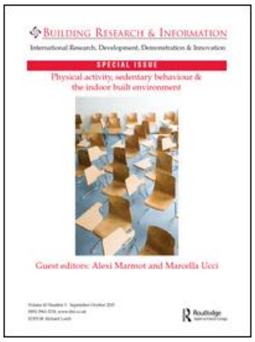

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INFORMATION PAPER

Governance strategies to achieve zero-energy buildings in China

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In response to climate change, governments are developing policies to move toward ultra-low-energy or 'zero-energy' buildings (ZEBs). Policies, codes, and governance structures vary among regions, and there is no universally accepted definition of a ZEB. These variables make it difficult, for countries such as China that wish to set similar goals, to determine an optimum approach. This paper reviews ZEBs policies, programmes, and governance approaches in two jurisdictions that are leading ZEBs development: Denmark and the state of California in the United States. Different modes of governance (hierarchy: principal–agent relations, market: self organizing and network: independent actors) are examined specifically in relation to policy instruments (prescriptive, performance or outcome-based). The analysis highlights differences in institutional conditions and examines available data on energy performance resulting from a building policy framework. The purpose is to identify ZEBs governance and implementation deficits in China and analyse alternative governance approaches that could be employed in China, which is currently developing ZEBs targets and policies. Conclusions suggest that the ZEBs governance structure in China could benefit from widened participation by all societal actors involved in achieving ZEBs targets. China's ZEBs policies would benefit from employing a more balanced hybrid governance approach.

Keywords: building performance, building regulations, energy codes, energy policy, governance, net-zero, outcomes, policy, regulatory systems, zero-energy buildings, China

Introduction

In the developed world, buildings consume more energy than any other sector. In response to climate change and growing resource shortages, major world regions are developing policies to move toward zero-energy buildings (ZEBs). Building energy performance policies and codes, definitions of ZEBs, and governance structures for implementing policies vary among regions. Currently, the European Union (EU) Energy Performance of Buildings Directive (EPBD) requires 'nearly-zero-energy buildings' (nZEBs) target for all EU member countries' new construction by 2020, and the United States is pursuing a 'net-zero-energy buildings' (NZEBs) goal. Despite the apparent similarity in these terms, there are significant differences in the definitions, policies and support mechanisms associated with them. This variation makes it difficult not only to understand and evaluate global progress toward ZEBs but also for countries such as China that are considering setting similar goals to assess the optimum approach to adopt. For simplicity, in this paper the umbrella term 'zero-energy buildings' (ZEBs) is used to refer to all the various types of low-energy buildings encompassed in the various initiatives studied. However, when referring to policies specifically tied to EU EPBD initiatives, or US net-zero activities, the abbreviations 'nZEB' and 'NZEB', respectively, are used.

Defining a clear target is the first step in the ZEBs governance process. ZEBs definitions have been widely studied from a technical perspective, but there has been little examination of the governance of ZEBs. Moreover, in the building industry, the concept of governance is commonly understood as referring to only regulations and administrative instruments (*e.g.*, mandatory or voluntary codes). This paper aims to fill a knowledge gap by providing guidance toward ZEBs definitions and governance strategies in China and elsewhere, based on an understanding of ZEBs targets and policy instruments adopted in leading world regions, as well as overall governance approaches that influence their policy design and outcomes. That is, a jurisdiction's governance mode affects how a ZEB target is interpreted and implemented. This issue has several dimensions. One is the overall governance approach (*e.g.*, whether policies are formulated and imposed by government or in deliberations among societal participants/stakeholders). Another is the numerous elements that must be integrated to achieve a ZEB (*e.g.*, building energy efficiency, plug loads, renewable energy sources, etc.), which requires consensus among various stakeholders. Related to this complex integration is that traditional building codes cannot address all the elements necessary to achieving a ZEB. Finally, a strategic governance process will be always partly technical and objective, and partly political and subjective (Simmons, 2015).

This paper reviews ZEBs targets in leading world regions and ZEBs policies and governance modes in two jurisdictions where ZEBs targets have been successfully implemented: Denmark in the EU and California in the US. These two jurisdictions exemplify different governance modes. The selection of these two cases is primarily based on their successful implementation of ZEBs policies. Denmark is one of the first two countries in the EU that established a binding national target for ZEBs. In 2014, one-third of all ZEBs in the US were located in California. The experiences in these jurisdictions are relevant to China where similar ZEB goals have just recently been proposed. An often-cited challenge is that China's green governance and implementation do not match the government's stated green objectives (The World Bank and Development Research Center of the State Council of China, 2014).

The aim of the current paper is to provide guidance for China and other regions interested in developing ZEBs goals. Given the different institutional conditions in the selected jurisdictions, our guidance is not necessarily focused on directly transferring policies from region to region. Based on the assumption that the choice of specific policy instruments is likely dictated by the prevailing governance processes, the aim is to develop guidance for other regions based on identification of the governance and implementation strengths and deficits in these jurisdictions, and an understanding of how they designed and implemented ZEBs targets appropriate to their local institutional conditions.

The remainder of this paper discusses major features of ZEBs definitions in leading world regions, gives an overview of governance modes and identifies governance strategies in Denmark and California, and reviews building energy-efficiency and renewable-energy (mainly solar photovoltaic – PV) elements of the ZEBs policies in these two regions. The analysis emphasizes the overall governance strategy and existing policy framework to support compliance with and enforcement of ZEBs targets. Finally, the paper describes current ZEBs activities and governance in China, and concludes key features of China's prospective ZEBs targets, and key governance strategies for China to achieve the ZEBs goal.

Building energy code approaches

Globally, there are two main types of building energy performance codes: 'prescriptive' and 'performance' based. The prescriptive-based code approach specifies how a building must be constructed, including specifying energy performance values for building elements such as window *U*-values. In contrast, the performance-based approach specifies total energy consumption for new construction, based on modelled energy use. In other words, performance codes would state a minimum and/or maximum target (generally excluding the method by which this is achieved), whereas the prescriptive method defines a specific target and/or method to comply. In the US, some jurisdictions are moving toward a third type of code, an 'outcome-based' approach that requires a measured, post-occupancy energy performance level (IPEEC, 2015). The outcome-based approach is similar to a performance-based code in that it specifies requirements for building design, construction and commissioning. The main difference is that an outcome-based approach also includes requirements for the building's actual operation. An advantage of an outcome-based code is that by assessing actual measured energy demand rather than predicted energy consumption, it addresses the impacts of plug loads and occupant behaviour, which are currently not covered by most building regulations. In China, new energy-consumption standards (energy quotas) are being developed in the official public review copy of draft 'Standard for Energy Consumption of Buildings', which states a maximum energy intensity by building type and climate/location. The quota is similar to an outcome-based code in defining a maximum energy consumption intensity by building type over a specified period (usually 12 consecutive months) (Xin, Lu, Zhu, & Wu, 2012). However, the quota applies only to actual energy use for existing buildings (that is, it is outcome-based). For new buildings, the quota is based on predicted energy performance (performance-based).

