How building regulations ignore the use of buildings, what that means for energy consumption and what to do about it

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Abstract
Building regulations have been, and are still, strong policy instruments for changing the material structures of residential buildings. Hitherto, little attention has been given to how building regulations could be designed to influence household energy consuming practices in a less consuming direction. Social science research on household energy consumption for heating purposes widely acknowledges that households' everyday habits are as important as the energy efficiency of the buildings when it comes to explaining actual energy use for residential heating. It is also widely acknowledged that the energy consumption of buildings varies with the way households use them. Rebound effects have been calculated, showing that improvements in building energy efficiency are offset by changes in the inhabitants' comfort and convenience practices. Building regulations are, however, still grounded on improving energy efficiency, with no consideration of how this simultaneously influences everyday life and energy consumption. This paper critically reviews the implications this can have. It begins with a brief history of the Danish building regulations, which are among the strictest in Europe, and highlights studies and statistics to evaluate this policy. Following this, we outline where things can go amiss in the production of buildings, if a user perspective is not included. We consider three phases of a building's lifetime that are especially relevant for our discussion of the building regulations' influence on household energy consumption, i.e. in the development of new building technologies, the design and construction of buildings, and the actual use-phase. Emphasis is given to the likely effects that the building regulations can have in each of these three phases and to what happens when the user is forgotten. We then discuss what implications these insights can have for the further development of building regulations.

Introduction
Mitigating climate change calls for drastic reductions in CO_2 emissions and, thus, for major changes in society's use of fossil fuel; changes that can either relate to the way energy is produced or consumed or both. Roughly 40 % of global energy use is attributed to buildings, and they are often said to offer great potential for GHG emission reductions (United Nations Environment Programme, 2017). Furthermore, with reference to McKinsey's "global GHG abatement cost curve" (Bress et al., 2007), it is often argued, that when it comes to emissions abatement, this can be achieved in the building sector at relatively lower cost than in other sectors of the economy. There are, thus, good reasons for EU and national policies having a strong focus on the building sector as an area for climate change mitigation, and an area where the needed savings can be cost-effectively achieved through energy efficiency measures. Based on recent research on building energy consumption, it can, however, be questioned if the assumptions behind these arguments are realistic (Galvin, 2014; Visscher, Meijer, Majcen, & Itard, 2016).

In challenging the assumption that energy efficiency requirements in building regulations are strong tools in reaching GHG emission reductions, we focus on the Danish residential building sector as our case. Given that the Danish building sector to a large degree is regulated through the EU's EPBD (Energy Performance of Buildings Directive), many of the issues raised in the paper are likely to have bearing in other European countries.

In Denmark the major national policies for reducing energy consumption from buildings include committing utilities to energy saving obligations, mandatory energy labelling schemes, educational schemes providing knowledge to building professionals, and different campaigns to promote energy retrofitting in existing buildings, as well as the building regulations, which seeks to limit buildings' energy use while also ensuring a healthy indoor climate (Gram-Hanssen, 2014; Togeby, 2012). All of these policies are, however, premised on the same assumption regarding how to achieve energy savings, namely by improving the energy efficiency of buildings and building technologies. The efficiency requirements are defined in the building regulations, as are the supporting measurements and calculations. If, however, the assumption of energy efficiency and the way this is calculated does not hold, then a major part of our climate policies may rest on shaky ground.

Danish building regulations – some (missing) achievements

Building regulations, outlining general technical requirements and standards for new buildings, were first introduced in Denmark in 1961, but energy performance requirements were not introduced until 1977 (effective from 1979). From 2006, the building regulations were extended to also include the retrofitting of existing buildings, and since then the building regulations have been aligned with the European EPBD.

Energy provisions were first introduced through prescriptive requirements stipulating minimum performance standards for specific building components, e.g. the use of specific amounts of insulation. Subsequent revisions of the building regulations introduced so-called functional requirements stipulating the overall energy performance for new buildings as well as for retrofitted ones, while maintaining some prescriptive requirements. This performance-based approach is generally considered as providing more flexibility in achieving energy performance improvements, e.g. it allows designers and developers to select components and technological systems best suited to meet the energy performance requirements. Assessments as to whether a building meets the current energy requirements is calculated using a standard model, based on the assumption of a uniform indoor temperature of 20 degree Celsius and other standard assumptions related to the use of the building. Such calculations provide theoretical values for energy consumption per square meter. Building energy efficiency is evaluated, independent of their actual use. Nevertheless, it is widely assumed that following building regulation based calculations of energy efficiency will ensure reduced energy consumption in the built environment.

