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RESEARCH PAPER

Comparative review of building commissioning regulation: a quality perspective

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Building regulations are an important policy instrument available to governments wishing to improve building energy efficiency, which should be a priority to policy-makers wishing to target cost-effective avenues in support of carbon-abatement targets. Meanwhile, building system commissioning has been recognized as a cost-effective measure to cut energy consumption, but in practice commissioning quality can deliver less-than-satisfactory outcomes. Regulation needs to better support commissioning outcomes. A five-grade commissioning scale is developed to assess the quality of commissioning and propose a common language to assist with regulation setting. Using this scale, building regulation and polices related to new and refurbished building commissioning were analysed in comparative case studies between jurisdictions England and California. This study finds that Californian regulations mandate a higher quality of commissioning and regulations that are more enforceable. The crucial elements to support better-commissioned buildings were identified as: outputs-focused regulation (not input based); regulation and process clarity; commissioning agents and building official training; as well as acknowledging the financial burden of upholding more complex building regulations. For the full benefit of commissioning to be realized, policy and regulations for existing buildings will be required.

Keywords: building regulations, commercial buildings, commissioning, energy efficiency, enforcement, governance, policy, regulation framework

Introduction

With climate change featuring on many political agendas, governments are seeking to reduce anthropogenic greenhouse gas (GHG) emissions in a cost-effective manner. Energy efficiency represents a unique opportunity to reduce simultaneously GHG emissions and cost. The International Energy Agency (IEA) has identified residential and commercial sectors as the largest final energy consumers with buildings being a major contributing factor (IEA, 2008, p. 7). In 2010, buildings were responsible for 32% of global final energy use (IPCC, 2014, p. 678). Clearly buildings have a substantial role to play in the efficiency agenda.

The UK has committed to reducing emissions by 80% by 2050 against a 1990 baseline (Climate Change Act 2008, Clause 1.1). Additionally as a European Union (EU) member state, the UK is required to meet 20-20-20 targets, which will see a decrease in GHG emissions by 20% and increases in energy efficiency and renewable energy each by 20% (European Commission, 2015) as well as ensuring that all new buildings will be nearly zero carbon (NZC) by 2020 (Energy Performance of Buildings Directive, 2010, Article 9, 1(a)). Similarly, California has commitment to cut GHGs and has legislated 2020 targets (California Global Warming Solutions Act 2006; California Environmental Protection Agency, 2006, clause 3855). A 2030 goal has been set for all new commercial buildings to be zero net energy (ZNE) (California Energy Commission, 2007, p. 5). Only the EU commitments are externally enforced and so UK commitments are considered more ambitious than California's.

A common method deployed to reduce energy consumption is through tightening building codes (IEA, 2008, p. 15). This approach is consistent with Belzar, McDonald, and Halverson's (2010, p. 37) US policy analysis that establishes that emissions reductions have been achieved through strengthening building codes. If governments seek to enforce provisions, thereby reducing GHG emissions through building regulations, then regulations must be strong and enforceable and coupled with inspections at appropriate intervals by qualified persons (Burby, May, & Paterson, 1998, p. 332).

Building commissioning (Cx) has been identified as a cost-effective method to avoid GHG emissions in meta-analysis by Mills (2011, pp. 154–159). This is the largest study to date of new and existing building Cx, analysing 643 commercial buildings. The study estimated the cost of emission avoidance to be –US$110/tonne of CO_2 in existing buildings and –US$25/tonne of CO_2 in new construction. Further, payback periods were found to be 1.1 years in existing buildings and 4.2 years in new buildings, which should be attractive even with tight budgets. This should be of interest to both governments that need to meet GHG emission reduction commitments and for clients paying for Cx services. Since Cx offers such a high rate of return, it should be a defensible option for regulation enforceable against spendthrift clients. Development of new technologies is leading to new perspectives to tackle GHG emissions. However, commissioning will remain relevant, as it is conditional to the operational success of such energy-efficiency technologies and strategies.

In the building context, commissioning now refers to a number of activities that occur at different points in a buildings life cycle (*i.e.* from construction to operation). It can be a defined stage of work within a building contract, but here it is applied more widely. There are differences in definition of commissioning for new and refurbished buildings according to location:

• The UK-based Chartered Institution of Building Services Engineers (CIBSE) provides the definition of Cx as:

> The advancement of an installation from the state of static completion to full working order to the specified requirements. It includes the setting to work of an installation, the regulation of the system and the fine tuning of the system.
>
> (CIBSE Commissioning Code M, 2003, p. 2)

• The US-based American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) provide the definition of Cx as:

> A quality-focused process for enhancing the delivery of a project. The process focuses upon verifying and documenting that the facility and all of its systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet Owner's Requirements.
>
> (Knebel and McBride, 2005)

Even if a building has been commissioned during construction, drifting of calibrations, ageing equipment and changes to building function can mean a building requires recommissioning (Castro & Yoshida, 2008, pp. 8–15; Lewis, Riley, & Elmualim, 2010, p. 6). In this paper, the different commissioning processes applicable to existing building will be referred to as R-Cx. R-Cx is the correct objective for long-term energy efficiency and will be discussed when applicable. However, current regulations mostly address commissioning for new system and assembly installations and will be the main focus of this paper. Unless otherwise mentioned, Cx will then refer to new and refurbished buildings.