The type of code – prescriptive, performance or outcome-based – dictates the approach by which the ZEBs goal will be achieved. For instance, the prescriptive approach would require minimum levels for different building components such as *U*-values, airtightness and the share of renewable energy use, while the performance approach would specify that the building's *predicted* annual final/primary energy demand or modelled carbon emissions be offset by renewable energy produced on-/off-site or by credits purchased from the grid. Under an outcome-based approach, the ZEBs target would be achieved in a manner similar to that of the performance approach, *i.e.*, by measuring and balancing energy use and carbon emissions, except that the measurement and calculation of the *actual* energy/carbon balance would occur during the post-occupancy period. Implementing outcome-based ZEBs codes would require some market actors to alter their roles and strategies. For example, because occupant behaviour affects compliance with outcome-based codes, designers would likely engage more with energy management and building occupiers than is currently typical, and officials who currently typically only evaluate designs and plans would need to extend their involvement into the period after a building is operating (Denniston, Frankel, & Hewitt, 2011). Capacity building and education, benchmarking, measurement, verification, and incentives would be critical elements of an outcome-based approach (Evans, Halverson, Delgado, & Yu, 2014).

There are currently few international experiences with outcome-based codes. Most countries require that building designs be reviewed for compliance with building energy codes, but only a very few jurisdictions also inspect buildings to ensure code compliance, for example, Swedish building code enforcement includes an option of verification of actual energy consumption once the building is operational (Global Buildings Performance Network, 2014). In most jurisdictions, actual energy use in buildings is usually considered in programmes such as benchmarking, labelling, energy audits and commissioning. These existing programmes provide feedback mechanisms to support code compliance and documentation of actual energy savings. This paper's focus is not whether or not China should adopt an outcome-based code but instead it considers the positive and negative aspects of different ZEBs definitions, code compliances approaches and governance strategies that China might adopt.

Zero-energy buildings' definitions and targets

This section reviews the ZEBs definitions and targets adopted in leading world regions. The purpose of this review is to identify key considerations for the Chinese ZEBs definition, not to recommend a single type of ZEBs definition.

Definitions of zero-energy buildings

ZEBs definitions for policy purposes encompass numerous location-specific factors, including the technologies to be adopted in ZEBs, the economic viability of ZEBs, the feasibility of implementing ZEBs technologies, impacts on the regional electricity grid and benefits to different stakeholders. These factors, in turn, influence the deployment of ZEBs technologies.

There is currently no universally accepted definition of a ZEB. One aim of the joint International Energy Agency (IEA) SHC TASK40/ECBCS Annex 52, was to illuminate different international ZEBs definitions. Existing definitions correspond to regional political and other considerations associated with promoting ZEBs (Sartori, Napolitano, & Voss, 2012). A key element underlying a ZEB definition is the balance between weighted energy demand and supply (Figure 1). Currently, four definitions of this balance are commonly found around the world: net-zero site energy, net-zero source energy, net-zero energy costs and net-zero energy emissions (Table 1). In practice, approximately 75 methodologies are used around the world to determine this balance. Some jurisdictions consider more than one metric (Ecofys, Politecnico di Milano, & University of Wuppertal, 2013). This wide variety of metrics indicates the regional diversity in the interests and motivations of ZEBs market actors.

Figure 1 underscores the importance of energy efficiency in achieving the ZEBs goal. The ZEBs design concept generally requires more than passive design strategies. Table 2 summarizes the differences among ZEBs definitions in selected world regions.

Table 2 shows that different regions interpret factors differently, particularly the weighting factors of energy supply and demand, the ZEBs boundary (whether on- or off-site renewable energy is included within the ZEBs 'footprint' and whether a zero-energy goal must be achieved by a single building or can be achieved over a group of buildings), what energy use is accounted for in the ZEBs, minimum ZEBs requirements, and building types. Newly proposed building codes must take into account existing

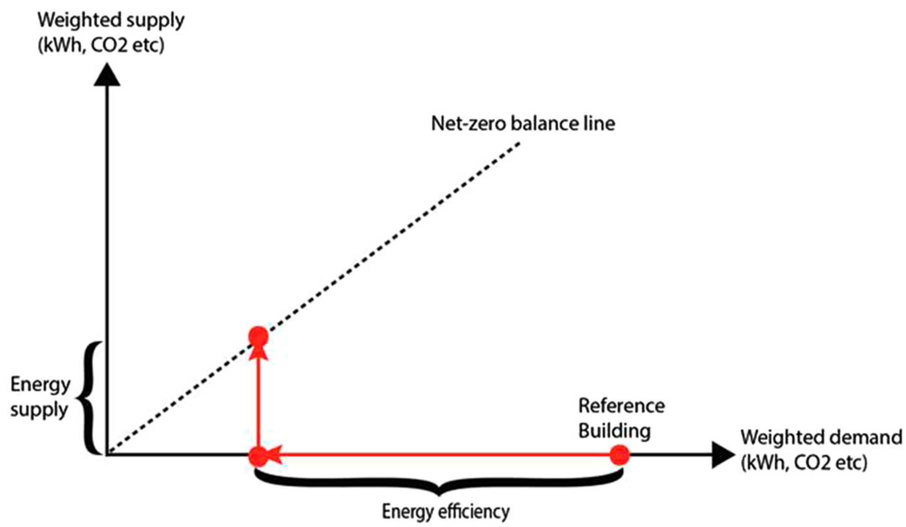

Figure 1 Zero-energy buildings' (ZEBs) balance concept.
Source: Sartori et al. (2012).

building codes and voluntary efficiency standards. For example, in Europe, the Passive House standard and other voluntary codes are widely disseminated and form a baseline for developing the ZEBs concept.

