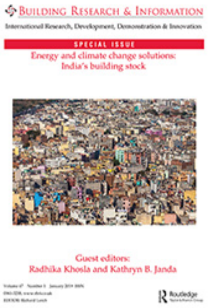

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EDITORIAL

India's building stock: towards energy and climate change solutions

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Reducing energy demand is increasingly recognized for its ability to boost climate change public policies and strategies, despite the historical focus on supply-side energy solutions (Creutzig et al., 2018). Energy use in building design and operation is integral to these efforts. In 2010, buildings accounted for 32% of total global final energy use and 19% of energy-related greenhouse gas (GHG) emissions, with projections for further increase (Lucon et al., 2014). Energy efficiency advocates suggest that new buildings can (and should) be net-zero energy, and retrofitting existing buildings can achieve savings of approximately 50% (Architecture 2030, 2014). Yet, the global promise of building-level interventions remains mixed, at best. Analytical projections are yet to be rigorously adapted for application in specific local circumstances, making country-, city- and building-level research necessary components for longer term progress. This is even more true in emerging economies, where ongoing structural transitions can align (or derail) long-term development and climate objectives by (re)shaping spaces, preferences and professional practices in a rapidly growing built environment (Creutzig et al., 2016; Janda & Parag, 2013).

This *Building Research & Information* special issue contributes to the field by considering energy and climate change solutions in India's building stock. The focus on the building stock as an object of study is rooted in the recent literature that recognizes the need to understand the characteristics and dynamics of national building stocks at different levels, from the building to the city scale, and from the local to national (and international) scales (Kohler, Steadman, & Hassler, 2009). Recent advances in computing have facilitated 3D urban stock models that include building morphology and use (*e.g.* Evans, Liddiard, & Steadman, 2016), which offer further data challenges and opportunities for local and national policy formulation and validation. At the same time, comprehensive understanding of any building stock is difficult to achieve due to its structural complexity, the uncertainty of rates of change in the future, and the interrelations between economic, physical, social and cultural aspects (Kohler & Hassler, 2002). This is particularly relevant when discussing issues related to climate change and sustainable development, which requires research to be inherently transdisciplinary in nature.

This special issue's focus on the building stock in India is important for global climate change outcomes for three reasons: (1) India's size and scale; (2) its rate of growth; and (3) its stage of development. First, India is among the top five economies of the world in gross domestic product (GDP) terms and the third largest, and growing, GHG emitter. It is the seventh largest country in land area, and it is second only to China in population (1.35 versus 1.39 billion). These characteristics alone make India's growth trajectory salient to global climate change outcomes.

Second, according to the International Energy Agency (IEA), the country is projected to undertake the largest global growth in energy consumption between now and 2040, a large proportion of which will take place in its building stock. This is largely due to the increase in the provision of housing, expectations for amount of built space per capita and the provision of thermal comfort. Indeed, buildings are currently responsible for more than one-third of India's total energy consumption, and projected to grow as overall quality of life improves (GBPN, 2014).

Third, in spite of its growing economy and GHG emissions, India is starting from a low base of development and is home to a large number of the world's poor. The country has amongst the lowest ranks in the

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multidimensional poverty index and very low historic and current per capita GHG emissions.

Clearly, India's scale and stage of economic development – with characteristics of both developed and developing countries – make it a unique site to study the interrelationships between energy, climate change and the built environment.

An important implication of these characteristics is the potential to reduce energy demand (and the carbon footprint) from India's building stock. It is estimated that two-thirds of the commercial and high-rise building stock in 2030 will be built between 2015 and 2030 (Kumar, Kapoor, Rawal, Seth, & Walia, 2010), as urban and socioeconomic transitions occur. And because these buildings form long-lasting components of the economy and shape long-term energy use patterns, the next two decades present a real opportunity to lock in (or block out) sustainable consumption patterns. If end-use technologies with poor energy performance (*e.g.* inefficient buildings and appliances) or cities with high energy demands (*e.g.* low-density development requiring private transport, increased levels of air-conditioning, *etc.*) become the standard in yet-to-exist infrastructures and lifestyles, it can lead to a series of path-dependent outcomes. These patterns will shape and be shaped by technologies, institutions and behaviours associated with the burgeoning building stock, which would make it extremely difficult to reduce consumption for many decades to come. Some studies estimate that the path-dependency resulting from the long lifespans of India's new buildings makes the country's risk of carbon lock-in higher than anywhere else in the world (Urge-Vorsatz et al., 2012). India's early stages of development thereby provides a distinctive opportunity to examine and inform public policy and practice that will profoundly influence future energy and carbon trajectories, with implications that extend well beyond the country's borders.