Cx has been a feature of the commercial building industry since the introduction of building services at the beginning of the 20th century (Xiao & Wang, 2009, p. 1145). Commissioning was previously focused on setting to work of heating, ventilation and air-conditioning (HVAC), before becoming a quality process addressing all systems and assemblies (Sterling & Collett, 1994). More recently, Cx has been applied to resolve energy concerns and introduced to building regulations. Two of the first locations to introduce Cx to regulations were the UK and California. In 2002, reference to Cx was first introduced by the UK to building regulations Part L Conservation of Fuel and Power (Conservation of Fuel and Power L2, 2002, pp. 26–27). California introduced voluntary provisions in 2008 and mandatory provisions in 2010 (California Building Standards Commission, n.d., p. 1). California provides an excellent comparative case study as according to the IEA it most likely has the most comprehensive building energy efficiency standards in the world (IEA, 2008, p. 47). This study compares country and state-based cases, which is appropriate because each has the jurisdiction to establish building regulations and have made commitments to abate carbon emissions.

Despite the relevance of Cx regulations to the climate debacle, peer-reviewed research on building efficiency and regulation is scarce. Little literature is found that examines Cx in the context of regulation design, and Pitt & Sherry Consulting (2014) found that Cx is not well covered in codes and regulations. Considering the importance of the climate change agenda and the role that Cx may play, this research aims at assisting policy-makers to understand how policy can encourage better Cx, better efficiency and therefore reduced emissions.

The paper is structured as follows. The next section describes the methods used including key propositions and scope limitations. The third section proposes a model of Cx to evaluate the outcome of commissioning regulations. The fourth section inventories the regulations and policies relevant to Cx in England and California. The fifth section discusses the results of the comparison between both regulations. The sixth section gives the recommendations and conclusions of this work.

Methods

A comparative study approach was undertaken to understand how and why each regulatory authority context differs in its approach to Cx regulation (Yin, 2003). A representative selection of literature, based on keywords, source location and date range, was critically analysed to define research questions and the model of Cx established. The model of Cx is based on the different qualities of Cx, which refers to the overall benefits, such as improved energy/water efficiency or improved occupant comfort, derived from Cx. Governance frameworks for each location were constructed from literature and regulations published on online sources (Table 1).

Approved guidance and appropriate subsidiary codes were considered in light of the research questions. The intent of relevant regulations was analysed, verified and discussed through an iterative review process between the authors and key informants. Since the academic literature relating to building regulation is limited and introduction of Cx to regulations relatively recent, it was necessary to conduct a limited number of interviews to identify the most important current issues and shed light on issues not discussed in the literature or explored in regulation or guidelines. Interviews were conducted with British and Californian Cx agents (CxAs) and senior representatives from the National Environmental Balancing Bureau (NEBB), arguably the most established international certification association for training building systems experts, and CIBSE, an internationally recognized body for setting best practice and training building services engineers.

Table 1 Documents analysed

Case	Law, policy, guidance or government reports
California	California Energy Code California Code of Regulations 2013.
California	Guide to Title 24 California Building Standards Code 2010.
California	Non-residential Compliance Manual 2013.
California	California Green Building Standards Code California Code of Regulations 2013.
California	California Global Warming Solutions Act 2006.
Europe	Council Directive 2010/31/EU on The Energy Performance of Buildings (recast) [2010]. OJ L 153.
Europe	Council Directive 2012/27/EU on Energy Efficiency [2012]. OJ L 315.
Europe	Progress by Member States Towards Nearly Zero-Energy Buildings 2013.
United Kingdom	Climate Change Act 2008.
England and Wales	The Building Regulations 2010.
England and Wales	The Building (Amendment) Regulations 2012.
England and Wales	The Energy Performance of Buildings Regulations 2012.
England and Wales	Improving the Energy Efficiency of Our Buildings: A Guide to Air Conditioning Inspections for Buildings 2012.
England and Wales	F1 Means of Ventilation 2010.
England and Wales	The Energy Performance of Buildings 2012.
England and Wales	CIBSE Commissioning Code M 2003.
England	Conservation of Fuel and Power L2A 2013.
England	Conservation of Fuel and Power L2B 2013.

Finally, English and Californian contexts were compared by contrasting methods of enforcement and gap analysis between content. Findings were synthesized and policy recommendations generated.

Some limitations are acknowledged. Firstly, it was necessary to distinguish between qualities of commissioning. This research adopts Mills' (2011) findings that a higher quality/comprehensiveness of Cx will result in greater energy and water savings and that a Technical Cx approach is superior to a Process Cx approach. The distinction between Process and Technical Cx is made by McFarlane (2013) as being that Technical CxAs will personally test every building system and service when Process CxAs would samples the results of the test made by contractors. By inference this means that a Technical Cx should have a deeper understand of how other building systems may impact on the expected readings as well as be better able to trouble shoot issues. This makes Technical CxAs personally responsible for accurately documenting any inaccuracies, allowing one specialist systems expert to see a building as a system rather than the sum of the individual parts (McFarlane, 2013, pp. 33–34).

Secondly, this study focuses on the minimum required by building regulations and so therefore there are some items that are out of scope even though these items may also play a role in the final outcome. These include display certificate regulation (energy performance certificates (EPCs) and Energy Star); differences in normal contractual practices (*e.g.* which party hires the person responsible for delivering successful Cx); publically funded incentives; and certification schemes (*e.g.* Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Methodology (BREEAM)). Finally, the inherent nature of case study analysis means for results to be extrapolated to other locations context specific differences will need to be considered.

Model of commissioning

The IEA (2010, p. 1) reports a lack of consistent definition between Cx processes internationally, and so to interpret the outcome of regulatory requirements it was necessary to establish a model that distinguished between qualities of Cx.

Mills (2011, p. 152) reports that Cx varies substantially in scope and ambition, which may be reliant on client budget and project size. However, a lack of consistent terminology applied in the literature may also contribute. The same study also finds a positive association between the comprehensiveness of Cx and impact or outcomes. It is acknowledged that Mills' (2011) research focused on energy consumption, and for a holistic perspective, consideration of all resources including water is necessary (*e.g.* water systems and sprinklers) (US Department of Veteran Affairs, 2013), increased lifespan and cost avoidance from equipment failure, reduced operational and maintenance costs (IEA, 2010, p. 158) and finally occupants' comfort (CIBSE, 2008), which is linked to employee productivity (IEA, 2010, p. 159).

