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Policy strategies for achieving large long-term savings from retrofitting existing buildings

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Abstract In order to achieve long-term targets for energy savings and emission reductions, substantial savings will be needed from existing buildings. For example, a recent analysis for the USA examines aggressive strategies to cut carbon emissions in half by 2040 and finds that in order to achieve this emission reduction target, more than half of existing buildings will need comprehensive energy efficiency retrofits. Germany is targeting an overall primary energy consumption reduction of 50% in 2050 including increasing building renovation rate to 2% per year. In France, ambitious targets have also been set for existing buildings: 50% reduction of primary energy consumption in 2050 compared to the 2012 level. Multiple countries have realized the importance of comprehensive building retrofits and have begun to adopt policies to spur these improvements. For example, Germany is emphasizing grants and loans through the KfW Development Bank, complemented with building and heating system labels, a new "heating check" programme, and possible technical renovation requirements. France has established a goal of bringing all buildings up to "A" performance level (on their A–G scale) by 2050 in order for them to be sold or leased, with lower performance levels required as soon as 2020. In the USA, the focus has been on a combination of rating and disclosure of energy use, financing, and technical assistance. Focused community approaches show promise. This paper summarizes the efforts, successes and challenges, future directions, and savings of building retrofit policies in the three countries. We conclude by contrasting the three countries and discussing areas of opportunity for these and other countries.

Keywords Energy efficiency policies · Retrofitting · Existing buildings · Energy savings · France · USA · Germany

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Introduction

With the climate agreement reached at the climate conference in Paris at the end of 2015 (United Nations 2015), the international community committed itself to the target, which is binding under international law, of holding global warming to well below 2°C compared to pre-industrial levels. In order to achieve such an ambitious long-term target, all main contributors to

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greenhouse gas (GHG) emissions have to achieve substantial energy savings and emission reductions. In 2010, this sector accounted for 32% of global final energy use and 19% of all GHG emissions (Chalmers 2014), and building sector CO_2 emissions from fuel combustion represented 17% in the European Union in 2016 (Enerdata 2018). This means that substantial energy savings will be needed from new and especially existing buildings during the next several decades. For example, a recent analysis for the USA examines aggressive energy efficiency strategies to cut energy use and carbon emissions in half by 2050 and finds that in order to achieve these targets, more than half of existing buildings will need comprehensive energy efficiency retrofits (Nadel 2016). Germany aims to reduce its heating requirements by 20% by 2020 and the primary energy demand of buildings by 80% by 2050. This means a doubling of the building renovation rate from 1 to 2% per year (BMWi and BMU 2010). In France, ambitious targets have also been set for existing buildings: e.g. 60% reduction of final energy consumption in 2050 compared to the 2010 level for the service sector (Legifrance 2016).

The target of this paper is to examine retrofit policies for buildings in three countries—France, Germany, and the USA. With these countries, we cover around 21% of world energy consumption of buildings in 2015 (Enerdata 2018). From a policy perspective, these countries adopt different approaches to reach their targets for the building sector. Therefore, we think that a comparative examination of the building policies used in these countries and their pros and cons can be helpful for multiple countries which have realized the need for suitable policies to achieve comprehensive retrofits of the building stock. We first describe current policy efforts, their successes and challenges, and future directions in these countries. We then discuss cross-cutting findings across the three countries and the applicability of these strategies for other countries around the world. Finally, we draw some conclusions on an effective energy efficiency policy design for buildings.

France

Current efforts

In France, the first thermal building code (RT) was implemented in 1974 and has been updated and strengthened six times since then. Still, around 55% of the current residential building stock was built without energy building codes (INSEE 2017). As a result, the average performance of the building stock in terms of energy consumption per square meter is one of the worst in Europe (Ademe, Enerdata, 2011). Today, the potential for energy savings in these older buildings is huge while the building sector is one of the top priorities in the energy efficiency policy roadmap in the country (Ministère de la transition Ecologique et Solidaire 2015). The specific building-related energy saving goals have been set in the 2015 Energy Transition Toward Green Growth Act:

- 60% reduction of final energy consumption in 2050 compared to the 2010 level for the service sector buildings;
- Renovate 500,000 homes per year starting in 2017, at least half of which are occupied by low-income households, aiming for a 15% reduction in fuel poverty by 2020 (Art. 3);
- Prior to 2025, all private residential buildings whose primary energy consumption exceeds 330 kWh/m^2/year of primary energy must have undergone an energy renovation (Art. 5).