Some general findings about the range of definitions can be summarized as follows:

- The primary energy metric (source energy) is more commonly used in the EU, while the site energy metric (final energy) has been used extensively in the US, although the US Department of Energy (DOE) recently defined the primary energy metric for ZEBs (DOE, 2015).
- Plug loads are generally not included in European definitions but are required in US definitions.
- To help meet the EU's long-term climate target, some EU definitions include both minimum energy-efficiency and renewable-energy requirements; renewable energy is less prominent in US definitions.
- Embodied energy is considered only in Norway's and Switzerland's definitions. When buildings become much more efficient, the share of embodied energy from materials and manufacturing can be as high as 62%, according to a case study in California (Faludi, Lepech, & Loisos, 2012).
- EU building code requirements have gradually shifted from prescriptive to performance-based. In the US, codes generally offer both prescriptive and performance-based options; the US building industry has also begun to experiment with outcome-based codes.
- In East Asia, *e.g.*, South Korea, where high-rise buildings are more common than in Western countries, the system boundaries for high-rise buildings and community-level ZEBs are extended to include off-site renewable options.

Table 1 Common zero-energy building (ZEB) definitions.

Concept	Definition[a]
Net-zero site energy	$m - r - r0 \leq 0$
Net-zero source energy	$m + g - r - r0 \leq 0$
Net-zero energy costs	$\$m - \$r \leq 0$
Net-zero energy emissions	$CO_{2m} - CO_{2r} - CO_{2g} \leq 0$

Note: [a]m = Final energy use at the meter; r = renewable energy produced on-site; $r0$ = renewable energy supply off-site; g = energy transmission lost; $\$m$ = bought energy cost; $\$r$ = on-site renewable production sales; CO_{2m} = CO_2 emissions from final energy use; CO_{2r}= offset CO_2 emissions from on-site renewable energy production; CO_{2g} = CO_2 emissions offset through carbon-trading schemes.
Source: Ji and Guo (2013).

EU and US zero-energy buildings' targets

Europe aims to reduce building-sector greenhouse gas (GHG) emissions by 88–91% by 2050 compared with 1990 levels (Boermans & Grözinger, 2011). The revised EPBD requires that all new EU buildings occupied and owned by public authorities are nZEBs after 31 December 2018, and all new buildings are nZEBs by 31 December 2020. The EPBD, the Energy-Efficiency Directive (EED) 2012/27/EU, the directive on renewable energy sources (209/28/EC), and directives on ecodesign and energy labelling (2009/125/EC and 2010/30/EU) provide the legal framework for the EU's nZEBs target. As required by EED Article 4 (2012), member states must also establish long-term

Table 2 Zero-energy building (ZEB) definitions in leading world regions

Region	Definition/label	Metric			System boundary		End uses and life-cycle stages included					Minimum requirements		Single building types	
		Primary (source) energy	Final (site) energy	Carbon emissions	On-site	Off-site	HVAC[a]	DHW[a]	Lighting	Plug load/ appliance	Embodied energy	EE[a]	RE[a] share	New	Existing
EU	EPBD[a]	✓			✓	✓	✓	✓	✓			✓	✓	✓	✓
DE[a]	EffizienzhausPlus	✓			✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
DK[a]	BR10	✓			✓	✓	✓	✓	✓			✓		✓	
CH[a]	Minergie-A	✓			✓		✓	✓	✓	✓	✓	✓		✓	
NO[a]	Zero-emission building			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
UK[a]	Zero-carbon standard			✓	✓	✓	✓	✓	✓			✓	✓	✓	
US[b]	Zero-net-energy building	✓	✓		✓	✓	✓	✓	✓	✓		✓		✓	
SK[a]	Nearly zero-energy building	✓			✓	✓[c]	✓	✓	✓			✓		✓	
JP[a]	Net-zero-energy building	✓			✓		✓	✓	✓	✓		✓		✓	

Notes: [a]HVAC = heating, ventilation and air-conditioning; DHW = domestic hot water; EE = energy efficiency; RE = renewable energy; EBPD = Energy Performance of Buildings Directive; DE = Germany; DK = Denmark; CH = Switzerland; NO = Norway; UK = United Kingdom; SK = South Korea; JP = Japan.
[b]In the US, California has proposed to use the time-dependent valuation (TDV) metric in a definition of ZEBs, which is a conversion of final energy metric; at the national level, the Department of Energy (DOE) recently provided the primary energy metric (source energy) as an option for a definition of ZEBs.
[c]In South Korea, the system boundaries for high-rise buildings and community-level ZEBs are extended to include off-site renewables options.
The definitions/labels listed are provided mostly by public authorities. Others from the research community or voluntary sources are not included here. The ZEB target is usually required in new buildings. Building code regulations usually refer to single buildings; however, the ZEB concept can also be realized in cluster of buildings. End uses and life-cycle stages included (accounting system); electro mobility is generally not included, except in DE. Balance period: this is typically based on the operational year; the life-cycle perspective is only considered by definitions in CH and NO. Minimum requirements also include indoor climate and comfort elements that are not listed here. The minimum renewable integration requirements in UK definition are met through carbon compliance minimum levels.
Sources: Zhang, Xu, Jiang, Feng, and Sun (2014), Ecofys et al. (2013), Dokka, Sartori, Thyholt, Lien, & Lindberg (2013), Atanasiu, Kunkel, & Kouloumpi (2013), Zero Carbon Hug (2014), UK Green Building Council (2014), APEC Energy Working Group (2014).

strategies for mobilizing investment to renovate national building stocks, with emphasis on 'deep' renovations to achieve the nZEBs goal. In contrast to 2013 when only five member states had nZEBs definitions in place (Groezinger et al., 2014), by 2014 a majority of EU member states had adopted or were in the process of approving definitions. Denmark was one of the few countries that first established a legally binding (coercion regulation) national nZEBs plan and definitions for new buildings by 2020. The EU directive requires that the nZEBs goal be achieved but does not dictate the means by which this must be accomplished.