How can India undertake its large projected growth in buildings while simultaneously meeting its development, energy and climate objectives? This special issue sets out to help answer this question by developing and extending the growing body of research on the topic, with the aim to help define the built environment in India as an emerging and important field of socio-technical enquiry. The special issue's framing of the problem departs from the often used techno-economic view and instead suggests that both technical infrastructures, such as the built environment, and social infrastructures, such as policies, professions, habits and norms, shape behaviour, and as a consequence offer significant potential for reducing overall energy demand and GHG emissions (Creutzig et al., 2016; Janda, 2011; Moezzi & Janda, 2014). The special issue also seeks to address the research, policy and management implications of different approaches to India's buildings. In doing so, it helps fills a gap in the literature created by the dominant focus on developed countries (Bai et al., 2018; Stern et al., 2016).

This editorial sets a three-pronged multidisciplinary framework for current and future research on India's building stock, and associates the papers in the special issue with this agenda. It also points to the importance of international research collaborations in seeking solutions to India's energy and climate change challenges.

An integrated research agenda

India's socioeconomic diversity and development needs require attention that technical solutions alone will not solve. We propose that a multidisciplinary, integrated research agenda can be anchored around three interrelated approaches:

- *techno-economic*: the potential of available energy saving techniques and technologies
- *institutional*: the arrangements of regulations, finances, professional and educational capacities required for developing effective practices in policy, manufacturing and construction
- *behavioural*: the role of individuals and organizations in managing energy consumption

The papers in this special issue (Table 1) crosscut these approaches and represent three themes that are core to overcoming challenges and achieving solutions in India's building stock. These papers largely take a techno-economic approach to their topics, which is not surprising as this approach is dominant in the built environment field (Lutzenhiser, 2014). However, they also explore institutional aspects and there is room for further behavioural research.

While the papers are specific to the Indian case, they allow insights for other developing countries as well, which are at the brink of similar large-scale socioeconomic and urban transitions. Specifically, the themes examined in the papers are:

- the role of data in developing a knowledge base for policy and research
- the role of construction techniques and materials, given the scale of new investments to be made, as well as the skills required to ensure actual building performance
- the role of India's building stock within the larger context of energy transitions and a changing climate from both a national and an international perspective

Table 1. Authors and titles of articles in this special issue 'Energy and Climate Change Solutions: India's Building Stock', *Building Research & Information* (2019) vol. 47(1); guest editors: Radhika Khosla and Kathryn B. Janda.

Authors	Title	doi
R. Khosla and K. B. Janda	India's building stock: towards energy and climate change solutions (editorial)	10.1080/09613218.2019.1522482
A. Mastrucci and N. D. Rao	Bridging India's housing gap: lowering costs and CO_2 emissions	10.1080/09613218.2018.1483634
S. Kumar, N. Yadav, M. Singh and S. Kachhawa	Estimating India's commercial building stock to address the energy data challenge	10.1080/09613218.2018.1515304
S. S. Vishwanathan. P. Fragkos, K. Fragkiadakis, L. Paroussos and A. Garg	Energy system transitions and macro-economic assessment of Indian building sector	10.1080/09613218.2018.1516059
R. Gupta, M. Gregg, S. Manu, P. Vaidya and M. Dixit	Customized performance evaluation approach for India's green buildings	10.1080/09613218.2019.1525962
A. Chunekar and A. Sreenivas	Towards understanding residential electricity consumption in India	10.1080/09613218.2018.1489476
S. Gokarakona, S. Shrestha, P. R. Caleb, V. Rathi, R. Jain, S. Thomas, K. Topp and Z. Niazi	Decoupling in India's building construction sector: trends, technologies and policies	10.1080/09613218.2018.1490054
P. Graham and R. Rawal	Achieving the 2°C goal: the potential of India's building sector	10.1080/09613218.2018.1495803
A. Mathur	Public costs and private benefits: governance of energy efficiency in India	10.1080/09613218.2018.1514743

Each theme is discussed below together with the papers that elaborate on them.

