_vol2.pdf〉 (accessed 15.01.15).
[73] Ministry of Power. The Electricity Act – 2003. Government of India. New Delhi; 2003 (online) 〈http://faolex.fao.org/docs/pdf/ind82256.pdf〉 (accessed 22.01.15).
[74] Planning Commission. Integrated Energy Policy: Report of Expert Committee. Government of India. New Delhi; 2006 (online). 〈http://planningcommission.nic.in/reports/genrep/rep_intengy.pdf〉.(accessed 10.09.12).
[75] Bureau of Energy Efficiency. National Energy Labelling Programme. Ministry of Power. Government of India; 2006 (online) 〈http://220.156.189.25:8080/beeLabel/index.jsp〉. (accessed 12.09.12).
[76] Bureau of Energy Efficiency. Energy Conservation Building Code (ECBC). Ministry of Power. Government of India; 2006.
[77] Bureau of Energy Efficiency. Energy Conservation Building Code (ECBC). Ministry of Power. Government of India; 2007 (online) 〈http://www.eco3.org/ecbc〉 (accessed 14.07.14).
[78] Planning Commission. 11th Five Year Plan (2007–12). Govt. of India. Oxford University Press. New Delhi; 2008 (online) 〈http://planningcommission.nic.in/plans/planrel/fiveyr/11th/11_v2/11th_vol2.pdf〉 (accessed 14.02.15).
[79] National Action Plan for Climate Change. Prime Minister's Council on Climate Change. Ministry of Environment & Forests (MoEF).Govt. of India; 2008 (online) 〈http://www.moef.nic.in/modules/about-the-ministry/CCD/NAP_E.pdf〉 (accessed 22.10.14).
[80] National Mission on Enhanced Energy Efficiency 〈http://www.energymanagertraining.com/NAPCC/NMEEE-forPublicComments.pdf〉 (accessed 23.02.12).
[81] Bureau of Energy Efficiency. Bachat Lamp Yojana (BLY) Lighting Programme. Ministry of Power. Government of India; 2009 〈http://www.beeindia.in/schemes/schemes.php?id=1〉 (accessed 15.07.11).
[82] EnEff:ResBuildIndia: Toolkit for energy efficient residential buildings in India (online) 〈http://www.ittoolkitindia.com/〉 (accessed 30.01.15).
[83] Ministry of New and Renewable Energy (MNRE), Government of India 〈http://www.mnre.gov.in/〉 (accessed 10.09.12).
[84] Chandel SS, Aggarwal RK. Performance evaluation of a passive solar building in Western Himalayas. Renew Energy 2008;33(10):2166–73.
[85] S.S. Chandel, S. King, D. Prasad. Implementing passive solar housing technology in mountains. W.Y. Saman W.W.S. Charters (Eds.). Bringing Solar Down to Earth. Proceedings of ISES. Solar World Congress; 2001: p. 183–9.
[86] Chandel SS. Strategy for the promotion of passive solar housing technology in western Himalayas. Int Energy J 2006;7(4):273–7.
[87] Chandel SS, Sarkar A. Performance assessment of a passive solar building for thermal comfort and energy saving in a hilly terrain of India. Energy Build 2015;86:873–85.
[88] Green Rating for Integrated Habitat Assessment (GRIHA) Manuals. TERI Press. New Delhi; 2010: p. 1–5.
[89] Bureau of Indian Standards (BIS). SP41: Handbook of Functional Requirements of Buildings. New Delhi; 1987,〈https://law.resource.org/pub/in/bis/S03/is.sp.41.1987.pdf〉 (accessed 18.01.15).
[90] Nayak JK, Prajapati JA. Handbook of energy conscious buildings of India. Ministry of New and Renewable Energy. Government of India; 2006. (online) 〈http://mnre.gov.in/centers/about-sec-2/hand-book-on-energy-conscious-buildings/〉 (accessed 14.07.14).
[91] Department of Town and Country Planning. Development Plan Hamirpur. Government of Himachal Pradesh (online) 〈http://admis.hp.nic.in/himachal/tcp/DPHamirpur.pdf〉 (accessed 31.08.14).