In the US, based on the Energy Independence and Security Act of 2007 and Executive Order 13514, the DOE's goal is to create the technology and knowledge base for cost-effective zero-energy commercial buildings by 2025. The DOE formalized a NZEB definition in September 2015 (DOE, 2015). To date, there are 39 NZEB verified or building clusters that, as a group, achieve zero-energy targets. These projects have been documented to meet, over the course of a year, all net energy demand through on-site renewable energy sources (New Buildings Institute, 2015). Several US state and local jurisdictions have set NZEBs goals. For example, the California Energy Commission plans to update Title 24, the energy-efficiency portion of the California building code, to include the NZEBs goal (CPUC, 2008). About one-third of US NZEBs are located in California, which is recognized as a leader in NZEBs market transformation (Cortese, Higgins, Lyles, & Hamilton, 2014). Overall, NZEBs targets in the US have been initially advocated by a non-governmental organization, NGO Architecture 2030, using a bottom-up approach. The US NZEBs goal is non-binding but includes detailed recommendations (targeting regulation).

Method and theoretical framework for analysing governance modes

This study's conclusions relate to two main themes: ZEBs governing targets and ZEBs governance strategies that might be adopted in China and elsewhere. The research material collected for this study is largely based on a literature review of ZEBs definitions (Table 2) and relevant policy instruments (see the supplemental data online). The conclusion about governing targets for ZEBs in China is based on a review of ZEBs technical definitions in leading world regions as well as the current status of building codes and energy use in China. For governance strategies, it is not sufficient to draw conclusions based on transfer of successful policy instruments from one jurisdiction to another, because the institutional conditions in each region are fundamentally different from one other. Ultimately, China needs to develop its own governance approaches that are based on its own institutional environments – the simple adaptation of approaches from other regions is unlikely to be directly transferable. Nevertheless, there are broad governance strategies that can be drawn from governance theory and case studies for China to consider. More specific step-by-step governing approaches or a proposed roadmap are beyond the scope of this paper; such an analysis would require a more in-depth investigation of China's case and its evolving policy-making and implementation processes. The conclusions about alternative governance strategies are based on an understanding of the theoretical background of governance concepts and governance modes, and their adoption in the ZEBs policy design and implementation in the selected jurisdictions. It is important to emphasize the concept of governance first and identify governance deficits. By understanding how different governance modes influence policy design and implementation, it is possible to identify the linkage between empirical policy instruments and overall governance strategies. Our central claim is that the policy instruments adopted to achieve ZEBs targets are embedded in the dominant governance mode in each region, rather than the other way around. In this paper, the governance strategies specifically refer to building energy performance, without taking into account other types of requirements for buildings, such as health or life safety building codes. In the remainder of this subsection, the theoretical background of governance concept and modes of governance are introduced.

The core meaning of governance is the means employed to steer and coordinate a region's economy and society (Pierre & Peters, 2000). Much debate centres around definitions of governance and modes of governance processes. Governance comprises actors from all segments of society working together to pursue collective goals. General categories of governance modes are state-centric, society-centric, and hybrid forms that are a mix of state intervention and societal autonomy. In reality, hybrid governance is the most common type and it often operates in the shadow of hierarchical and administrative forms (Hildingsson, 2015). Governing modes can be discerned from the dimensions of polity (a region's institutional properties), political (actor constellations), and policy (policy instruments) (Treib, Bähr, & Falkner, 2007).

The paper examines modes of governance in relation to policy instruments. In political science literature, much discussion concerns what constitutes legitimate input (*i.e.*, accountability, participation, transparency) to governance, referred to in aggregate as the quality of the decision-making process. Whether a governing mode results in legitimate output (*e.g.*, effectiveness of institutions, environmental performance) is not well researched (Bäckstrand, Khan, Kronsell, &

Lövbrand, 2010), for example, with regard to problem-solving capacity or effectiveness. The current analysis does not focus on which modes of governance are preferable but on describing policy alternatives under different governance modes. The modes of governance considered in this paper are:

- hierarchy (principal–agent relations): a state centric mode of governance that normally operates through administrative orders and sets of rules and is exercised by states, governments and bureaucracies in relation to societal actors (Bäckstrand et al., 2010)
- market (self-organizing): a society-centric mode with explicit focus on non-state actors (Hildingsson, 2015)
- network (interdependent actors): based on resource dependencies between private and public actors and/or individuals (Bäckstrand et al., 2010)

Each governance mode is made up of different combinations of three elements: administrative, economic and deliberative rationality (Bäckstrand et al., 2010). It is essential to note that we are not looking at governance modes and their combinations of types of rationalities as if those constituted a checklist that could be used to design a governance strategy. Instead, governance modes and their combinations of rationalities are an overarching conceptual lens to guide the analysis of empirical policy documents.

As an alternative to analysing output legitimacy, this analysis focuses on effective policy outcome and distinguishes policy output and policy outcome. Policy output is the direct result of policies, *e.g.*, more energy-efficient design, integration of renewable energy. Policy output is a means to achieve policy outcome. Examples of policy outcome are achieving ZEBs targets or reducing GHG emissions (Lucia, 2012). Policy outputs are the main resources by which we can understand the policy background in each region. These can be found in the supplemental data online for this paper as well as the 'ZEBs policy background' subsections for each jurisdiction discussed below. Policy outcomes are discussed in the subsection 'Implications for building regulations to achieve ZEB outcomes' below. The governing process influences how a policy is implemented or enforced. For example, a policy can be implemented by coercion (detailed standards with little leeway in implementation), voluntary compliance (non-binding instruments that only define broad goals), targets (non-binding instruments that offer detailed recommendations), or framework regulations (binding law, with leeway in implementation) (Treib et al., 2007).

Governance of zero-energy buildings in Denmark and California

This subsection identifies the ZEBs policies and governance approaches in Denmark and California, two regions leading ZEBs development. California has been leading the US ZEBs market in terms of total built projects, and Denmark, which has among the most progressive and ambitious energy and climate policies in the world, was one of the first two EU member states to establish a national ZEBs plan. For this analysis, the research team disaggregated Denmark's and California's governance frameworks into eight policy outputs: targets and building codes, certification, economic instruments, compliance and enforcement, information tools, demonstration projects, education and training, and research and development (R&D) (Ecofys et al., 2013). This policy output broadly covers the relevant elements of ZEBs, including building energy efficiency, solar PV and plug load. Details of these components can be found in the supplemental data online. The subsections below summarize the general ZEBs-relevant governance strategy in Denmark and California.