The building regulations' energy provisions have been continually tightened over the course of almost four decades, stipulating the use of the latest and most energy efficient components and technologies. This gradual tightening of the building regulation has been conducive for promoting material and technological innovations within the building industry (Copenhagen Economics, 2014). By introducing future, minimum performance levels as voluntary some years prior to their being made mandatory, this supports increasing stringency while also providing the building industry with a strong signal about future regulations. Knowing that a voluntary energy standard will later be made mandatory gives companies time to develop and exploit investments in new technologies, materials and construction methods. Furthermore, since the 2010 revision of the building regulations, it has been possible to build according to (voluntary) performance requirements that are some years ahead of their implementation. Buildings for which the calculated energy performance complies with these voluntary standards can get a special low-energy label. As can be seen in Figure 1, this has been quite popular with regard to the construction of new buildings, as more than half of all new builds in 2015 were low-energy buildings, and thus ahead of the requirements.

As mentioned, the building regulations have since 2006 also applied to existing buildings. When existing buildings are retrofitted, then any alterations must comply with the energy requirements of the latest revisions of the building regulation, although the extent to which this is required is considered in terms of profitability, aesthetics and building physics.

Following the EPBD, all buildings sold, both new-build and existing buildings, have since 2008 been required to have an energy label establishing the building's energy standard. The labels are indicative of the building's energy performance, the calculation of which is based on the same model used as when documenting whether or not a new building fulfils the building regulations' energy efficiency requirements. In principle, thus, the building regulations' requirements are strongly related to this theoretical calculation method. In what follows, this policy approach and its strong focus on efficiency will be evaluated in two different ways: First by looking at how energy consumption for space heating has developed over the years, and second by comparing measured and calculated energy consumption for different types of houses.

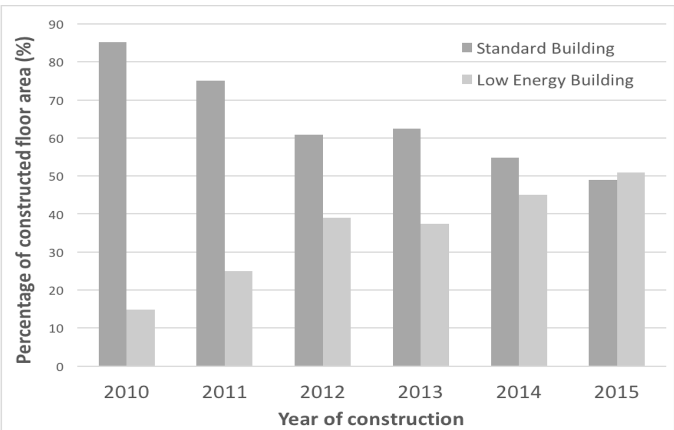

Figure 1. Development of new low energy buildings constructed from 2010-2015 (Warming, 2016).

EVALUATING ENERGY EFFICIENCY AND FINAL ENERGY CONSUMPTION

Figure 2 shows that over a period of almost 25 years energy consumption for heating Danish homes has been more or less stable. The figure shows that energy efficiency per square meter has improved, as consumption per square meter has decreased. The number of heated square meters has, however, increased correspondingly. In other words, even though energy savings has been a policy goal for more than 25 years, energy consumption has not been lowered as expected. However, in the face of the current climate threat, savings in energy consumption is a must. It is, thus, relevant to discuss whether energy consumption per square meter is the most appropriate unit of measure to use when seeking to steer the build environment in a low carbon direction.

Data from Statistics Denmark reveal that the Danish population has grown over the last 25 years. However, the main explanation for the growing amount of heated area is that the living area per person has increased by 13 %. In 2014 each person had, on average, an area of 57 square meter heated home. New single, family houses are being built bigger than ever, even though the average size of a family is decreasing. Today almost 40 % of all Danish households consist of only one person. Although these changing demographics have nothing directly to do with the building regulations' requirements, they point to important factors that can partly explain why efficiency achievements are not delivering the necessary energy savings. Furthermore, it is worth mentioning that when it comes to complying with the building regulations' energy performance requirements, this is easier to achieve if houses are built bigger rather than smaller.

