Energy transition and technical energy regulations in the building sector

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Abstract. Energy demand from buildings accounts for about 31% of global final energy demand and 23% of global energy-related carbon emissions. Technical energy regulations or building energy codes - policies that set minimum requirements for energy in buildings – have proven effective and efficient in decarbonizing the building sector. However, despite their long history and success, policymakers increasingly recognise that TERs in their current design have reached a point of diminishing returns. This study evaluates five countries with innovative building energy codes – Denmark, France, England, Switzerland, and Sweden – through reviewing legal documents and conducting expert interviews with researchers, practitioners, and regulators. Our results highlight the implementation challenges of innovative building energy codes and we provide learnings in form of six design principles.

1. Introduction
The building sector accounts for about 31% of global final energy demand and 23% of global energy-related carbon emissions [1]. While buildings provide a remarkable potential for energy savings and carbon emission reduction [2], many energy-efficient opportunities are not realized despite being economically superior compared to their carbon-intensive alternatives. Technical energy regulations or building energy codes (BEC), which set minimum requirements for energy in buildings, have proven effective and efficient in reducing energy demand and carbon emissions in the past – for example, up to 22% energy savings in Europe [3] and China [4].

However, despite their success and long history, BECs in their current design have reached a point of diminishing returns [5]. Literature outlines the following five reasons: First, BECs traditionally focused on prescriptive requirements such as minimum U-values. Second, current BECs regulate the energy demand during the use phase of buildings, and thus neglect embodied energy (i.e., energy used to produce construction materials). While this is appropriate for conventional buildings with up to 90% of their lifecycle energy use during their operational phase, net-zero energy buildings have up to one-third of their energy use, and up to half of their carbon emissions embodied in their materials [6]. Third, most BECs still allow fossil heating systems, which are subsequently still the prevalent technology in many industrial countries, despite economically superior renewable alternatives. Fourth, most BECs regulate building design and construction based on calculated energy use but not measured energy use, despite an average difference between calculated and measured energy use at 34% [7] – termed as ‘performance gap’. Fifth, while stipulating requirements for retrofits, with retrofitting rates below 1% per year in many countries [8], a fast decarbonization of the entire building stock is unlikely.

Although literature highlights these challenges of current BECs, it lacks providing a comprehensive analysis of how to overcome these challenges and thus achieve a low-carbon building sector. Further, due to being mandatory for the entire sector, BECs’ implementation has been outlined as a key issue [9]. This study aims to address this gap by evaluating how policymakers can design and implement innovative BECs that address challenges of their predecessors. To do so, we first elaborate on the five challenges of current BECs –in the following termed ‘key leverage points’. We then review five
2. Methodology
We aim to increase our understanding on how policymakers can design and implement innovative BECs that address key leverage points in three parts.

Part 1 - Key leverage points: We first analyzed the few existing review studies on BECs, which mention several limitations current BEC designs have. We then consolidated and extended the findings from the review paper with a forward and backward search from the review literature and an independent keyword search.

Part 2 – State-of-the-art of building energy codes: First, we identified and selected innovative BECs that address key leverage points. To do so, we collected innovative BECs in a ‘long list’. We then applied two selection criteria: BECs are already in the process of their implementation and in countries that have similar climatic conditions. The former is required as most challenges of BECs disclose during their implementation – for example, politicians might set ambitious targets and introduce new laws but fail to implement them. The latter is required as climatic conditions influence the sources of energy demand that regulation needs to address. We ultimately selected Denmark, France, England, Switzerland, and Sweden. Second, to understand selected innovative BECs, we scanned through the relevant legal documents for building regulation (707 pages) and validated our understanding with secondary literature. For comparing BECs, we developed a categorization framework that covers the essentials of previous, prevailing, and innovative BECs (in total 63 indicators). We validated the filled framework concerning comprehensiveness and correctness in several rounds with building and energy experts.

Part 3 - Implementation challenges of innovative BECs: To discuss the challenges that disclose during their implementation, we conducted 18 semi-structured interviews (Table 1). To account for different perspectives, we conducted interviews with researchers, practitioners, and regulators. We selected the interview partners through targeted snowball sampling. In the first round, we identified experts by drawing on secondary data of BECs, industry reports, and academic publications in this field. In the second round, we then asked interviewed experts for recommendations for other experts. We conducted the interviews between March 2018 and January 2019. The response rate was 24% (researchers 33%, practitioners 20%, regulators 22%). We validated our findings by asking the interviewed experts to check their interview summary and the final case summaries, including the statements of the other experts.