Several regulations are being implemented to meet these targets, starting with the abovementioned building code that, as of 2013, requires all new buildings to meet nearly zero energy building standards (nZEB) established by the EU (i.e. new residential buildings are required to have a primary energy consumption lower than approximately 50 kWh/m^2/year, varying by climate zone). Therefore, the cost-optimal level for NZEB has been evaluated along with the last French Building Code. Concerning renovation, the building code asks that each building with a surface area more than 1000 m^2 (and built after 1948) meet a global energy performance target: the target is for dwellings to reach consumption between 80 and 165 kWh/m^2/year since 2010 compared to an average of 240 kWh/m^2/year for the existing stock. The range depends on the climate zone and the heating fuel. For non-residential buildings, the savings should be of 30%. Concerning other residential buildings (i.e. with a surface area below 1000 m^2), the element-by-element thermal regulation (called *RT element*) sets a minimum performance level for elements replaced or installed (insulation, heating and cooling, hot water, ventilation, etc.).The German

and French initiatives on energy efficiency labelling for buildings are both rooted in the European Energy Performance of Buildings Directive (EPBD) that requires Energy Performance Certificates (EPC) to be included in all advertisements for the sale or rental of buildings. The EPC is the European Union energy rating scheme for buildings which assigns each building a rating (e.g. using an A–G scale in some countries like in France). France have implemented this scheme in 2006–2007 and was also the first country in the EU to implement the advertisement requirements in 2011. Additionally, as mentioned earlier, the Energy Transition Law enforces private residential buildings where the primary energy consumption exceeds 330 kWh/m^2 to undergo thermal renovation. This affects all buildings with an EPC in the two lowest levels, F or G (~ 15% of the stock). These buildings, including rented and owner-occupied, will have to be renovated before 2025. This measures will be tightened every 10 years starting in 2020 so that it will accelerate the needed transformation of the existing building stock, and help achieve the goal of bringing the entire building stock to low energy levels ("*Bâtiment Basse Consommation*" (BBC) or equivalent—this is equivalent to 80 kWh/m^2/year in primary energy for the regulated loads (heating, cooling, lighting, ventilation and hot water), by 2050, which is also part of the 2015 law.

To accompany these regulatory instruments and to help consumers to manage the upfront investments of energy efficiency upgrades, the French government offers a mix of policy incentives and support targeting both residential and commercial buildings, for instance:

- Label and grants for high energy performance (e.g. nZEB) retrofit offered by some regions in France: for instance, Region Bourgogne Franche-Comté offers grants for energy audit (equivalent to 80% of the audit cost) and renovation process (up to €10,000) for a deep renovation;
- The "Energy Transition Tax Credit" for residential sector (tax credit of 30% without income conditions to assist landlords purchasing efficient materials and equipment to limit energy consumption). To smooth and accelerate renovation activities, this tax credit will evolve and become from 2018 a grant offered to households as soon as renovation is ended;
- Since 1999, a reduced value-added tax (VAT) for residential sector (from initial 20 to 5.5% VAT rate) applies for work carried out on dwellings older than 2 years, including refurbishment work;
- The zero interest rate eco-loan scheme for the residential sector ("*eco-prêt à taux zero*" *in French:* landlords get a loan at 0% to fund energy efficiency works) was introduced in 2009 to allow owners to get a loan in order to fund energy efficiency work (insulation, heating or water heating using renewable energies) for their main residence. The maximum amount per building of this loan is €30,000 with loan repayment extending over 10 years. It is granted by banks which must meet specific agreements established by the government;
- The Energy Saving Obligation scheme (white certificate) for both residential and non-residential sectors, using the same principles as the European Union's Emissions Trading Scheme, obliging energy retailers and fuel suppliers to meet specified energy saving targets.[1] Obligated parties meet these targets by encouraging their customers, mainly in the building sector (with a special focus on energy poverty), to reduce their energy consumption (e.g. boiler replacement). Moreover, from 2018, government will offer grants to incentive modest households to scrap polluting heating systems (grants up to €3000 when converting heating systems towards renewables, Ministère de la transition Ecologique et Solidaire, 2017);
- Dedicated grants or programmes are implemented to tackle energy poverty in France and to meet the ambitious abovementioned target of 250,000 dwellings retrofitted per year. Dedicated programmes such as the "*Habiter Mieux*" have a budget allocated through the white certificate scheme to finance renovation in private housing owner;
- Energy audit subsidies targeting mainly service buildings;
- Quality label (certification scheme for professionals) including training and qualification of practitioners.