Denmark

ZEBs policy background

Denmark's ZEBs goal has been seen as an opportunity to increase the renewable energy share in the national energy mix (Marszal et al., 2010), and, in the long-term, to achieve a fossil fuel-free country by 2050. Therefore, ZEBs policies in Denmark tend to apply to multiple sectors. The ZEBs target is accepted by a broad majority in Denmark's parliament and thus has long-term credibility (Low Carbon Transition Unit, 2013). Denmark's ZEBs goal covers new and existing buildings as well as the electricity and heat production systems. The Danish government has signalled to the construction industry that the ZEBs goal will be mandatory in the building code by 2020. Since 2006, the Danish building code has provided three different performance levels that builders can choose. This approach makes clear that the industry needs to prepare for the future ZEBs market. The national policy has inspired several municipalities to adopt ambitious building performance targets. This policy process is considered 'dynamic' in that clear energy-savings targets have been set within a long-term time frame, building energy codes are regularly revised to move buildings toward those goals, and the overall approach encourages developers to go beyond the minimum code requirements (Global Buildings Performance Network, 2014).

The ZEBs policy package in Denmark has a regulatory focus (PRC Bouwcentrum International and Delft University of Technology, 2011), consistent with Denmark's history since the oil crisis of the 1970s of levying energy and carbon taxes and establishing building regulations to mandate energy efficiency. In general, since the 1970s, Denmark's financial mechanisms to encourage energy-efficient buildings have been heavy energy and carbon taxes. Today, Denmark has a comprehensive set of taxes, charges and other fiscal instruments on energy, transportation, pollution and resources. Most of these taxes and charges flow into the general governmental budget, with exception of a 'public service obligation' that is charged as a tariff collected by a state-owned non-profit enterprise (Energinet.dk), which is independent of the government budget. Renewable-energy deployment in the building sector is supported by a feed-in tariff and net-metering rules (Ministry of Climate Energy and Building of Denmark, 2013). In 2012, solar energy grew exponentially in Denmark; the country achieved its 2020 solar goal in just one year (Solarplaza, 2013). Solar PV is only one of the renewable alternatives for achieving ZEBs in Denmark. Regarding plug loads, Danish appliance energy-efficiency standards generally depend on EU codes (The Danish Government, 2011).

Governance mode in relation to ZEBs policy

Overall, Denmark's ZEBs policy package is balanced. The governance mode for ZEBs can be described as a mix of the hierarchical, market and network forms defined above. Standards, taxes, subsidies and labelling schemes were applied in steering Danish society to adopt ZEBs goals, which are incorporated as part of broader energy policy. The ZEBs goal has been implemented in connection with local planning that also takes into account district heating and renewable energy development (Quitzau, Hoffmann, & Elle, 2012). In addition, the institutional frameworks and lines of responsibility between central and local governments are well defined for municipal energy planning (Sperling, Hvelplund, & Mathiesen, 2011). This governance strategy creates a legitimate way for interdependent actors to participate in establishing ZEBs policies, and communication and information-sharing are imperatives. This approach has helped to elicit high-level political support and unified action (World Green Building Council, 2013). Denmark's ability to act as a society is viewed as a key factor in the country's successful energy transition since 1970s (Lund, 2010).

Key building regulations for energy code compliance

The essential elements for complying with Denmark's ZEBs regulations are: capacity-building and education, benchmarking and disclosure, measurement, verification, and incentives. Denmark was the first country to introduce benchmarking legislation in 1997. The legislation requires energy labelling (energy performance certificates) for new construction and for existing homes at the time of sale (Kjaerbye, 2009). Building owners and property (real estate) agencies face financial penalties for violating energy performance requirements (European Commission, 2013). Formal legislation passed in 2013 (Law No. 642) authorizes rolling out smart meters to 100% of customers by 2020 (European Commission, 2014). Denmark's energy performance certificate scheme and smart metering programme create preconditions for measuring and verifying building performance. Compliance measures include mandatory and voluntary inspections and sample testing of boilers, appliances, airtightness etc. (European Commission, 2013; Low Carbon Transition Unit, 2013). In particular, periodic furnace/boiler performance checks are mandatory (Evans et al., 2014). For new buildings meeting 2015 or 2020 (ZEBs) requirements, the air-tightness sample size must be 100%. Many municipalities have already applied these requirements to all new buildings (Low Carbon Transition Unit, 2013). Denmark's ZEBs target is performance based. Under the current building regulations, post-occupancy performance requirements are linked to the energy performance certificate scheme. Overall, Denmark has robust programmes to ensure building code implementation and compliance. On issue of building energy code, the compliance procedures are also adjusted over time (Yu, Evans, Delgado, & Northwest, 2014).

California

ZEBs policy background

As a frontrunner in US energy-efficiency and renewable-energy policy and technology deployment, California already has a substantial policy package supporting ZEBs, explicitly outlined in California's ZEBs action plans (CPUC, 2012, 2013). In addition, the state's mild climate and mature solar market help make ZEBs technically and financially feasible. The state's targets are new residential ZEBs by 2020 and new commercial ZEBs by 2030. To date, the California Energy Commission and California Public Utility Commission (CPUC) have, with stakeholders, developed ZEBs action plans for research and technology; codes and standards; heating, ventilation and air-conditioning (HVAC); lighting; and other areas (CPUC, 2012, 2013).

California's overarching goal is bottom-up, market-driven development and deployment of the ZEBs concept. The market-based approach is evident in the economic instruments devised to support ZEBs, *e.g.*, solar PV incentives include tax credits, low-interest loans and rebates. These economic incentives, along with the state renewable portfolio standard and net metering and other interconnection standards, help eliminate the up-front costs of ZEBs technologies. As the solar cost makes up the majority of the incremental cost of ZEBs, the variety of regulatory and financial programmes supporting solar technology helps to motivate builders and building owners to move toward ZEBs. In some cases, commercial ZEBs paid no extra up-front costs (PG&E, 2012) when integrated design trade-offs were made appropriately. However, from the regulatory perspective, there are still barriers to mandating a ZEB goal. The California Energy Commission can only use the building energy-efficiency standard, Title 24, as a regulatory vehicle for this mandate if the measures needed to achieve the ZEBs goal are deemed cost-effective (Heschong Mahone Group Inc., 2012). Therefore, the ZEBs goal is currently not legally binding. In addition, revisions to the state's appliance standard, Title 20, to achieve ZEBs face legal challenges in part because California's appliance standard is subject to federal pre-emption (Chase, McHugh, & Eilert, 2012).