COMPARING MEASURED AND CALCULATED ENERGY CONSUMPTION

Another way to evaluate and discuss the energy efficiency approach of Danish energy policy related to buildings is to compare measured and calculated energy consumption for different types of homes. This has been done in a Dutch and a Danish study (Majcen, Itard, & Visscher, 2013; Gram-Hanssen & Hansen, 2016). The two studies show similar patterns, and here we focus on the Danish results. Based on more than 130,000 detached houses with an energy label, and thus with a calculated energy consumption, it is possible to compare the actual energy consumption delivered from utilities, either gas, district heating or oil, with the theoretically calculated. All houses included in the study had an energy label issued between 2006 and 2014. The database thus includes all houses sold during this period, and where the heat consumption is known for the year 2012. Heat consumption data was provided by the utility companies, which are required to report this to the authorities. The comparison is shown in Figure 3.

In Figure 3 the dark column shows that for A-labelled houses, the ones with the lowest energy consumption, the theoretical consumption is only about 15 % of the theoretical consumption for G-labelled houses. This is the success story behind the energy efficiency. However, as is seen from the light columns, the actual consumption shows a slightly different pattern: the A-labelled houses only provide a 50 % reduction compared to the energy consumption in the energy inefficient G-labelled homes. This points to a systematic difference: in the inefficient houses, actual energy consumption is lower than the theoretical predictions, whereas the opposite is true in the low-energy houses. There are several reasons for this pattern, but the most important reason is that people adjust their behaviour to the type of building they live in. This will be further developed in what follows, but suffice it here to say that Figure 3 shows that houses, which according to the building regulations' theoretical calculations are A-labelled, consume less energy than the more inefficient houses, but the actual energy savings is far from to the extent which can be determined theoretically. It is even more important to note that energy retrofitting of E-F-G-labelled homes up to B-C-D labelled homes will most likely lead to much less savings compared to what is assumed in the mandatory calculations used when retrofitting old buildings.

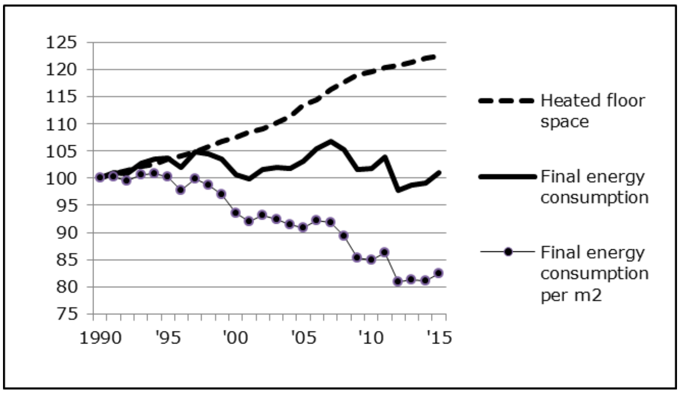

Figure 2. Energy consumption for heating (including domestic hot water) in dwellings, reproduced from Danish (Danish Energy Agency, 2016). Year 1990 is used as a reference (= 100). Data are climate adjusted.

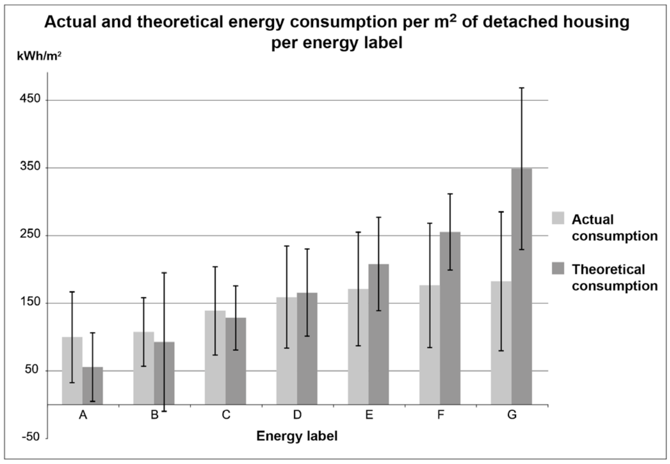

Figure 3. A comparison of average actual consumption and average calculated consumption for each type of energy label with the spread plotted on each column. Adapted from (Gram-Hanssen & Hansen, 2016).

Building regulations – user aspects in phases of a building's lifetime

As noted above the building regulations and related calculation methods seeks to increase building energy efficiency, particularly in new-build but also when retrofitting older buildings. Although some gains have been made, they are far from the extent needed to meet current climate goals, and only just enough to counter the increasing energy demand following from increases in heated living space. In what follows we focus on the influence that building regulations can have in three important phases of a building's lifetime and how this can be of importance for the use of buildings. The three phases are: innovation and development of building technologies; the design and construction (or retrofitting) of buildings; living in and managing the buildings, as illustrated in Figure 4.