Figure 1 is proposed as a reference point and has been synthesized from aggregating existing models (ABS Consulting, 1998, p. 17; Noye, Fisk, & North, 2013, p. 3). Additionally, findings from other sources have been integrated. This includes Claridge et al. (2004, p. 19), Liu (1999, pp. 46–56), and Xiao and Wang (2009, p. 1145), who find the highest quality of Cx occurs regularly over the lifetime of a building, and NEBB's definition of the highest quality of Cx as whole building technical commissioning (WCx):

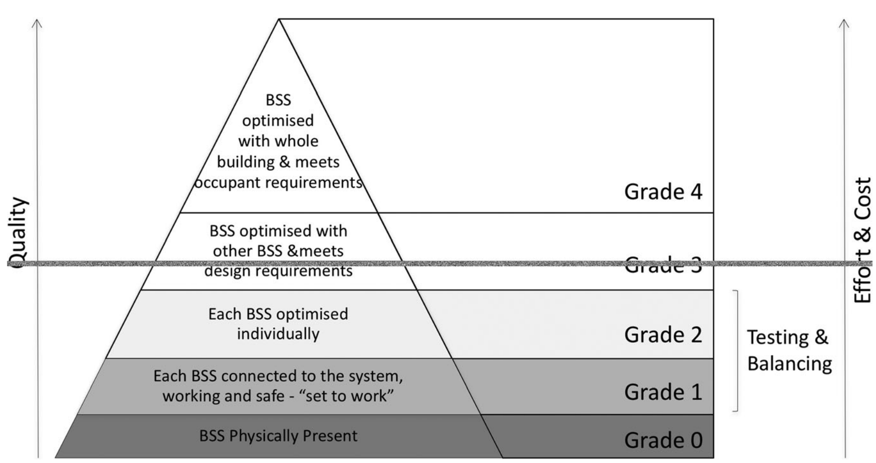

Figure 1 The quality model of commissioning

> Cx of all building [systems and] services including building envelope, HVAC, electrical, special electrical (fire alarm, security & communications), plumbing and fire protection.
> (NEBB, 2014, p 50)

Figure 1 explains the quality commissioning model. Each grade builds on the former in increasing quality (efficiency balanced with comfort), effort and cost. It is the role of regulation to set the minimum grade of Cx to ensure new buildings reach acceptable performance. However, it is the client's responsibility to establish which grade above the minimum they believe provides the best trade-off between cost and quality. Cx quality can also indirectly be affected by decisions made during the different stages of the construction process.

Grade 0 is the lowest level and only requires building systems and services be physically present irrespective of any other requirements. This level will be achieved for any building and therefore it is important to draft it well. For example, in the case of renewable energy, Grade 0 would make sure that the specified solar panels are attached to the roof, but would not certify that it is wired to the system.

Grade 1 ensures each building system and service is installed; its components work in isolation, is connected to the system, and is safe. It is equivalent to the British interpretation of 'set to work' and will ensure that the system turns on, but makes no claim to how well it works. For example, solar panels may be installed under shade, thus reducing energy production. If regulation were directed at producing a specified amount of renewable energy, Grades 0 and 1 would be avoided.

Grade 2 ensures that each building system and service has been optimized (usually for efficiency) in isolation of other building systems and services. Grades 1 and 2 are the equivalent of testing, adjusting and balancing (TAB) in the US. As outlined by Nakahara (2003, p. 2), the main focus of TAB is on HVAC, although testing and adjusting can be applied to any building system or service, whereas Cx focuses on the entire building and takes into consideration the interrelated nature and impact of building systems and services on each other. As such, TAB results in an operable building, whereas Cx ensures the system (building envelope, electrical, plumbing and fire systems) functions optimally. All grades to this point require the input of installers. According to interviews, installers rarely receive manufacturer training and so may not have sufficient expertise to adjust the system should it not function to specifications, which is a barrier to Grade 2 Cx. The exception being any issues that could bring unsafe plant on stream where trained engineers are required.

At Grade 2 an installer requires skills to competently test and adjust outputs (*e.g.* airflow, temperature and humidity) to match design specifications. Peter Kinsella, CIBSE President says:

> As installers tend to focus on their own building systems and services they are unlikely to initiate adjustments required by other contractors to ensure that the building works as an interrelated system rather than the sum of the individual parts.
> (Kinsella, personal communication, 2014)

This issue is extended by McFarlane (2013, p. 29) who provides:

> Specialists [installers] do not understand the 'big picture' of how all of a building's various systems interact, nor do they speak the same language as other trades.

To achieve Grade 3, an integrated or systematic approach is required. For this grade, Cx also extends to other elements such as the need to provide client specification, integrated design of building systems and services, a Cx plan, operator training and documentation as well as reporting to ensure benefits are realized. As such this requires: contributions from multiple installers and a coordinator; or installers to have systems expertise; or extremely careful design, necessary because system settings are interdependent. For example, low-power LED lighting emits less heat and so HVAC may need adjustment. This grade also requires activities be scheduled across design, construction and up to handover and will likely require expertise beyond any individual. Therefore, to achieve this level a coordinator/CxA is required. In this context, a CxA is not required to have any particular skills or experience. A CxA completing Process Cx generally reviews contractor reports and witnesses samples from TAB results to verify completion.