Governing mode in relation to ZEBs policy

Overall, the market-based governance mode dominates in California. Tax credits and rebates are employed rather than subsidies and tax charges, and voluntary certificates have been established. These are in line with the broader US political–economic context of free market (neo-liberal) policies in the 1980s and 1990s, which weakened states' abilities to govern the public good (Kallis, Kiparsky, & Norgaard, 2009). California's administrative structure exhibits characteristics of hierarchical, market and network governance in the form, respectively, of renewable portfolio standards and voluntary targets, expert and NGO networks, and decisions deliberatively made through advisory boards, multi-stakeholder panels and campaigns.

Key building regulations for energy code compliance

A mandatory benchmarking and disclosure policy for commercial buildings adopted in 2007 and widespread smart meters in the three investor-owned utilities' (IOUs) service territories provide a baseline for measuring and verifying actual building performance. California has a strong inspection programme for both prescriptive and performance building codes. To obtain a construction permit, builders must submit plans to the local building department for code compliance review. A code official also conducts a field inspection prior to issuing a certificate of occupancy (Misuriello, Penney, Eldridge, & Foster, 2010). Other efforts to ensure code compliance include simplifying the regulatory process and providing training (California Energy Commission, 2014). However, none of these measures is linked to a post-occupancy energy performance requirement for buildings. In the US, some voluntary initiatives already encompass an outcome-based compliance path, including the Living Building Challenge certificate and the new IgCC outcome-based code. The US Environmental Protection Agency (EPA) Energy Star voluntary programme (for commercial buildings) and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Building Energy Quotient programme (for commercial buildings) also include post-occupancy requirements (Khanna, Romankiewicz, Zhou, Feng, & Ye, 2014). Currently, California is participating in the national discussion of outcome-based building codes (Denniston et al., 2011). A major challenge for building energy code enforcement and compliance in California is the lack of prioritization of energy codes relative to health and safety codes (Misuriello et al., 2010). This problem is commonly faced by other jurisdictions as well (Misuriello et al., 2010).

Zero-energy-building governance in China

ZEBs policy background

In 2013, China added nearly 3.9 billion m^2 of new buildings (National Bureau of Statistics of China, 2014). This represents about half the world's annual new construction. Therefore, implementing a clear ZEB target along with the associated governance strategies will have a very significant impact on future building energy consumption in China. Since the ZEBs concept has just recently been introduced in China, as of the end of 2015, fewer than 10 demonstration projects have been reported (China Academy of Building Research, 2014; Ye, Zuo, & Hu, 2013). Most of these projects are commercial buildings and not certified as ZEBs. These cases were mainly supported by leading building developers and building research institutes that intended to test their design and building components. Other types of ultra-low energy buildings, such as those meeting the Passive House standard, have been developed and tested more than ZEBs in China. For instance, there have been 40 buildings proposed by 28 public/private actors to meet the Passive House standard by the end of 2015 (Zhang, 2015). Considering the enormous size of the new building stock growth in China, these practices represent just the beginning of ZEBs development.

Currently, national building codes require that both commercial and residential buildings be 65% more efficient than the baseline from the early 1980s; some province and city codes are even stricter, requiring a 75% energy-efficiency improvement for residential buildings. These codes are currently prescriptive. Performance-based codes have only recently been proposed by China's Ministry of Housing, Urban and Rural Development (MOHURD). These proposed codes define energy quotas for different types of buildings in four climate zones. Some pilot cities, *e.g.*, Beijing, Shanghai and Shenzhen, have adopted commercial-building energy quotas. In Shenzhen, the proposed annual on-site electricity intensity quota is 90 kWh/m^2 for governmental buildings and 120 kWh/m^2 for office buildings (Housing and

Construction Bureau of Shenzhen Municipality, 2015). Existing buildings must meet energy quotas based on actual energy measurements; for new buildings, the requirement is based on predicted energy performance. When a new building is completed and begins operating, the energy quota is regarded as the rated value of energy use, which can be used as a benchmark to manage building energy performance (MOHURD, 2014).

China is facing a choice of direction for the next phase of building-sector energy requirements. Discussion about a building sector roadmap by 2030 has been initiated within MOHURD and among building industry leaders. Although a final ZEBs target has not yet been released, a conference presentation by roadmap working group participants described elements that are being considered for inclusion in the roadmap. A building sector road map would be the first signal from Chinese officials to the market of the goal of realizing ZEBs by 2030 (Wu et al., 2015). In contrast to the EU and US ZEBs goals, the Chinese ZEBs goal is part of the building sector roadmap that is planned to encompass not only energy-efficiency requirements but also water and material efficiency, indoor environment enhancement, and waste reduction goals. Currently, the draft plan does not explicitly state a ZEB goal but refers to the Chinese Passive House standard (Wu et al., 2015) and proposes a non-binding targeting regulation.

China's existing policies related to ZEBs are summarized in the supplemental data online. Because ZEBs have just appeared on the Chinese market, policy instruments such as certification, information tools, demonstration projects, education and training, and R&D are lacking. In general, China's building energy-efficiency policies impose regulations that grow incrementally more stringent over time, with stricter building codes and energy consumption caps for different types of buildings. In addition to these requirements, a variety of financial incentives encourage high-performance building pilot projects, *e.g.*, green buildings, highly energy-efficient buildings and energy-efficiency retrofits of existing commercial buildings. For PV, the most relevant policies are MOHURD subsidies initiated in 2006 for building-integrated renewables, the Golden Sun demonstration subsidy programme launched by the Ministry of Finance and the National Development and Reform Commission (NDRC) in 2009, and the feed-in-tariff for renewables (NDRC, 2013). Traditionally, China's renewable-energy policy has paid more attention to wind than solar, and the PV policy has mostly been formulated from the supply side (Zhi, Sun, Li, Xu, & Su, 2014). Solar PV projects did not achieve a large scale in China until 2009. In response to international trade barriers to Chinese PV products, policies are shifting slowly to expand the domestic market. Regarding plug loads, the newly proposed energy quota can be seen as an attempt to regulate actual electricity use once a building is operating.