DEVELOPMENT AND INNOVATION OF BUILDING TECHNOLOGIES

There is no doubt that the Danish building regulations have had a tremendous effect with regard to increasing building energy efficiency, though as argued above, the energy efficiency improvements have neither lead to the expected very low energy consumption in high performance buildings nor to an overall reduction in energy consumption for space heating. The following provides a few examples of how the regulations and related theoretical calculations have influenced development and innovation in building technologies which, in theory, should be energy efficient, but which in actual use have had unintended consequences and not led to the expected energy savings. One explanation is that several of the "new" generation of technologies (e.g. demand controlled ventilation, solar shading, etc.), introduced to fulfil the strict energy efficiency requirements involve a higher degree of user interaction, and their performance is thus more dependent on the use of the building than the previous generation of technologies (e.g. insulation, air tightness, etc.) (Buso, Fabi, Andersen, & Corgnati, 2015). The examples of energy efficient technologies, which if not used as intended, increase consumption rather than reduce it, is:

- Low temperature heating from either district heating or provided by heat pumps are technically more efficient than having high water temperatures in the district heating net, or having heat pumps to deliver high water temperatures. When using low temperature heating, however, large radiators or underfloor heating are needed to secure enough heating capacity from the low temperature. One problem with underfloor heating is that it allows for the use of different flooring materials than wooden flooring, e.g. tiles which feel cold if not used together with under-floor heating. This can, therefore, prompt inhabitants to use floor heating all year round so as to avoid having floors that feel cold in the summertime, as was reported in a low-energy house (Kristensen et al., 2010). The result of which is an increase in energy-use.
- Another example is mechanical ventilation with heat recovery, which has been introduced as it reduces the calculated energy use for ventilation considerably. However, studies have not been able to demonstrate that the use of this technology actually leads to energy savings (Hasselaar, 2008; Macintosh & Steemers, 2005). The challenge in actual use is that many inhabitants continue to ventilate by opening the windows, thus, limiting or completely reducing potential heat saving to nil (Guerra-Santin & Itard, 2010). This is particularly the case, if the occupants have a negative perception of the mechanical ventilation system, i.e. find it difficult to use (Schnieders & Hermelink, 2006).
- A last example pertains to the use of solar shading. It is often necessary to install solar shading in well-insulated and (air) tight buildings in order to reduce the calculated risk of overheating in the summer. The inhabitants, however, often use the solar shading for other purposes such as ensuring privacy (Brunsgaard, Knudstrup, & Heiselberg, 2012) and they use them at other times of the year, e.g. during winter, to avoid being blinded by the sunlight; the result of which is an increase in energy use for room heating (Foldbjerg, Worm, Asmussen, & Feifer, 2012).

These three examples show, how some technologies are given too much importance when it comes to meeting the building regulations' performance requirements because of the associated calculation procedure. The ways in which these technologies are used in buildings and the influence this has on energy use is not taken into consideration when evaluating their energy efficiency impact. Paradoxically, there might be other technologies, such as ventilative cooling (Pollet, Germonpré, & Vens, 2014), which will not be considered, because it appears less energy efficient in the calculations, even though it can lead to less actual energy use. Hence, the existing building regulations – and supporting calculations of energy performance – promote the use of certain technologies and the construction of certain types of buildings that do not necessarily lead to the lowest possible energy use.

As described previously, the users and the use situation are purposefully not taken into consideration in calculations of a building's energy performance, presumably because it is difficult to generalize and capture user behaviour in formulas in the same way as it is for material use, envelope constructions and economic consequences. Building energy performance depends, however, on how the building is used. Energy consumption in technically identical buildings can vary up to 2–300 % due to differences in the inhabitants' use of the buildings (Gram-Hanssen, 2013). This is exactly why one of

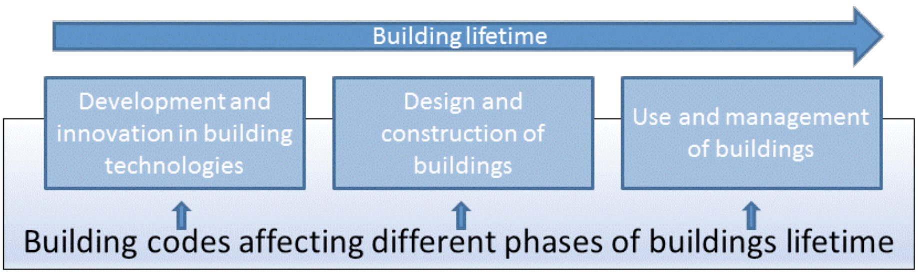

Figure 4. Illustrating three important phases of a building's lifetime when it comes to understand the energy consumption. The figure emphasizes how the building code affects all of these three phases.