Grade 4 is the highest level of Cx and is consistent with the definition of Technical WCx, a concept that appears to be absent from existing European literature. Interviews substantiate that this concept may be absent from the language of English practitioners. As with Grade 3, the Cx timeline extends beyond functional performance testing. However, this grade better considers the entire building as a system, requires the coordinator to be technically competent and certified (*e.g.* systems engineer with US-based NEBB certification), and also ensures the building suits the requirements of the occupier as it changes with climatic seasons and potential uses throughout the year. This will require regular R-Cx. A Technical rather than a Process CxA is required to achieve this level. Grade 4 recognizes the importance of ongoing adjustments after handover to ensure a building meets occupant needs, which can vary throughout the lifetime of a building and even between design and occupation.

Evidence from interviews (although no reference could be found in literature) point to Quality Cx not being performed regularly, more so in England than California.

The Quality Cx Model proposes four grades to assess the outcomes of building regulation on Cx. As the grade of Cx increases, as does the skill level of CxAs (and building inspectors) and therefore training is considered to be a substantial barrier to broad application of Cx. Similarly, the time required to deliver and therefore costs are expected to increase in accordance with quality. These attributes of the model correlate with the likelihood that Quality Cx is being performed on a broader scale, This model forms the basis of understanding how regulation in England and California differs.

English and Californian commissioning regulations

The following section analyses Cx and relevant regulations in both England and California. It identifies gaps in each context and reveals areas that have developed differently.

England

Regulatory framework

Section 1, Clause 1 of the Building Act (1984) allows for building regulations in England to be established by the UK government. As such the regulations relevant to this section are: the Building Act (1984) (UK); The Building Regulations (DCLG, 2010b) and associated amendments (England and Wales); Conservation of Fuel and Power L2A (HM Government, 2013b) and L2B (HM Government, 2013c) and associated amendments (HM Government, 2013a), also referred to as the Approved Documents; and CIBSE Cx Code M (CIBSE, 2003). Additionally, the Energy Performance of Buildings (England and Wales) Regulations (DCLG, 2012a) and associated guidance Improving the Energy Efficiency of Our Buildings (DCLG, 2012b) were analysed.

The Building Regulations (DCLG, 2010b) provides minimum mandatory standards. The approved documents are an option to people who do not wish to use their own methods to meet the regulations. However, since the regulation is silent on what occurs when a person chooses not to follow this method, it is reasonable to analyse the method outlined in the approved documents. Additionally, as the method approved by the secretary of state is that outlined by CIBSE Commissioning Code M (CIBSE, 2003), even though it was never designed as a vehicle for regulatory action, analysis of this document was also necessary.

Depth and breadth of Cx regulation

English Cx regulations apply to all newly constructed buildings. They are also triggered for existing buildings being extended or altered when changes result in new or replacement controlled services or fitting and other limited circumstances. As such, regulations apply to new construction and the opportunity to accrue benefits in existing building stock limited (Figure 2).

A lack of continuity between the Building Regulations (DCLGb, 2010), approved documents and CIBSE Cx Code M (CIBSE, 2003) were identified (Lau, 2014, pp. 13–17). There are inconsistencies between definitions of Cx and discrepancies between requirements. It also lacked clarity between distinguishing mandatory or voluntary provisions. The brevity of Cx regulation, including a failure to define Cx in mandatory regulation, affords greater latitude when interpreting the law. If Cx is not defined in enforceable regulation then there is potential to argue a lower quality of Cx meets the requirements.

Listed below are the attributes that lead the authors to believe that minimum Cx required by English regulation is equivalent to Grade 2:

- Schedule 1 Part L of the building regulations refers to providing fixed building services which – (iii) are commissioned by testing and adjusting as necessary to ensure that they use no more power than is reasonable in the circumstance (DCLGb, 2010, p. 39). Although not specific, this implies the intention of Cx is to improve efficiency (Cx > 1).

- The definition of Cx encompasses a wide range of activities including set to work, balancing and adjusting to ensure that building systems and services run efficiently. Failure to distinguish between processes could lead to the incorrect understanding that Cx is equivalent to setting to work (Cx $= 1$ to 2).

- Cx is required only for controlled services, fixed lighting, hot water and HVAC systems installed in new or existing buildings, however standards apply individually to each component rather than employing an integrated or systematic approach (Cx < 3).

- Cx does not extend to the building envelope, however thermal values and pressure testing are covered under separate regulation (Cx < 3).