Governance mode in relation to ZEBs policy

Overall, the hierarchical governance mode dominates in China, exhibited in a variety of building codes and updates, governmental subsidies, periodic inspections and a 'target responsibility' system to ensure compliance. The decision-making process for ZEBs policies and codes is restricted to experts on advisory boards. There are some market governance-mode elements, such as voluntary standards, industrial alliances and incorporation of the building sector into a carbon cap-and-trade scheme. Campaign-style approaches also exist, but they are limited to efforts to address emergent local environmental crises (Liu, Lo, Zhan, & Wang, 2014). From a governance perspective, this approach of formulating and implementing ZEBs policies means a collective and complex goal is being pursued without participation by all societal actors who will directly influence the policy outcome.

Key building regulations for energy code compliance

China is increasingly investing in real-time, on-line building energy monitoring, and MOHURD has committed to incorporating benchmarking into the 13th Five-Year Plan (Szum, 2014). In addition, the voluntary Chinese green building codes provide design and operational rating options. Together with China's energy quotas, these elements create the preconditions for performance- or outcome-based code compliance. In China, building code compliance is verified by local governments and third parties. The central government relies on annual inspections and the target responsibility system to ensure compliance. In contrast to the compliance checks in the US, the annual inspection check in China also involves enforcement, and corrections are required, if needed, to meet the corresponding energy codes (Yu et al., 2014). Local governments are usually subjected to publicity pressure about violations of the target. In some pilot cities, *e.g.*, Beijing and Shenzhen, commercial building owners face legal and financial penalties if their buildings exceed the energy quota (Dong, 2014). This approach indicates that the code compliance path is beginning to achieve legitimacy.

Governance target and policy implications for China

Zero-energy buildings' terminology in the Chinese context

Table 2 shows a broad range of US and European ZEBs definitions. This range of definitions tailored to local conditions suggests that China could develop its own

ZEBs definitions to suit the country's diverse climate zones and societal goals (*e.g.*, emissions reductions goals). Currently, increasing numbers of ZEBs projects in China have adopted the 'site energy' definition, with on-site renewables only. However, although there have been a few attempts in the research community to define a concept tailored to the Chinese context, a clear, official ZEBs definition is still lacking (Zhang et al., 2013). Several aspects of ZEBs in China might differ from features of other international examples. These aspects, discussed below, could be considered in the process of officially defining China's ZEBs concept.

First, achieving ZEBs in China's urban areas will be challenging if the ZEB system boundary is limited to on-site renewables. This is because of the predominance of urban high-rise buildings that have a limited roof area for PV panels. To address this challenge, the ZEBs definition could take into account energy use at the neighbourhood or community level rather than at the individual-building level; it could allow renewable-energy credits to offset energy use in urban high rises, or it could allow for other diverse alternative energy sources. A preliminary technical study by Chinese researchers using the site-energy ZEBs definition shows that, in theory, it is possible to build an 8–10-storey commercial ZEB and a 9–11-storey residential ZEB in China's three climate zones (*e.g.*, Beijing, Shanghai and Guangzhou) (Huang, 2014).

Second, many regions in Europe developed ZEBs definitions based on existing codes, *e.g.*, Minergie-A in Switzerland, or as a progression from the Passive House standard. In China, MOHURD has already gained significant experience implementing green building codes and has recently started to experiment with the Passive House concept and the energy quota described above. These experiences could be considered in developing the Chinese ZEBs concept.

Finally, most European and US ZEBs definitions adopt one operational year as the balance period for determining net energy use. This suggests that the Chinese code needs to move from being prescriptive to being performance- and outcome-based. China's proposed energy quota policy is a step toward addressing the actual measured energy performance of buildings. Monitoring and new mechanisms to help ensure compliance need to be developed, *e.g.*, fines or denial of occupancy permits (IPEEC, 2015).

Policy implications for China

This analysis of governance strategies for implementing ZEBs targets focuses on the policy dimension. In many cases, more than one policy instrument can be used, however the choice of specific instruments is affected by the prevailing governance process in each jurisdiction (Young et al., 2015).

Strategic governance of zero-energy buildings in China

Large variation exists within any governance system, so generalizations are by definition simplifications. Nonetheless, it is possible to identify dominant features in the governance processes. For instance, defining a clear, stable and long-term collective target is the prerequisite for governance, and leadership is important in all governance systems, whether from government, market actors or civil society. The policy options that have been adopted in each region are consistent with the governance modes in the region, which are various balanced hybrid forms made up of a mixture of hierarchy, market and network. The governance mode in China is distinctly hierarchical, although some market elements have been introduced. Deliberative forms of governance involving non-governmental actors are less evident in China's decentralized authoritarian system. Energy efficiency, renewable energy and other environmental issues are understood to be the government's responsibility in China. While a strong state that takes progressive steps toward climate change mitigation policies is an important element of successful energy policy, the absence of participation from societal actors who directly influence ZEBs policy outcome is a barrier. By contrast, in California where ZEBs policies have succeeded, responsibility is shared among government (at all levels), the market and society. Similarly, a key lesson from Denmark is that the ability to act as a unified society is a key factor in the Danish energy transition that has taken place since the 1970s. And state institutions implemented these high-level agreements to ease the governance process. Thus, from a governance perspective, the key question for China's developing ZEB policies appears to be not how government can better control the issue (Zhou, Ai, & Lian, 2012; Zhou & Lian, 2012), but how government can adapt to and encompass participation by the diverse, complex set of stakeholders whose contributions are essential to the success of ZEBs policies.

In addition to lack of participation from all societal actors, China's policy implementation outcomes are also often affected by differences between national and local priorities. In China's fragmented vertical and horizontal governance structure ('*tiaotiao kuaikuai*'), mandatory standards and hard targets have been the most important measures (Kostka & Hobbs, 2012). These are interconnected to a cadre evaluation system for government workers, in which performance evaluation and political promotion are based primarily on short-term economic growth. Projects that favour the local economy and are initiated by developers are usually preferred. At the same time, urban planning guidelines, including building regulations, may be ignored (Lu, 2012). In this context, building energy-efficiency incentive implementation is solely through a top-down target responsibility system. The target responsibility system has been found problematic (*e.g.*, unscientific targets that are inflated and difficult to verify, with compliance responsibility placed on less powerful bureaus compared with the bureaus in charge of economic growth, among other issues) (Lo, 2014). Researchers have suggested that, under the current governance mode, policy bundling, interest bundling and policy framing could facilitate effective implementation by local governments (Kostka & Hobbs, 2012). Kostka and Hobbs (2012) noted that bundling processes are carried out informally; local officials and enterprises cooperate on energy efficiency in exchange for compensatory benefits for each enterprise on other issues. Policy framing can be accomplished using reframed language to incentivize participants. To address coordination issues, Ran (2015) suggested that environmental policies can be effective when overseen by local party secretaries or mayors. These are only a few possible remedies to improve policy effectiveness under the current governance mode. More studies are needed to analyse how China's very long governance history has resulted in the country's current system of bureaucracy and how that, in turn, affects the options for new policies and transitions in governance mode. Applying a general environmental target to implement ZEBs would likely face similar, if not greater, barriers at the local level as are faced by the current target responsibility system.