3. Results
3.1. Part 1 - Key Leverage Points
In the following, we will briefly summarize the five identified key leverage points for decarbonizing the building sector:

(i) In many countries, BECs have been effective in ‘Improving Energy Efficiency’ in buildings [10]. Historically, most energy-efficiency gains came from mandating better thermal insulation of the
building envelope and installing energy-efficient building technologies for heating. While this was achieved mainly by increasing the stringency of prescriptive requirements, there are limits to which this approach can achieve energy savings, resulting in diminishing returns for each incremental improvement. For example, adding insulation material to an uninsulated wall reduces heat loss by about 75%, while adding the same amount of insulation material again only results in 11% more reduction [5].

In turn, a shift from a traditional focus on prescriptive requirements for individual building parts (e.g., U-Value) to performance metrics for the entire building energy (e.g., primary energy demand) is necessary. Besides performance and prescriptive requirements, BECs can also limit service capacities such as maximum electricity or natural gas supply [11].

(ii) Current BECs neglect ‘Considering Embodied Energy’ while concentrating on energy consumption during the use phase of buildings and thus neglect embodied energy. While this might be appropriate for conventional buildings with up to 90% of their lifecycle energy use during their use phase, net-zero energy buildings have up to one-third of their energy use, and up to half of their lifecycle carbon emissions embodied in their materials [12]. Further, energy-efficient buildings often use many energy-intensive materials [13]. Also, the transport of materials significantly affects the amount of embodied energy; for example, while timber originating from sustainable forestry is almost carbon-neutral, due to its energy-intensive transport, the embodied energy varies drastically depending on its destination [14]. Further, the recyclability of building materials contributes to the overall reduction of a building’s embodied energy [14]. BECs can help to reduce the embodied energy and carbon by taking a lifecycle perspective for performance metrics, thereby providing a more holistic picture of a building’s energy consumption.

(iii) A complete decarbonization of the building stock requires ‘Integrating more Renewable Energy’. While some BECs already prescribe the use of renewable energy, most still allow fossil heating systems, which are the prevalent technology in the building stock [15], despite energy-efficient alternatives are available. BECs could increase the share of renewables in four different ways: First, increasing the stringency of performance metrics that are based on primary energy demand or carbon emissions. Such a performance metric could also be extended to neighborhoods and districts, which facilitates the cost-effective integration of renewables. Second, prescriptive requirements can directly stipulate the use of renewable energy, indirectly increase the share of renewable energy – for example, through mandatory feasibility assessments of renewables – or directly ban fossil fuel technologies such as gas and oil boilers.

(iv) While on paper new buildings are increasingly energy-efficient, ‘Closing the Performance Gap’ – the difference between the calculated and the measured energy use – is crucial as this gap amounts to 34% on average [7] but can even increase up to 300% [16]. Causes of this gap are manifold, for example, wrong estimates of the energy-use behavior of occupants, deviations to as-planned building properties such as insulation and air permeability, rebound effects, and unfamiliarity of occupants with complex energy efficient technologies. BECs can contribute to close the performance gap by, first, improving the compliance check through additional testing of the constructed building (e.g., blower-door test) or checking compliance based on measured energy performance. Second, BECs can stipulate training and tools for building developers and owners.

(v) With retrofitting rates below 1% per year in many industrialized countries [8], many of today’s existing buildings will also exist in 2050 and beyond, making a fast decarbonization of the entire building stock challenging; BECs should therefore particularly focus on ‘Accelerating Retrofits’. Besides less stringent requirements for retrofits compared to new constructions, BECs can accelerate retrofitting by, first, stipulating retrofitting of buildings during a change of ownership or occupant – during such special occasions energy efficiency measures are typically more profitable – and, second, providing a long-term perspective on minimum energy requirements that existing buildings have to meet. Such a long-term perspective would serve as a roadmap, making it easier for building owners to make retrofitting decisions involving time horizons of a decade or more.