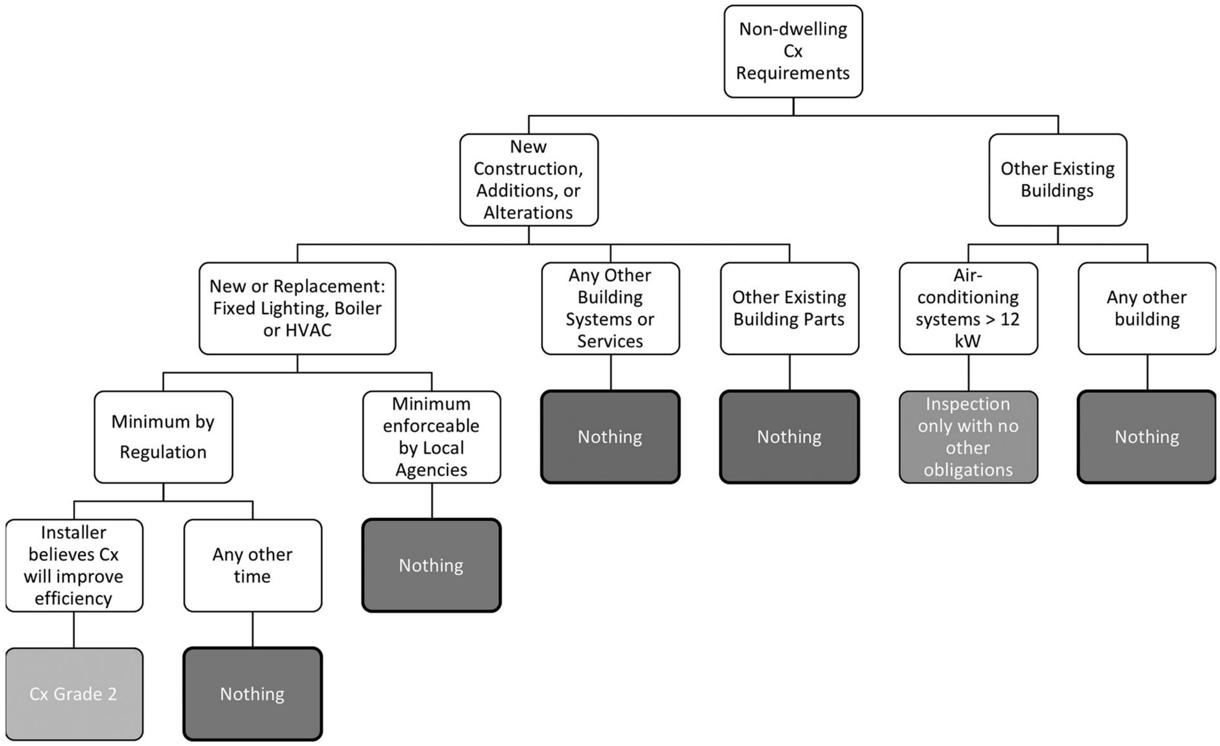

Figure 2 Limitations to the scope of building commission regulation in England and Wales

- Although some qualifications or experience are suggested no requirement for persons responsible for Cx exists (Cx < 3).
- There is no requirement for a CxA (Cx < 3).

In addition, Part 4 of the Energy Performance of Buildings requires any air-conditioning systems of 12 kW or more be inspected by an approved and qualified energy inspector every five years (DCLG, 2010a), which is a step towards regulating R-Cx. Inspections are mandatory and provide recommendations on improving efficiency; however, no legal requirement exists for recommendations to be acted upon (DCLG, 2012b, p. 8). As such, no enforceable requirement to improve the efficiency of existing buildings exists; however, reports may alert owners to air-conditioner issues and encourage action.

Cx regulations are applicable to newly installed controlled building systems and services in new and refurbished buildings and the minimum grade of Cx equivalent to Grade 2. The regulation governs inputs rather than outputs. It could be argued that a higher grade is achieved through R-Cx since air-conditioners inspected over the lifetime; however, as the regulation is aimed at reporting rather than consumption levels, this provision offers limited offset against unambitious Cx regulation. In addition, this includes only one of the systems that should undergo R-Cx. The next step is to consider the ability of local authorities to enforce these measures.

Enforcement

Enforcement should be considered in light of: who is responsible; motivations; enforcement method; and the power of regulators to apply penalties.

In England and Wales building inspectors can outsource work to persons deemed to be 'approved inspectors' (DCLG, 2010a, p. 4). This would be normal in cases involving difficult structural engineering. The regulation requires inspectors to observe a document confirming that Cx is complete. Unfortunately no public data are available that stipulate the level of Cx training local authorities or inspectors receive. Furthermore, the regulations are silent on actions required when Cx is completed by untrained persons. However, given the level of training required to commission a building well and the level of coherence of regulations, it is unlikely local authorities or inspectors are trained to a professional level on auditing Cx. This is consistent with anecdotal reports from industry practitioners.

Another aspect is the quality of information received by local authorities. The primary method of enforcement is for each installer to submit a notice to the local authority confirming the controlled service or fitting has been commissioned in accordance with CIBSE Cx Code M (CIBSE, 2003), only necessary when the installer decides a building system and service would be more energy efficient if commissioned (DCLG, 2010b, Clause 44(2)). L2A suggests a Model Cx Plan (BSRIA BG 8/2009) be completed and submitted for all new non-dwelling construction (HM Government, 2013b, Clause 3.16), which requires details of all building systems and services irrespective of whether Cx is required by law. If required in all circumstances, local authorities would have sufficient detail to conduct a desk audit. However, in absence of a plan, local authorities have no knowledge of installed building systems and services without a thorough site inspection, which may require removing walls or fittings to gain access, particularly if Cx was not considered during design.

It is also necessary to understand the likelihood of provisions being enforced. Since enforcement is costly, unless safety is a concern, no short-term financial incentive exists for local authorities to enforce beyond the minimum requirements necessary. Clause 11 of the Building Regulations (DCLGb, 2010, p. 10) have provisions which allow local authorities the *power to dispense or relax requirements*. This clause applies to almost all provisions in the building regulations, except for those necessary to satisfy EU directives, thus local authorities have the option of not enforcing Cx provisions at all.

The final aspect for consideration is level of deterrence. Should local authorities decide owners are in breach of regulations, they may withhold approval required prior to building occupation, until satisfied (DCLG, 2010b). Failing this, local authorities may sue through the magistrates court imposing penalties of £50/day and up to £5000 in fines (Building Act 1984). As such, the power to enforce provisions is considered relatively substantial.

In theory, the Building Regulations give local authorities both the power and deterrence mechanisms to enforce Cx regulations (DCLG, 2010b), but issues no requirement for local authorities to enforce provisions. Since building regulations do not allow local authorities to insist on a model Cx plan, local authorities have no ability to assess whether a building is compliant without onerous and possibly invasive site inspections. Since there is a potential lack of training, it is unlikely that local authorities are tooled to assess compliance even if a site inspection were completed. These findings are consistent with interviews with English industry representatives reporting that Cx provisions lack enforcement.

California

After analysing English regulations relevant to Cx, this section will perform the same investigation for California as a point of comparison.