Role of data in developing a knowledge base for policy and research

Effective energy and climate research, policy, and evaluation relies on rigorous analysis of readily available, reliable and comprehensive data. Such data are also important for citizen engagement, business strategy formulation, and creating models of future energy and low-carbon scenarios and their implications across development objectives. Analogously, the availability of such data requires institutional mechanisms to collect, process and disseminate data in a timely manner (Dukkipati, Iyer, & Sreenivas, 2014). This is especially true for emerging economies such as India, which need to rapidly expand their energy infrastructure, improve the affordability and reliability of energy supply to their masses, and have a leapfrogging opportunity in doing so (Rai, Tongia, Shrimali, & Abhyankar, 2017). At the moment, Indian energy-policy-making institutions tend to focus on the supply side, in silos for coal, oil and gas, power, renewable energy *etc*. There is little integration with and across demand sectors such as transportation, housing and industry. Energy demand in the building stock is even more complex as it is indirectly governed by ministries that typically have non-energy objectives, such as urban development, and are often governed at the state and local scale, which introduces a further complication to coordination. Enhancing data availability, with enough granularity and timeliness to serve policy and research, is thereby a precondition for characterizing patterns of building energy demand and subsequently informing decisions (and validating them) for the transition towards a low-carbon future.

Data issues and frameworks, including their presence and absence for energy use and related GHG emissions are discussed by two papers. Chunekar and Sreenivas focus on India's growing residential electricity use, which increased by a factor of 50 since 1971, although India's electrified households still consume less than one-third of the global average. They present a comprehensive literature review to shed light on this topic, which has, surprisingly, received limited attention so far. As residential electricity continues to grow, with increasing electrification, incomes and technologies, the authors call for more systematic collection and analysis of household demand to develop effective energy efficiency policies, optimize the addition of generation capacity, and tackle challenges of climate change and environmental pollution. In a complementary analysis of commercial building energy use, Kumar et al. focus on the need for a standardized framework that accounts for developing country differences in workforce capacity and resources, national priorities, and data and analytics availability. The authors present the results of an energy-accounting exercise for commercial buildings in India, categorize different building typologies, and make estimates for the floor area and energy intensity of the commercial stock – to serve as a first step for creating successful energy and climate policies.

Both papers describe the current state of knowledge, and emphasize that it serves as a starting point for more rigorous data collection and analysis, while recognizing the challenges of doing so in a data-scarce and rapidly transitioning environment.

Achieving building performance: the role of construction techniques, materials and skills

Another dimension of the changing building stock in India is the immense amount of construction that is underway. For residences alone, the housing gap amounts to about 19 million units in urban areas (NBO, 2013) and at least 43 million in rural areas (MoRD, 2011). The choice of technology, design and materials, and the complementary skilled expertise for implementing energy-saving options can have significant impact on the cost and CO_2 emissions of the impending building stock. At the same time, decisions about techniques and materials may present trade-offs or synergies between cost and energy use/carbon emissions, and between upfront investments and long-term operation. The knowledge base on these interrelationships that arise from the anticipated growth in building construction and India's environmental sustainability are, however, largely unexamined. Although much research examines *what* the built environment should be, rather less exists on *how* to get there and *who* needs to participate in the transition (Bordass & Leaman, 2012; Janda, Killip, & Fawcett, 2014).

Two papers consider the issues of construction and materials (the *what* question); and there is one paper on education and skills (the *who* and *how*). Mastrucci and Rao discuss life cycle costs, life cycle energy and CO_2 emissions impacts of replacing 60 million unfit homes in India with decent housing, using different materials and technologies, and creating reasonable standards of indoor comfort. Based on assessments under different climatic conditions and residential behavioural patterns, using urban and rural housing archetypes, they argue that stabilized-earth blocks are a preferable solution to the prevailing norm of fired bricks for creating low-carbon, resource efficient and thermally comfortable housing. Gokarakonda et al. have a related focus on decoupling economic growth from resource consumption during building construction. They analyze the existing trends, technologies and policies for India's building construction that aim to decouple economic growth from resource use and environmental impacts, and make recommendations for policy initiatives at the national, state and local levels.