[1] In France, energy saving obligation targets are specified in terms of kilowatt hour cumac of final energy, "cumac" meaning "cumulative and discounted" a specific measurement unit corresponds to the energy savings accumulated over the life-time of the implemented operation and actualized (discounted) at a rate of 4% per year. Saved energy is calculated with reference to average existing devices—*additionality principle*, for instance: a 18-W LCB save 49 kWh/year–880 h/year; 70% of sold LCB replace incandescent bulbs; time for life is 7.5 years with a discount factor of 0.88; energy saving is 49*0.7*7.5*0.88 = 230 cumac-kWh.

To overcome the information barrier and make sure that citizens are aware of the availability of public support for energy renovation, France has set up one of the most comprehensive advisor service centre for free. The Point Renovation Info Service (PRIS) one stop shop initiative is a key element of and is driven by the Energy Transition Toward Green Growth Act (World Energy Council 2016). The idea is to give owners a single contact point in the form of a website and national phone number directing users to one of 450 local centres across the country. The PRIS is a network of advice centres and is a key part of the relatively comprehensive policy landscape to promote energy efficiency in buildings.

In general, the residential sector is more targeted by policies in France (and most other EU countries) than the service sector. There are less statistics and few policies that target only non-residential buildings. However, the public sector does play a leading exemplary role under the Energy Efficiency Directive. Also, in France, there is an extensive energy services company (ESCo) market for non-residential (Duplessis et al. 2012, Sebi et al. 2016).

Successes and challenges

The French building renovation strategy is integrating three interrelated action areas: (1) Support to renovation decision-making by providing households with individual coaching with consultants in renovation; (2) Financing energy renovation of private residential building stock and social housing (e.g. by providing subsidies, grants, preferential loans, and personal income taxes reduction); (3) Mobilizing/encouraging professionals to control costs and quality in residential and non-residential buildings as part of training for building professionals.

Furthermore, France's strategy foresees that the quality of the renovation should be improved by continuous training for building professionals and support to professionals in order to control costs. The PRIS network has moderate levels of public recognition but it has not consistently grown, with a 2013 study showing recognition at similar levels as in 2008 (18%) (World Energy Council 2016).

The EU ZEBRA2020 (ZEBRA 2016) project developed a "major renovation equivalent rate" to monitor and benchmark renovation activities in line with EPBD article 7 definition, with France having the second best rate in the EU concerning residential sector (1.75% of the stock major renovated in 2013—no data available concerning non-residential building stock—ZEBRA 2016). However, despite all economic incentives and related financial instruments established in France, 40% of thermal renovations are light (OPEN-ADEME 2015), i.e. one measure maximum implemented) and the maintenance work (i.e. renovation without thermal improvement) is still too high. This lock-in effect (or missed insulation opportunity during esthetic or enlarging building work for instance) is problematic and becoming a priority for policymakers who are interested in figuring out how to encourage consumers to make steps towards thermal renovation (Toleikyte, A., et al. 2016). The barriers that hinder deep retrofitting existing building stock are diverse and include (Sebi et al. 2016):