Regulatory framework

The 1787 Constitution of the United States of America establishes the rights of congress, presidents and federal courts over certain national and cross-jurisdictional matters, including federal buildings. California retains the right to create and enforce building regulations through the California Code of Regulations. Part 6 of the California Energy Code (CEC) provides regulations for minimum energy-efficiency standards and techniques for most non-residential buildings except hospitals, nursing homes, daycare centres or prisons (California Energy Commission, 2012). The CEC also addresses hospitals, nursing homes daycare centres and prisons in other parts; however, these have not been considered as part of this study. Part 11, California Green Building Standards Code (CALGreen) provides additional green building standards and Cx requirements for all new construction (California Energy Commission, 2013). A 2016 Code exists; however, this was not considered at the time the study was conducted. The guide to building energy efficiency standards Non-Residential Compliance Manual (California Energy Commission, 2015) explains how to interpret the code and, unlike Approved Documents L2A and L2B, guides are enforceable. California's building codes provide an option to meet requirements via either performance or prescriptive means, however the option for performance is not extended to Cx provisions.

Depth and breadth of Cx regulation

According to Clause 2.1 Non-residential Compliance Manual Californian Cx regulations apply to new construction and altered parts of existing buildings (California Energy Commission, 2015). As such, the opportunity to accrue benefits in existing buildings is limited. Figure 3 explains how this plays out in new and existing buildings in California.

Model energy codes are published by ASHRAE and the International Codes Council; however, California opted out (VanGeem, 2014), instead extending ASHARE 90.1-23010 to provide more stringent requirements (Ware & Bozorgchami, 2013, p. 16).

On an industry level, the US defines Cx separately from TAB (ASHRAE, 1988). This understanding is mirrored in CALGreen, which stipulates testing and adjusting in circumstances where Cx is not required (California Energy Commission, 2013, Section 5.410.4). Balancing is also required for HVAC. Since TAB in this context ensures that building systems and services have been adjusted in accordance with manufacturer

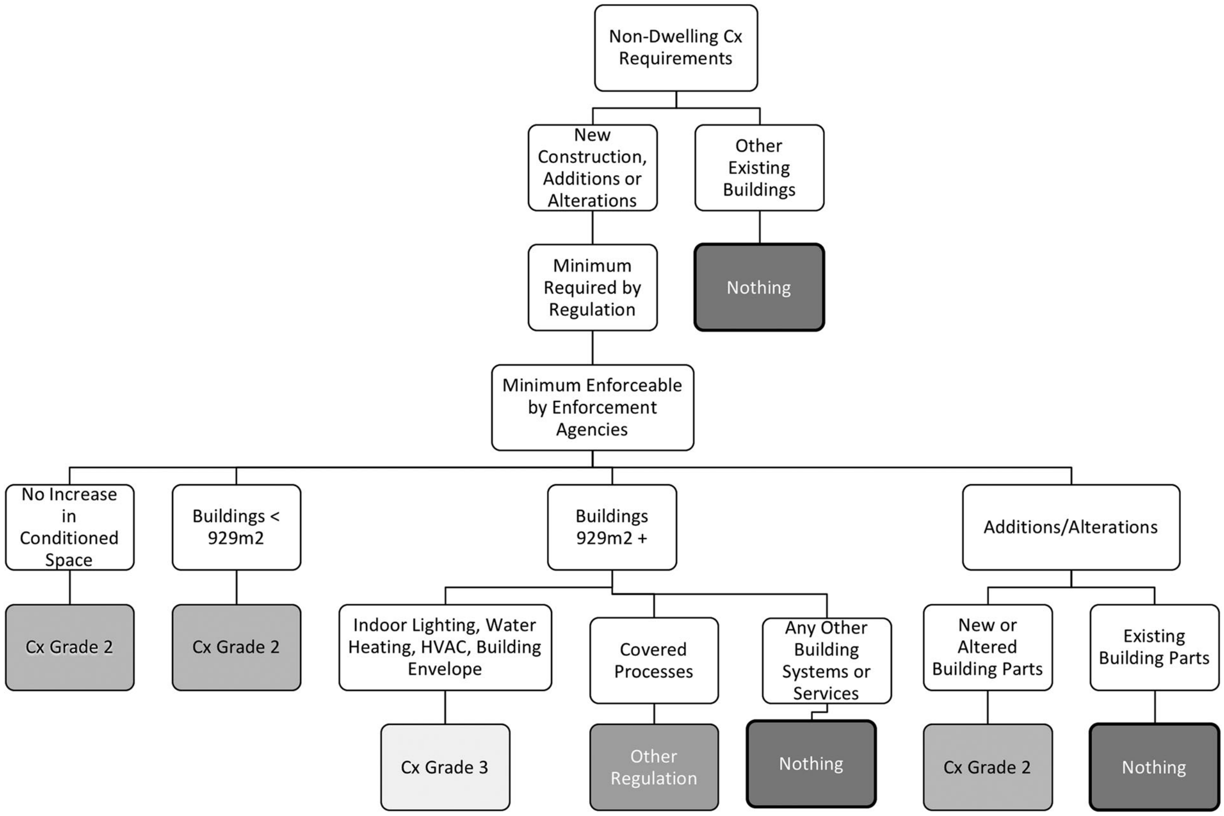

Figure 3 Limitations to the scope of building commission regulation in California

specifications TAB provisions are equivalent to Cx Grade 2.