Gupta et al., on the other hand, highlight the missing link between design intent and built form: the actual performance of buildings. This gap between the predicted performance of a building and its real energy consumption exists across countries (Sunikka-Blank & Galvin, 2012). The authors propose a 'how' and 'who' to close this gap in India, with a standardized evaluation process adapted to local context. In India, for instance, successful approaches require acknowledging that there is less documentation of design decisions, larger degrees of freedom during construction to change design specifications, less formalized building operation and limited access to expensive equipment for performance evaluation. In this context, the authors propose a customized building performance evaluation approach and argue for a new cadre of third-party evaluators, architects, engineers and building professionals who can bridge the energy and carbon savings gap.

Energy transitions and climate change

It is important to place the evolution of India's building stock within the larger landscape of energy and climate change debates. As noted above, India's buildings are already responsible for around 35% of the total energy consumption and their energy use is increasing at 8% annually. The country's building stock is integral to energy consumption and GHG emissions, with projections for dramatic increase over the next few decades (GBPN, 2013). If left unchecked, Indian building energy demand could increase by as much as 700% by 2050 compared with 2005 levels (GBPN, 2014). The technical opportunity estimated from this unprecedented future growth is estimated to be a 30% reduction in energy use in new residential buildings and 40% in new commercial buildings through energy efficiency measures (MoEF, 2012). Understanding the scope and feasibility of realizing this opportunity is particularly relevant in the current climate negotiations architecture of the United Nations Framework Convention on Climate Change's (UNFCCC) Paris Agreement, where mitigation targets are set by countries themselves and an understanding of global emissions trajectories will need to be built on a granular understanding of national energy and emissions trajectories (UNFCCC, 2015).

Mathur provides an overarching view of India's building stock and discusses the arc of building energy efficiency governance, with a regard for future solutions. The paper focuses on operationalizing the opportunities presented by the development of India's building stock over the next 20 or more years. An alignment and creation of incentives for local authorities, businesses and citizens is urgently needed in order to implement the (national) Energy Conservation Building Code at regional and local levels. Vishwanathan et al., on the other hand, couple bottom-up and top-down energy models to capture the complexity of the energy transition of the building stock, and its linkages to the broader issues of macroeconomic and employment impacts. They demonstrate that moving towards decarbonizing the buildings sector is fundamental to attain an overall emission reduction in the long term, especially give the shift in cooking technologies (from traditional biomass to cleaner energy). The study also suggests a resulting shift away from low-skilled jobs in agriculture to medium-skilled and specialized technical jobs in manufacturing, construction and power-generation sectors. Beyond domestic macroeconomic impacts, the question remains about harnessing the ability of India's building stock in enabling a low-carbon society and in meeting international climate goals. Graham and Rawal discuss the initiatives for buildings being undertaken in light of India's nationally determined contribution towards the 2015 Paris Agreement. They argue that while large reductions in building energy demand and related GHG emissions will be key to meeting the country climate contribution, current initiatives are not enough. Their paper calls for strategically aligned national, subnational, and private-sector energy and climate action commitments to facilitate a transition to a low-carbon emissions pathway.

Collectively, the content in this special issue serves to raise the profile of, and strengthen, the domestic and international case to prioritize energy and climate change solutions in India's building stock in the next few decades. More, however, needs to be done to bridge methodological knowledge gaps as described above to bring together diverse research and policy communities. This is a worldwide concern, not limited to developing countries. In the case of India, international collaborations may be helpful in building and broadening this integrated and interdisciplinary understanding.

Internationally collaborative research

Given that climate change is a global problem, India's issues are not just her own. The international salience of managing energy demand in India's buildings is marked by a series of active international and bilateral programmes and research collaborations between India and other countries (Khosla, Sagar, & Mathur, 2017). A complete accounting of these collaborations is beyond the scope of this editorial, but brief descriptions of three recent initiatives give some indication of the significant international and interdisciplinary engagement in this area.