Implications for building regulations to achieve ZEBs outcomes

Various code enforcement and compliance evaluation tools exist in Denmark, California and China. However, curbing building energy use in China is particularly challenging. Building energy use intensity in some EU and North American jurisdictions has decreased during the past 10 years. By contrast, it has been challenging to reduce building energy use in China, even with implementation of energy-efficiency policies, because of increased saturation of energy-using appliances and improved interior comfort conditions as incomes rise. In some EU and North American jurisdictions that achieved near-total saturation of the most energy-efficient appliances between 2000 and 2012, electricity use per household decreased and residential total final energy use per floor area dropped during the same period (IEA and IPEEC, 2015). In Denmark, for example, residential energy use per capita decreased 7.5% (climate adjusted) from 2000 to 2012 (ODYSSEE, 2015; Statistics Denmark, 2015). The same metric in California decreased 3.15% from 2000 to 2012 (US Census Bureau, 2015; US EIA, 2015).

However, during the same period, the per capita energy use in the Chinese residential sector (both urban and rural) increased substantially by 137.5% (National Bureau of Statistics of China, 2015), even as district heating energy intensity has been continuously decreasing because of significant building energy conservation work. And, further complicating the picture, the current average whole-building energy intensity in China is still significantly lower than in the Western world and thus has potential to continue growing as China's living standards increase (IEA and IPEEC, 2015). These conditions indicate that successfully implementing a ZEB target in China will be challenging, with efforts to make buildings more energy efficient potentially offset by growing energy demand from increasing living standards.

In the two regions studied in this paper, code compliance has been facilitated through regular inspection and testing of building components. Benchmarking and disclosure programmes along with widespread smart-metering programmes have provided feedback on code compliance. At the same time, voluntary codes and labels reflect actual post-occupancy energy consumption.

In China, the voluntary green building evaluation and labelling programme consists of a design and operation rating label; reporting of actual energy consumption once the building is operating is not required (Khanna et al., 2014). Currently, China is investing in real-time, on-line building energy monitoring. MOHURD is also committed to incorporating benchmarking into the 13th Five-Year Plan. And a transition from prescriptive to performance (energy quota) codes has started in some pilot cities where associated incentives and penalties ensure code compliance. This infrastructure provides the basis for adopting a future outcome-based code if appropriate. Given the challenges in transitioning from prescriptive codes to performance- and outcome-based codes, it is likely that all three types of codes would co-exist for a period of time.

Although governance modes in Denmark, California and China differ, building regulations and code enforcement and compliance in these three regions share many common features, such as capacity-building and education, benchmarking, verification and code compliance checks. In China, the question is how these similar strategies can be expanded and strengthened, how policies can be implemented effectively at the local level, and how to address implementation gaps between central and local governments.

Summary and conclusions

A clear, stable, long-term, collective target is the basis for governance. China's building energy code has begun to transition from prescriptive to performance-based, and in some cases outcome-based (the new

Table 3 Summary of key zero-energy buildings (ZEBs) policy governance considerations

Defining a clear, long-term governing target for ZEBs	• ZEBs definition boundary could consider going beyond the individual-building level • Develop ZEBs definitions based on existing codes and industry practices • The current Chinese code needs to move from being prescriptive to being performance- and outcome-based. Monitoring and new mechanisms to help ensure compliance need to be developed
Key building regulations for energy code compliance	Building regulations, code enforcement and compliance measures have been established in China. These include capacity-building, education, benchmarking, verification and code compliance checks. The challenges lie in how these strategies can be expanded and strengthened for monitoring real ZEBs energy performance, and how the relevant policies can be implemented effectively at the local level
Key governing strategies	China could benefit by shifting to a more balanced, hybrid governance system that includes hierarchical, market and network forms. Other than administrative and market instruments, encompassing more deliberative elements in decision-making and implementation processes could help to reduce the current governance deficits. The complexity of ZEBs targets requires broader participation from a range of societal actors who will directly influence the policy outcome, including influential local officials, developers, consumers, building owners and occupants

energy quota policy). China's development of a ZEB definition could benefit from the example of China's existing voluntary codes as well as innovative definitions used in leading world regions. Building regulations and code enforcement and compliance in the EU, US and China share many common features, although there is a need to expand and strengthen these mechanisms in China (as well as other countries). One key element to consider is that traditional building regulations cannot address all key ZEBs issues; governance to implement a ZEB target needs to take a multi-sector perspective (including both the building and energy sectors), which also requires political consensus among various stakeholders. Most important, based on an understanding of governance concepts and an empirical analysis of ZEBs governing strategies in the selected regions and China, it appears clear that China's focus needs to shift to a governance process, in which all relevant societal actors participate in ZEBs policy development and implementation. That is, China could benefit by shifting to a balanced, hybrid governance system that includes hierarchical, market and network elements such as those illustrated in the cases of California and Denmark. Governance of the ZEBs target in China is currently limited by the structures and issues associated with the target responsibility system and the use of economic levers as the main policy instruments under the country's predominantly hierarchical governance mode. The complexity of ZEBs targets requires much more broad participation from societal actors who will directly influence the policy outcome, including influential local officers, developers, consumers, building owners and occupants (Table 3).

Finally, it is important to note that this paper only takes a snapshot of current systems of ZEBs governance, how these systems evolve were not taken into account by the study. An adaptive capacity is needed that allows for experimentation, failure, learning and recognition that any governance system operates at a less-than-optimal level. Due to the broad international scope (in terms of both geography and complexity) of ZEBs policies and activities, many examples and strategies are not included in this paper. Future research should study, in depth, the institutional and structural challenges to deploying the ZEBs concept in China.

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Supplemental data

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