Since TAB is equivalent to Cx Grade 2, Cx in new buildings with conditioned space larger than 929 m^2 is likely higher than Grade 2. Listed below are the other attributes, which lead authors to believe the minimum required by regulation is Grade 3:

- Even though a more comprehensive list of building systems and services is included (indoor lighting, water heating, HVAC and building envelope), the list is not exhaustive, notably excluding water systems (Cx < 4).
- The regulations require an individual be responsible for coordination (California Energy Commission, 2015, Clause 12.1) (Cx $= 3$–4).
- Regulations require Cx be considered during design and throughout construction. The regulation requires schedules for preventative maintenance and plans for future seasonal testing (Section 120.8 California Energy Code, 2013) (Cx $= 3$–4).
- Clause 12.1.1 of the Non-Residential Compliance Manual sets out some elements that a client may use to assess the background or appropriateness of an assessor, however no minimum levels of experience or training are specified (Cx < 4 (California Energy Commission, 2015)).

As such Cx is equivalent to Grade 3. There are some concerns for lesser quality outcomes from a Process Cx approach, which is encouraged through the method outlined in guidance. Results from interviews highlight that Cx responsibilities may be delegated to the 'cheapest available person', raising concerns for quality due to a lack of experience or training.

Similar to England, regulations also focus on the process of Cx rather than the outcome of a well-commissioned building. Regulating outputs would demonstrate that Cx has been completed to a specified quality, but would require a much greater technical understanding.

It has been established that Cx Grade 2 applies to most new construction and Cx Grade 3 to a small subset of larger buildings with conditioned space. Despite this, concerns are raised about quality when the role of CxA is assigned to inexperienced personnel. Issues could be addressed if outcomes rather than process were regulated.

Enforcement

Enforcement has been analysed in terms of training building inspectors, the motivations of enforcement agencies, methods of enforcement and access to sufficient penalties to deter non-compliance.

Interviews point to the level of training building inspectors receive being a concern. In particular, as building regulations have become increasingly stringent, fees have not been increased accordingly. Enforcement agencies are not being compensated to provide time and training for building inspectors required to enable them to assess compliance.

That said, the enforcement framework should provide sufficient information if issues with training are addressed. The regulations provide an eight-step process enforceable at multiple points. It requires an individual be nominated as CxA and responsible for submitting documentation and personal affirmations that each step has been completed appropriately and in accordance with the regulations. CxAs are required to certify enforcement forms under *penalty of perjury* and if found falsifying documents may be fined up to US$25 000 and/or gaoled for one year (CA Penal Code § 118–131, 2005). As such the level of deterrence is considered to be high.

A well-laid-out process with sufficient checkpoints allows enforcement agencies to check whether buildings meet regulations. This is necessary as enforcement agencies may be held accountable for not enforcing provisions. Furthermore, enforcement agencies are allowed to issue more restrictive requirements as necessary due to local conditions (Section 18941.5 California Health and Safety Code, n.d.).

Californian enforcement provisions have been deemed relatively fit for purpose; however, issues exist with training building inspectors to understand how to enforce provisions and allocating additional funding for the increased costs of enforcement. The next section discusses context specific findings.

Comparison and analysis of English and Californian regulations

This investigation has revealed key differences between contexts, in particular the depth and breadth of Cx regulation and enforcement frameworks.

Existing legislation and current government mandates will see building codes largely focus on Initial Cx, which occurs during/directly after construction rather than throughout the lifetime of the building. Even though under the current framework, enforcement would be difficult, it would follow that separate regulation would address existing buildings.

When modern codes apply, the depth and breadth of California's Cx requirements are comparatively more stringent and guidance documentation far more advanced than England. This study focused on regulation rather than practice and the authors assume that commitment is similar to enforcement.

The minimum Cx required in California is Grade 2 in most circumstances where modern codes apply, except larger buildings with conditioned space that require Grade 3 Cx. Comparing with England, regulations require Grade 2 Cx, for a subset of building systems and services and only when the installer believes commissioning is beneficial. This finding highlights the importance of language and definition when specifying qualities of Cx.

The specificity of mandatory regulation is substantially different between contexts. Less specificity in English regulation allows for broader interpretation. On the one hand, the regulation could be exploited, as it is possible to meet the regulation without quality Cx, or possibly none at all. On the other hand, optionality to meet the regulations through alternative methods allows scope for innovation and so as the industry evolves (*e.g.* introduction of auto-commissioning) fewer updates will be required. The reverse can be said for California where the certainty of outcomes is greater, but policy-makers carry a greater responsibility to ensure that regulations allow for new methods.

Another outcome of new methods could be the further development of simulations to test outcomes that could put a new pressure on Cx to deliver beyond 'set to work'. There may be future prospect for systems to be designed to auto-commission from black-start. This is likely to induce a shift from building regulation to equipment standards as bearing responsibility for Cx quality. Although the technology is unproven, these issues make for potentially interesting future research questions.

Even though the level of deterrence has been determined adequate in both contexts, the final outcome will be dependent on the level of enforcement. Training of persons responsible for either declaring that Cx is complete or verifying compliance has been highlighted an issue. This is confounded by the need for greater expertise as the quality of Cx increases, as predicted by the quality model of Cx, as well as with increased project size. If either context desires a greater level of certainty that buildings comply with Cx regulations, then clear training of building inspectors and certification requirements of CxAs must be addressed. Where this results in greater burden to responsible persons, then funding and/or incentives need to be increased accordingly.

It is anticipated that the likelihood of provisions being enforced is greater in California than England. California provides far clearer regulation and guidance as well as a greater number of consistent enforcement checkpoints, whereas English regulation cannot be practically enforced without multiple physical site inspections. Also, unlike England, California requires building regulations be enforced with repercussions should enforcement agencies not comply and so the incentive to enforce provisions is greater in California than England.

Finally, Californian regulations assigns Cx responsibilities to an individual, which not only alleviates communication issues between parties and diffusion/dilution of responsibilities, but also gives enforcement agencies a central point of communication and accountability.