- A lack of objectives and clear definition for deep renovation. The definition of deep renovation is not standardized and the national target of annual renovation (500,000 renovation/year) does not include concrete objectives in terms of level or type of renovation;
- A lack of compliance in building code implementation for existing buildings as there are no mechanisms in place to monitor renovation activities;
- High upfront cost of deep renovations: To meet nZEB or deep standards, investment renovation costs are high and unfordable to many owners/investors. A study (Saheb 2017) shows that if equally distributed, the €12.2 billion invested in 2015 in energy renovation in France is equivalent to €31,400 per retrofitted home or an average of €314/m^2. This cost should be compared to the current cost of deep energy renovation which is more than €1200/m^2 or €120,000 for an average home. A more recent empirical study (sample of 120 retrofitted houses in Alsace region) estimated that the average cost of deep energy renovation (BBC level) is around €465/m^2, equivalent to an average global cost per operation of roughly €70,000 (CEREMA 2017). The current level of investment per home will thus not allow France to reach its energy renovation ambition;
- Besides, the return on investment is difficult to evaluate: In France, it is estimated that a deep renovation has a simple payback of 20 to 30 years while a dwelling has a new owner on average every 8 or 10 years. There is a temporal constraint that

undermines incentives, lowers the leverage effect of instruments, and complicates efforts to take concrete action and trigger the renovation work ("passage à l'acte" in French);
- Split incentive dilemma between landlord and tenant: in the case of renting, for instance, if the landlord signs an Energy Performance Contract, the tenant will benefit from energy savings while landlords pay for thermal solutions. Today, though there are several incentives, landlords implement less thermal improvement solutions when the dwelling is rented.

Future directions and savings

In France, one of the main challenges is to provide building owners and investors with tailored advice according to a specific renovation roadmap (Sebi et al. 2016). As a first step, it is worthwhile to define official renovation levels (i.e. set different performance levels on a whole-building scale), to monitor and increase renovation activity by level and to make the step-by-step renovation possible. Governments will be able to propose financial instruments according to the different steps (and levels of ambition); this financial support should reward higher motivation and steer ambition towards the nZEB level in order to avoid potential lock-in effects. But, even if deep retrofitting is encouraged, financial instruments should allow step-by-step or successive investment with a short return on investment. To tackle the abovementioned lock-in effect, a May 2016 French governmental decree (Legifrance 2016) enforces thermal improvement work in the cases of façade cleaning, attic renovation, roof repair, or the conversion of attics or garages into living space.

The Energy Performance Certificate (EPC) has a weak impact today on the property value in France according to ZEBRA2020 real estate agents survey: 69% of real estate agents find there is no rent/price surplus of buildings/flats with high energy performance rating (Santos et al. 2016). Another study shows that a bad EPC (labels F or G) decreases the value of the property in France by around 10% while a good EPC (label A) increases its value by 10% compared to D-label EPC (Notaires de France 2017). In order to become drivers for renovation, the current EPC should evolve into building-specific renovation roadmaps, or "building passports", accompanying a building through its life cycle including improvement proposals and advice to owners and investors on how to make the building a nearly-zero energy use establishment (in a step-by-step approach to energy renovation which avoids lock-in effects and looks towards better solutions). A building roadmap or renovation passport will allow building owners to have an overview of the full range of renovation options and easily identify each renovation step from the beginning to the end at the same time. In order to become useful in individual buildings' improvement plans, EPCs should evolve towards more comprehensive and dynamic tools accompanying a building over its lifetime (Sebi et al. 2016). In France, the Energy Transition Toward Green Growth Act (LTECV) mentions that a digital notebook for the monitoring and maintenance of dwellings (*carnet numérique*) will be deployed: it is mandatory for new buildings since 2017 and will be for any real estate transaction by 2025. This building passport will make future building owners/buyers more aware of the building's energy performance/health and future benefits/costs.