- One of the earliest collaborations towards building energy efficiency improvements was undertaken by the United Nations Development Programme (UNDP) and the Bureau of Energy Efficiency (BEE), Government of India (2010–17; US$21 million) to assist in implementing and operationalizing the Energy Conservation Building Code (ECBC) for commercial buildings. The work was also supported by the Global Environment Fund (GEF) and the Swiss Agency for International Development to address informational, capacity, institutional and financial barriers to the ECBC (UNDP GEF BEE [Bureau of Energy Efficiency], 2016). More recently, ECBC 'cells' have been created in states to assist with code implementation, and this work continues with projects such as 'Adoption, Compliance, and Enforcement for Energy Efficiency' (ACE-E2) funded by the European Union to expand and interconnect the ECBC cells (ACE-E2, 2018).
- The US–India Centre for Building Energy Research and Development (CBERD) was a five-year (2013–17; US$5 million) collaborative effort focused on developing and implementing energy efficiency technologies in both the US and India (Chao, 2012; US DOE, 2017). Funded by two research councils in India, and the US Department of Energy (DOE), it brought together multidisciplinary expertise from 11 research institutions and two dozen industry partners in India and the US to promote clean energy innovation with measurable results and significant reduction in energy use in both nations (CBERD, 2018).
- Energy Demand Reduction in the Built Environment is an ongoing research collaboration between the UK and India (2017–21, £3.8 million (US$5 million)) funded by the Indian Department of Science and Technology, the UK research councils and the Newton Bhabha Fund (BHC New Delhi, 2017; UKRI, 2017). This effort comprises four projects:
  - Residential Building Energy Demand Reduction in India (RESIDE, www.reside-energy.org): to develop a data-driven residential energy code and implementation framework by assessing all aspects of residential energy use in India.
  - Integrated Urban Model for Built Environment energy Research (iNUMBER, www.inumber.org): to develop a new model of building and municipal energy services to help cities examine their energy–water nexus, reduce energy demand, and improve electricity and water services.
  - Zero Peak Energy Building Design for India (ZED-I, https://www.zedilab.com): to decouple building energy use from economic growth through a zero-peak energy building design for warm climates, and to build resilience and adaptation to higher urban temperatures.
  - Community-Scale Energy Demand Reduction in India (CEDRI, https://cedri.hw.ac.uk): to provide

strategies towards reducing energy demand in communities at neighbourhood or larger scales and improve the performance of energy supply networks.

The international collaborations described above have provided significant analytical, technical and programmatic support to the energy and climate change work in India and often propelled domestic efforts forward over the last decade and a half (Khosla et al., 2017). The work occurs in close cooperation with research institutions, local experts, civil society partners and state governments. An important trend in recent international engagements is the comprehensive nature of the collaboration between all relevant stakeholders, with shared input from all countries involved. Pursuing collaborative research of this kind is especially useful in an increasingly interconnected world, where many developing countries are actively absorbing technology-based solutions from other countries, and to better tailor solutions to local needs, cultures and lifestyles. It is also important to note that research, bilateral and multilateral programmes are best constructed around a collaborative and ongoing local assessment process that serves as a precursor to programme design to determine indigenous priorities, technology-cycle needs and capabilities. In particular, operational know-how and local adaptive and absorptive capability are key to successful technical projects. As discussed by a review across developing countries, the crucial ingredients of technology transfer were found rarely in 'hardware', but rather in people-embodied knowledge (Rai & Funkhouser, 2015). Promoting such international and strategic collaborations can also assist India's future research agenda and capacities to gain from broader global initiatives, where multidisciplinary approaches are finding traction.

Looking ahead

Collectively, the content in this special issue enables a clearer understanding of the state of knowledge and knowledge gaps that continue to exist on energy and climate change in India's building stock. It also outlines the tenets of a future research agenda for India's building stock, which is interdisciplinary in nature. Such socio-technical research is needed not just in India but more broadly in the developing world. Much of the investment in the developing world's infrastructure construction is yet to take place and multiple benefits can be reaped from building stock solutions that lock-in sustainable development pathways. The upcoming Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) also recognizes the need to focus on demand, services and social aspects of mitigation, and to integrate scientific knowledge from diverse and under-represented disciplines and geographies.

The emerging research on India's building stock reveals this is an essential sector for policy-makers to address climate solutions and where such demand-side solutions can be applied. Yet, this opportunity is only as useful as the early decisions that are made, especially in rapidly transitioning economies such as that of India. Doing so will require research and policies that strategically investigate the nature, scale and implementation of different measures, and also include the associated changes in lifestyles, social norms and wellbeing. While an understanding of India's current and future building stock across these different dimensions still requires much to be known, this special issue providing a starting point from which to stimulate such a shift.

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