In summary, the comparison between English and Californian policies finds that Cx regulations and policies substantively apply to new construction, largely omitting existing structures. In cases where modern codes apply, a lack of definition could mislead the quality of Cx required. Californian regulation is far more specific and detailed than English regulation, however this comes at an increased responsibility for regulators to keep regulation up to date. Enforcement is an issue in both contexts, but for different reasons and is of greater concern in England than California.

Conclusions

In an effort to reduce anthropogenic-fuelled climate change, California and England have implemented mandatory Cx requirements in building regulation with different approaches and enthusiasm.

In this perspective, the quality model of Cx, which provides the basis to define differing qualities of Cx, has been established and utilized to inform case studies. The proposed model offers an appropriate method of distinguishing between differences in terminology used in each context but is also relevant to the international setting. Adoption will enable policy-makers and enforcement bodies to have informed conversations about Cx, thus reducing the need for specialist training. A common language will reduce complexity and improve consistency, therefore reducing barriers to entry for other countries considering methods to reduce GHG emissions.

For countries considering reducing GHG emissions through updating building regulations, the authors recommend that Grade 3 Cx in larger commercial buildings and Grade 2 Cx in all other buildings is an achievable minimum standard for any country with established building codes. In order for Grade 4 to be achieved, governments would need to be certain that a sufficient number of trained CxAs who can deliver quality Cx are available. Although it is important to acknowledge the existence of Grade 4 Cx as clients should be offered the opportunity to access best practice Cx so they can make an informed trade off between cost and quality.

Cx regulation in both contexts focus on inputs rather than outputs. If the final goal is to mitigate climate change by reducing GHG emissions then equally regulation should focus on outputs rather than inputs. To do this it would be necessary to regulate to at least Grade 3 Cx as it provides for reporting of building performance during occupation. Among others, energy and water consumption should be key indicators for outputs based regulation. As such, in an ideal world, building regulation would be targeted at reducing these throughout a buildings lifetime. Rather, there would appear to be an overreliance on equipment installed as opposed to operation with little acknowledgement of the embedded environmental cost of manufacture. The authors acknowledge that it is important to install efficient equipment. However, in many circumstances it is the way the equipment is operated which is the key to driving true gains in efficiency.

In addition, the mechanism of enforcement being scheduled for building occupation has focused legislative requirements on Cx. If outputs were regulated for existing buildings, there would be a greater incentive for building owners to invest in Ongoing-Cx or Grade 4 Cx. Of note, this point is relevant to much broader regulation than Cx alone. California has recognized this in performance-based codes, but the concept is yet to be extended to Cx provisions. Presumably this is due the complicated nature of setting points suitable for every building and type of habitation. Alternatively, if promises for auto-commissioning are realized, the focus could be shifted to specify a quality of equipment. Nevertheless, future research to identify a performance-based Cx code would make an invaluable contribution.

In the meantime, it is important to acknowledge the ultimate objective and therefore consider building regulation in light of its ability to deliver reduced consumption. There is little value in creating regulation which applies to very few buildings and so the breadth of applicability of Cx regulation to the number of new buildings is relevant.

Californian regulation is more likely to provide more consistent and higher minimum quality Cx at the expense of increased burden on policy-makers to ensure regulation remains current. The key will be in striking a balance between cost and quality/quantity that extends beyond any individual policy portfolio. Even though English policy-makers may initially save costs by writing non-specific policy, if regulation is ineffective or even prevents enforcement, emissions reductions are likely to be compromised. If this results in EU fines for failing to meet 20-20-20 targets or changes to climatic patterns, the final cost needs to be weighed against any savings. The irony in this being that even though California has invested more in building regulation, this state (or even the US as a whole) is less likely to be held to account for a failure to meet carbon-abatement commitments due to a lack of legislated external penalties. Further investigation to quantify all costs and benefits including on flow affects would assist governments to prioritize resource allocation better.

Enforcement has also been revealed a key issue in both contexts, with England suffering from multiple confounding issues. Substantial gains could be made from adopting a framework of enforcement that enables Cx provisions to be verified with minimal site inspections. As an easy first step such a framework would require building regulations be updated to allow local authorities to enforce submission of Cx plans. Another important, but arguably more contentious, step would be to mandate local authorities to uphold and enforce the provisions of the building regulations. However, it is also necessary to acknowledge the time impost on assessors, for training and assessment.

For any country wishing to implement Cx regulation, it is critical to ensure the steps of enforcement are thought through in context with regulation, policy and guidance. There is little point in regulating a minimum standard of Cx without a system that enables and supports enforcement. Only when this is in place is it reasonable to expect enforcement agencies to enforce provisions.

For existing buildings, the situation is different. Since the final opportunity for enforcement is when the certificate of classification is issued, additional energy efficiency policy will be required to encourage R-Cx through regulations. This will pose specific complications with enforcement as there can be no threat of withholding occupancy. Furthermore, the highest quality of Cx occurs periodically throughout the life-cycle of a building. It would be cheaper and arguably more effective for governments to focus on regulation which influenced operational costs rather than regular reporting/auditing. As such the authors recommend a building tax based on gas, electricity and water consumption would offer a suitable mechanism for encouraging more efficient buildings and by inference quality Cx. This would provide an offset for the cost of implementing better policy, training and enforcement.

In conclusion, if policy-makers wish to make a genuine impact on GHG emissions through building regulation, a broader perspective must be adopted. Siloed portfolios and an inability to acknowledge the flow through affects of decision making (or even a failure to act) can prevent deployment of effective building Cx regulation. A common language and a focus on outputs sets the scene for better quality commissioning linked to better emissions reductions. Broader and more specific regulation will mean better outcomes. Any regulation is underpinned by appropriate enforcement provisions and a budget to match effort. These findings should be of interest to any country seeking to improve regulatory outcomes.

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