the ideas behind the theoretical calculations is to be able to compare different buildings, independently of the ways in which they are used. If user behaviour were included in the calculations, then these calculations would have to include these variations as well as variations in energy use that follow from technologies being used in other ways than intended. Even though it is very difficult, if not impossible, to develop these kinds of calculative methods, the issue of building technologies having unintended consequences suggests a need for debating whether theoretical calculations are the best to promote innovation in building technologies to reach a low carbon built environment.

DESIGN AND CONSTRUCTION OF BUILDINGS

In addition to the unintended increase in energy use associated with new building technologies, the ways in which the building processes take place can also have unintended effects. The construction of a building is often depicted as a linear process – starting with client specifications being given to designers, i.e. architects responsible for the overarching design and engineers responsible for the mechanical systems design, who hand the building project over to the contractors once the programming of the building is completed, at which point the construction process begins. There are multiple stakeholders involved in these processes, making construction a "complex systems industry" (Winch, 1998: 269) in which coordination is demanding, time consuming and in which energy considerations may not be given the same primacy as other concerns (Jacobsen, 2014). The design phases are particularly important in influencing the ways in which the residents use the buildings and the technologies in them. Too little attention is, however, given to understanding the users' everyday practices, how these influence energy use, and to the design implications that this understanding may have (Pihl, 2017).

Issues in the design phase

Performance-based requirements have generally been well received amongst designers, notably architects, because of the greater leeway this gives them in developing the form, orientation, fabric and functionality of new buildings, and in shaping retrofitting projects (Larsen, 2013). Most architects interact closely with their clients in order to gauge client aspirations, needs, and priorities with regard to building design and functionality (Jacobsen, 2014). If reducing energy consumption is not clearly stipulated by the client from the on-set, then energy considerations will most likely not have much influence on the building's overall design, and the building regulations' calculations will primarily be used to assess whether the different design options' calculated energy performance complies with regulatory demands (Pihl, 2017). The building regulations provide no incentive for the designers to consider how the design will impact user practices and energy consumption.

Other design related issues pertain to the architects' knowledge and experience. Some attribute architectural choices' negative impacts on a building's energy performance to the profession's limited insights into building physics, e.g. thermal bridging (Butera, 2013) and to architects' limited knowledge of alternative technologies, materials, etc. (Zero Carbon Hub, 2014). Another issue is the loss of energy-related information when the people involved in the concept and planning phase are not involved in the development phase, in which case work on the design concept, building envelop and mechanical systems are likely to be designed separately and sequentially and perhaps even by different professions (Zero Carbon Hub, 2014). Unless some concerted action is taken, each of the involved parties has the incentive to focus on their specific area of expertise, thus, limiting the development of systemic approaches to reducing energy consumption that also attend to how user interaction with the building influences energy consumption. Architectural and engineering companies are, however, developing more integrated design approaches (sometimes involving energy specialists). The success of which is hinged on the communicative skills of those seeking to promote energy savings (Gluch, 2009; Ludvig, Stenberg, & Gluch, 2013). There are a few positive examples of homes developed through more integrated design approaches, e.g. Housing+ (Realdania By og Byg, n.d.).

Issues in the construction phase

There is seldom much contact between the concept design team, the programming team and the construction team, i.e. problems pertaining to the detailing of the design and to construction are assumed to be resolved within each team. However, often design changes continue to be made during the construction process (which can lead to increased energy use). There are two main reasons for this: it can be because the contractors make simple mistakes and install things incorrectly (e.g. not fitting/securing the insulation properly) or that the design team's solutions prove to be too difficult or impractical from the contractor's point of view and are, therefore, changed (Zero Carbon Hub, 2014). Both of these issues relate to the quality of construction, which can lead to larger energy bills for the users as a consequence of the changes. Quality control can, however, be difficult, particularly if it is out-sourced to sub-contractors. Again, this points to the unintended effects associated with a complex systems industry: with each sub-contractor focusing on the quality of their work, there need not be anyone responsible for checking the overall quality and/or whether the entire building (rather than each technical system) performs as specified. If there is a main contractor or system integrator amongst the contractors (Winch, 1998), then it is more likely that changes will be discovered and reported back to the designers and, perhaps, factored into the energy performance calculations. This does, however, not ensure a systemic review of building (energy) performance, which also considers the users' use of the building.