3.2. Part 2 – State-of-the-Art of Building Energy Codes
In this second part we briefly outline the common denominator – or state-of-the-art – in BECs in the selected countries addressing the five key leverage points outlined above (Table 2).

(i) To improve energy efficiency, all selected cases implemented a performance metric, mostly considering primary energy demand. Further, all cases kept prescriptive requirements for the envelope
efficiency or a second performance metric for total heating demand. Such a ‘double metric’ allows the countries to, first, minimize building energy demand and, second, minimize the use of resources or carbon emissions to cover the remaining building energy demand. England and Switzerland add requirements for individual building technologies and Switzerland and Sweden limit the capacity for heating power. Only France includes a requirement for summer comfort – the temperature on the hottest five days is not allowed to exceed a certain threshold – and only Denmark pre-announces future energy efficiency requirements.

(ii) So far, no country considers embodied energy in their BECs. However, France announced to include embodied energy to be part of the next regulation in 2020. This regulation will include embodied energy in the existing primary energy metric and will put an additional focus on embodied carbon.

(iii) To integrate more renewable energy in buildings, all selected countries adopted a performance metric that supports the use of on-site and off-site renewables. While all other countries focus on primary energy demand, England adopted a performance metric based on carbon emissions. Also, all countries except Sweden adopted additional prescriptive requirements for the use of renewable energy. Denmark, France, and Switzerland directly stipulate the use of renewable energy. Further, Denmark and Switzerland include technology bans and Denmark only restricted the extension of their distribution network of fossil fuels. Also, Denmark and England take an indirect approach by stipulating an assessment of renewables in regards to their technological and economic feasibility.

(iv) To close the performance gap, all selected countries check compliance with the technical energy regulations before the start of the construction as part of the building permit process and directly after the construction as part of the building decommissioning. Further, all countries except Switzerland also conduct an airtightness test. Further, England requires building owners to provide occupants with a set of operating & maintenance instructions, and Sweden includes a compliance check based on measured data after two years of occupation.

(v) To accelerate retrofits, all selected countries except Sweden include less stringent requirements for retrofits compared to new constructions and allow buildings that are retrofitted to opt for compliance based on prescriptive requirements. Both less stringent requirements and the option for prescriptive requirements reduce costs for retrofitting buildings. Besides such requirements that aim at buildings that undergo a retrofit, France follows a unique approach and pushes for mandatory retrofitting of buildings. So far, they prohibit the sale of social housing with high-energy demand, thus hoping for an increase in the retrofitting rate of social houses.

3.3. Part 3 – Innovative Building Energy Codes and their implementation challenges
In this final part of the results we look at innovative BEC approaches in the five countries and what have been the challenges when implementing them.

Denmark - Increasing energy efficiency through pre-announcing energy standards: Denmark reduced the energy use of buildings drastically by pre-announcing future BECs, thus providing long-term regulatory certainty for the building industry. The building industry perceived the pre-announcing as a strong signal that drives innovation and cost reductions, and therefore, advocated for it. Knowing that a voluntary energy standard will become mandatory, companies had time to develop and exploit
investments in new technologies, materials, and construction methods. Ambitious building owners, too, advocated for the announcement of future regulation as it provides a target to aim at. However, Denmark stopped making BECs even more stringent as the requirements did not prove to be cost-effective; yet, concerning building sustainability, they might again pre-announce regulations in the future.

France – Considering embodied energy in central performance metric & Accelerating retrofits through situational retrofitting obligations: France will include embodied energy in the next update of the thermal regulations for buildings. However, the introduction of embodied energy is challenging, requiring extensive prior testing and continuous learning. Further, integrating a lifecycle perspective of buildings’ energy use is expected to transform the French construction industry. Besides embodied energy, another target of French policymakers is to accelerate retrofitting the existing building stock, for example, by mandating all private residential buildings to achieve steadily increasing energy levels over the next decades. However, while ambitious targets and laws exist, decrees to turn the targets into specific policy measures are lacking because the retrofitting obligation causes additional upfront costs for building owners and is premised on the French Energy Performance Certificate, which is perceived as unreliable by the population.

England – Increasing the share of renewables through adopting a carbon emissions metric: England adopted a CO2 performance metric to align requirements for buildings with national targets and international commitments. As a result, carbon-friendly technologies have been heavily adopted; shortly, the decarbonization of the electricity mix will pronounce this technology impact. However, the carbon emission metric is perceived increasingly critical because, first, reducing carbon emissions does not necessarily result in energy-efficient buildings and, second, primary energy factors are more stable than carbon emission factors. England is likely to shift towards a primary energy metric, also because the EU pushes the use of primary energy as part of its harmonization efforts.

Switzerland – Increasing the share of renewables through prescriptive requirements: Switzerland increases the share of renewables in buildings through two specific requirements: One requires new buildings to produce a certain amount of electricity on-site, the other requires residential buildings that have an oil or gas boiler to install a heating system based on at least 10% renewable energy in case of a boiler replacement. Both requirements – despited perceived to be very effective in pushing more renewables into buildings – are heavily debated. Mandatory on-site electricity production is perceived as technology specific and as challenging to achieve in the case of compact buildings. Renewable heating might result in high investments costs for homeowners.

Sweden – Closing the performance gap through compliance based on measured buildings’ performance: Sweden aims to close the performance gap by checking compliance based on the measured building’s performance two years after its occupation. This compliance path is viewed differently by building developers, owners, and municipalities. Larger actors seem to prefer the measured over the calculated compliance check, while for smaller actors, this is typically vice versa. This might be because, first, the available and required measurements are often different; the smaller the building, the less precise the measurements and, in turn, the larger this difference. Second, sanctioning the building owner in case of non-compliance two years after the building’s occupation is a delicate task for smaller municipalities; keeping the file open for two years requires more personnel capacities. Sweden plans to address the second challenge by, first, shifting the authority for the final compliance control from local municipalities to the regulator and, second, combining the compliance check with the issuing of the energy performance certificate, which has already previously done by the regulator’s energy experts.

4. Discussion
In the following, we synthesize the key findings across the five case studies. We derive six policy design principles from the challenges regulators were facing across our selected case studies when implementing innovative BEC designs. Despite the broad variety in innovative approaches addressing very different aspects of buildings’ energy use, the challenges faced showed a surprisingly similar pattern. Table 3 lists the six key learnings – or policy design principles – derived and illustrates them with examples from the cases.

(1) To keep the additional burden for building owners at bay, policymakers should design BECs as cost-effective as possible, thus only mandating what is economically beneficial – e.g. being net present value positive – to consumers but fails to diffuse in the market. This is especially important as many of
(2) Creating long-term regulatory certainty – e.g. through preannouncing of regulatory changes – provides a fair planning horizon for the building industry, in turn, spurs innovation, drives down technology costs and, ultimately, allows for stricter BECs.

(3) Avoiding technology-specific requirements allows all buildings to comply. However, even de facto not technology-specific regulations – such as a requirement for onsite electricity generation – might leave homeowners with very limited choice given the current technology landscape.

(4) Anticipating the impact on various actors the adoption of new BECs might have is crucial for a broad acceptance of the regulatory change; regulatory change is often particularly challenging for small actors. This has been observed across the board from small construction firms via homeowners to small municipalities struggling with the implementation.

(5) Ensuring sufficient knowledge about the regulatory innovation before implementing it, helps policymakers to improve its design (e.g., identify cost-effective stringency levels) and to justify its implementation (e.g., refer to frontrunners who prove cost-effectiveness).

(6) While learning from frontrunner firms and legislation helps to design BECs that enjoy broader acceptance, policymakers have to adapt these learnings to the local context, which includes existing infrastructure, level and pace of grid decarbonization, domestic resources, quality of domestic building industry, and current politics.

In summary we can say that the mandatory nature of BECs as a policy instrument seems to directly lead to the first four design principles derived, which all ensure that the broad range of actors in the sector are able to cope with the new regulation. With increasing distance from the traditional regulations – e.g. when including embedded energy – extensive testing becomes crucial. Further, despite the general findings, adapting an innovative approach to the context of the local building industry, infrastructure, electricity grid, and political system has been found challenging in all cases. Finally and beyond this study, BECs are only one of a mix of policy instruments (e.g. labels, subsidies, tax incentives etc.) which all have to work in concert to achieve a most efficient and effective transformation of the building stock.

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