A third reason for design changes during the construction process is that many of smaller contractors and installer companies lack knowledge and skills in using more energy efficient materials and production processes, which can lead them to sticking with what they know rather than following new design specifications (Menezes, Cripps, Bouchlaghem, & Buswell, 2012). Moreover, changes made during the tender process (e.g. the changing of materials and/or components to cut prices in order to get the contract, value engineering, etc.) will also impact the designed energy performance. However, many of these changes are likely not to be visible until the building is taken into use and the changes make themselves visible, also in the inhabitants' heating bills.

USE AND MANAGEMENT OF BUILDINGS

Whilst the previous sections focused on the unintended effects of new technologies and the design/construction processes on energy consumption in residential buildings, this section discusses how households live in their homes and use the buildings and the technologies, and how everyday living to a large degree determines the amount of energy consumed. Specifically, we focus on how recent developments within energy efficient building design and technology affect the users.

Rebound effects are obviously important for understanding why expected savings are not achieved, and they are well described phenomenon within research on households' energy consumption (Galvin, 2015; Sorrell, Dimitropoulos & Sommerville, 2009). Originally, the rebound effect was described as an economic mechanism where the savings from having more efficient technologies meant that households could afford to buy more of the same service (direct rebound effect) or of other services (indirect rebound effect). In relation to residential heating, one can distinguish between a spatial rebound effect (heating more space) and a temporal one (heating for longer periods) (Winther & Wilhite, 2014), as well as just keeping generally higher temperatures. In this approach the rebound effect are not just seen as an economic effect, but rather understood as a part of how everyday practices change with the introduction of new technologies, and how new and higher norms of comfort are simultaneously established (Shove, 2003). Different studies have shown these kinds of rebound effects: efficient heat pumps leads to higher indoor temperatures (Gram-Hanssen, Christensen, & Petersen, 2012), people keep higher indoor temperatures in low energy buildings (Kristensen et al., 2010), people wear less, and less warm, clothes in newer buildings (Hansen, Gram-Hanssen, & Knudsen, 2017).

Another reason behind not achieving expected energy savings relates to inhabitants not knowing how to best use the buildings and technologies. They are often not able to get the most out of these technologies. For example, studies of programmable thermostats show how these often do not lead to lowering consumption due to poor usability, or the users' lack of understanding of their functionality (Perry, Aragon, Meier, Peffer, & Pritoni, 2011). In other instances, inhabitants find other ways for using the technologies, which go against energy saving goals. Air-to-air heat pumps are officially promoted and supported as an energy efficient heating technology in Denmark, but the use of them as air conditioners in summer time is a new form of residential energy consumption, not previously considered normal in Denmark (Gram-Hanssen et al., 2012).

When it comes to everyday life in residential buildings, people do not think of themselves as energy consumers. They consume energy while doing what they want to do in their homes – while carrying on with their ordinary, everyday habits and practices (Shove & Walker, 2014). Users may be interested in saving energy, but this may not have any direct link to the way in which everyday routines related to heating are performed. Everyday living at home requires management of many mundane issues, most of which are accomplished tacitly, based on routinized practices. Home keeping is synonymous with managing maintenance and adjustment. It involves practices developed over time as a result of the complex interaction of peoples' personal, educational and occupational background, family relationships, economic possibilities, and the cultural characteristics of the places in which they live. Thus, our heating consumption patterns reflect both our current life situation and what we have learned during our upbringing (Hansen & Jacobsen, 2017). Routinized practices allow us to perform our housekeeping almost without conscious reflection upon the choices we make as, for instance, when we turn on and off the faucet in the shower, turn heating thermostat up or down, or open a window. Routines related to heating are thus part of everyday practices carried through unconsciously, but can, when studied, be seen as reflecting ideas of what a home is or should be, as well as reflecting interrelated ways of sensing different aspects of comfort including not only thermal comfort (Madsen, 2017).

A conscious focus from the users' side on energy management and discussions about rules and regulations in these matters can be seen as one of the ways to bring the users into these energy issues. There has been, and still is, widespread confidence amongst EU and national policy makers that feedback on energy consumption to households, based on digitalisation of metering, will motivate consumers to save energy. This approach has, however, been criticized for relying on assumptions of consumers as being *homo oeconomicus*, whose behaviour are guided by economically rationally decisions (Strengers, 2013). This understanding is far from the one described above, in which energy consumption is considered as a by-product of different unconscious habits related to performing different everyday practices. A large amount of research on the actual effect of giving feedback to consumers, furthermore, confirms that feedback often has little influence on actual consumption, although well designed feedback schemes may be able to deliver some savings (Darby, 2010).

Feedback to consumers on energy consumption can, however, take other forms than just informing about the amount of energy consumed. For example, there are experiments with providing households with feedback on indoor comfort parameters, accompanied by advise on how to achieve a nice indoor climate without having too high energy consumption (Andersen, 2016). Other researchers argue in line with this that feedback should focus on peoples' practices, and give specific energy related feedback regarding these practices rather than focus on the overall energy consumption (Stankovic, Stankovic, Liao, & Wilson, 2016). There is, however, also a major technical issue in processing the streams of information passing through the protocols measuring consumption to the smart displays, which have to be overcome, if feedback is to be more intuitive and more directly guide the users on how to interact with the building in the most efficient way. Conscious reflection upon the relationship between energy consumption, convenience and comfort, and economy and climate, is, however, poorly supported by information from the building, where the consumption takes place. Residential buildings are most often not very helpful in providing instant, visible, and easy-to-understand energy consumption feedback to its inhabitants, showing what difference it makes to open a window to cool down, or not – as opposed to the situation in cars where we are accustomed to getting information, which enables us at a glance to adjust our driving routines, based on information about the car's energy consumption.

Studies of home keeping practices show, however, that in many cases households do spend time discussing energy consumption (Andersen & Christiansen, 2013; Christiansen & Kanstrup, 2009), which might provide fertile ground for developing smarter consumption information. But the quality of information about the relationship between building performance, energy consumption and experienced convenience is poor to non-existing. Considering the complexity of socio-technical systems like energy supply and building, this should come as no surprise though: even if we exclude economic and political interests and focus solely on dataflow in such systems, the task of integrating and aligning data sources, and providing translation between data protocols is huge. And with no public instance to take responsibility for such integration measures, it is easy to realize that feedback interfaces that better support reflective energy management are not likely to be seen in the near future.

The Danish building regulations include requirements related to feedback and energy management either directly in the building regulations or through reference to other regulations as the Standard for heating and cooling systems in buildings (Dansk Standard, 2013) or the Order for metering (Transport- og Bygningsministeriet, 2014). All households are required to have an individual metering of their consumption and to pay accordingly, and they are entitled to have informative bills. Moreover, the regulations stipulate that it should be possible to regulate the temperature in every room independently of the temperature in other rooms and that it should be easy for the user to manage the control of this. The question, however, remains if these requirements are sufficient to ensure that households have the best possibilities of understanding and managing their own consumption. If buildings continue to get even more complicated technically, and if energy performance at the same time gets even more dependent on the actual use of the building, then building regulation should probably engage more in this issue.

Developing building regulations?

The previous sections have described how building regulations work in relation to promoting certain building technologies and designs, which according to theoretical calculations of energy efficiency are better than others. We have also shown how these building technologies and designs may, however, not be those that actually deliver the lowest energy consumption; for reasons related to how the users understand and engage with the buildings and their technologies. In the following we discuss what implications these insights can have for considering other approaches in building regulations.

Part of the difficulty in achieving the necessary reductions in energy consumption in residential buildings relates to the use of pre-construction and pre-occupancy measures, which are based on theoretical calculations based on standardized assumptions regarding building use. There are two ways in which the actual energy use of a building can be included in the building regulations: either by developing programs to predict how levels of energy consumption from a certain building technology or building design will vary according to use, or by using post-occupancy evaluation schemes rather than pre-construction evaluations.

Developing models, which simulate variances in energy consumption depending on building use, could be used to test the robustness of buildings and technologies. To actually include realistic simulations of the many possible ways in which a building could be used would, however, mean that human practices related to heating are somehow predictable. Putting in a range of different indoor temperatures and air change rates is an easy task, while predicting how households invent new ways of using different types of technologies, or in what ways they will overrule the intended use is much more complicated, if not impossible. One solution would be to include all the things that possibly could affect energy consumption in the calculations to show what variances this would yield. There are, however, obvious problems with this strategy. If people can open a window, should the building regulations' energy performance calculations include that people will do this more often? Building regulations based on this kind of principle would thus promote technologies where people have the least possibility of intervening.

Intelligent buildings will most likely be part of the future. Hopefully, they will be developed so as to allow users to operate the building, rather than preventing users from acting and intervening themselves. We can fear that building regulations, which build on more sophisticated pre-occupancy modelling, will promote intelligent solutions that seek to eliminate users interaction, rather than intelligent solutions supporting users. Another reason for not going in this direction with the building regulations would, furthermore, be the level of complication this introduces to an already complicated building process. This is, of course, not a general argument against developing more advanced models, it is just a word of warning against using too complicated models of pre-occupancy energy use as basis for future building regulations.

The other approach that can be taken in changing the building regulations so as to better include user-aspects is to change focus from pre- to also include post-occupancy measurements. If technologies and buildings are optimised according to actual use, rather than theoretically calculated energy efficiency, then much of the issues described previously would be accommodated. The problem with doing so is the documentation, control and imposition of sanctions if a building, one to two years after occupancy, turns out not to deliver the claimed goals of consumption. Learning from some of the previous successes with the Danish building regulations, namely the voluntary energy classes, where buildings could be classified as low-energy buildings prior to this being mandated, one first approach could be to introduce voluntary, post-occupancy performance classes. A voluntary performance class of this kind could include putting less emphasis on documenting pre-construction energy efficiency (although this still probably is a valuable design input), if project owners would instead agree to comply with some type of performance guaranties, including plans for how commissioning could be done particularly in instances where the (low) goals for consumption are not reached. This would most likely also include the appointment of parties responsible for an integrated approach to ensure a systematic assessment of the building at the time of delivery as well as after some period of usage, thus include the process of commissioning. It is quite likely that there could be a market for contractors willing to risk this kind of building projects, which promises to deliver houses that actually deliver in lowering of energy consumption, similar as to when designers and contractors engaged in developing housing that matched the voluntary low energy classes.

Furthermore, the building regulations could also be changed to better accommodate households' possibilities of energy management by setting certain standards for the feedback households get on their consumption. Although the building regulations contain some requirements in this area, we question whether they are sufficient. The usability of the new control technologies and the information that they provide seem to be particularly relevant areas to improve. Feedback is a widely-discussed subject, with digitalisation and smart grid approaches further highlighting the importance of feedback. Although the Danish building regulations already require that consumers should have informative bills, telling them about their consumption, as a background for informed energy management, would it be possible to stipulate some minimum requirements regarding the readability and usability of this kind of information? Energy management is, however, more an idea born within a certain type of energy policy regime, than an actual practice in an everyday life where people go about their everyday practices more or less unconsciously. Buildings, which give instant and easy guiding to its users should be promoted. This points back to the need for post-occupancy evaluations, which will demonstrate whether buildings are able to guide their users in minimizing energy use. This will, in turn, promote these building in favour of others.

Finally - in light of the fact that residential energy consumption is not decreasing and that the amount of heated space per capita in Denmark is steadily increasing, measuring building energy performance per square meter appears to be increasingly problematic. It is thus relevant to point at how energy policy will have to use many different approaches to reach the goal of reduced energy consumption. Amongst the more important reasons for the increase in heated space per capita is the growth of one-person households and peoples' tendency to stay in the same home for their entire life rather than changing homes according to their needs at different stages in their life. Issues such as these are regulated through housing policy and the housing market, developments that from an energy perspective warrant more interest.

Conclusion

We have in this paper outlined some of the problems regarding user influence on the energy consumption of residential buildings that are now well recognised within the research community, and subjected this knowledge to more detailed scrutiny. The Danish building sector and the Danish building regulations were taken as our example. Some of the discussions and issues raised may be slightly different in other countries, even though the Danish building regulations follow the EU's EPBD. However, as the Danish building regulations are often heralded as one of the frontrunners, the Danish case should be of broader interest.

The paper seeks to establish foundations for a discussion of what to do with the building regulations in the future. We acknowledge the achievements obtained so far in increasing the building stock's energy efficiency, but we question the fruitfulness of continuing with increasingly stringent regulations in seeking solely to minimize the calculated residential energy consumption per square meter. Rather we argue that we need to find ways to include parameters regarding users' way of managing their energy consumption in the building regulations, since innovation in building technologies and building design lead to a sub-optimisation on a too narrow set of parameters.

Although there are good reasons for the use of pre-construction measures in building codes, we invite colleagues within research and policy to acknowledge that we need to re-think how to actually achieve and increase energy savings within the built environment. Furthermore, we probably also have to accept that some of the previous assumptions regarding climate change mitigation have rested on overly optimistic estimations regarding the achievement of cost-effective energy savings within the building sector. This does not mean that we should not continue to work hard on developing policy within the built environment to reduce GHG emission, but points to the need for more emphasis on reducing energy consumption in other sectors as well.

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