According to the study lead by the French Energy ministry (Ministère de la transition Ecologique et Solidaire 2015), the current policy mix (and including measures and objectives as presented above for building) will permit France to achieve the main quantitative targets set by the law: i.e. to cut GHG emission by 40% between 1990 and 2030, and to divide it by four between 1990 and 2050; to cut final energy consumption by 20% by 2030 and 50% by 2050 compared to 2012 and to reach 2.5% for the annual fall rate of the final energy intensity by 2030. Particularly, the building sector will contribute up to 60% of these savings. However, this scenario takes into account the full implementation of ambitious targets (e.g. 500,000 existing dwellings retrofitted each year) without specifying any renovation level requirements to achieve this target. If these steps are taken, France will be on track to meet its current pledge under the UNFCC for the building sector, and more particularly for the existing building stock as a key player in this transition.

Germany

Current efforts

Energy policy targeting the uptake of energy efficiency measures in buildings comprises mandatory targets,

regulations, financial measures, and information measures. Within the framework of the German *Energiewende* (Energy transition), ambitious mid- and long-term targets have been adopted (BMWi and BMU 2010):

- Reduction of final energy demand for heating in buildings by 20% in the period 2008 to 2020;
- Increase of renewable energy sources for heating and cooling (RES-H/C) to 14% by 2020;
- Increase of the thermal retrofit rate to 2% per year which is currently below 1%;
- Reduction of non-renewable primary energy demand in buildings by 80% in the period 2008 to 2050.

Whereas the original sectoral targets of the German *Energiewende* were only set for the short term (2020) and the long term (2050), the new German *Climate Action Plan 2050* from November 2016 (BMUB 2016) for the first time also sets interim targets for 2030. For the building sector, the target for 2030 requires an emission reduction from 119 Mt. CO_{2eq}. to 70–72 Mt. CO_{2eq}., i.e. about a 40% reduction.

Various studies for Germany suggest that these long-term targets can only be achieved if ambitious energy efficiency standards for buildings are applied which consider not only the reduction of energy demand but also the transformation of the heating supply from fossil fuels to renewable energy systems (RES).

In order to reach these targets, a comprehensive policy strategy has been adopted with the *National Energy Efficiency Action Plan* (BMWi 2014), the *National Efficiency Strategy for buildings* (BMWi 2015), and the *Climate Action Programme 2020* (BMUB 2014). These programmes complement and revise the existing policy mix (Schlomann et al. 2015, 2016; Ringel et al. 2016). The main national policy instruments are regulations on the energy performance of buildings (energy saving ordinance) and the mandatory use of renewable energy sources for heating and cooling (Renewable Heat Act) as well as financial instruments to support efficiency measures and RES-HC (heating-cooling) installations.

The Renewable Heat Act obliges owners of newly constructed residential and non-residential buildings to source a certain share of their heating demand from renewable energy sources such as biomass boilers, heat pumps, or solar thermal. Alternatively, the use of district heating produced by at least 50% from combined-heat-power (CHP) or RES units, additional efficiency measures and on-site CHP units are allowed to comply with the law. In the state of Baden-Württemberg, the law has been extended to existing buildings requiring the installation of RES-HC units or alternative measures in case of boiler replacement. RES-H/C installations in existing buildings are supported by the Market Incentive Programme with an annual budget of 300 million Euros.

The energy saving ordinance (EnEV) regulates the maximum primary energy demand of new and existing buildings undergoing a major retrofit based on a reference building method. Furthermore, it defines maximum u-values for individual building components after a retrofit. The last recast of the EnEV has tightened the primary energy demand requirements for new buildings from 2016 onwards by 25% compared to the previous regulation introduced in 2009 (EnEV 2013). More ambitious standards and individual retrofit measures are financially supported by the Federal Development Bank (KfW) with low interest loans and investment subsidies. The highest support is granted for major renovations achieving the so-called KfW efficiency house standards. These energy performance standards are directly linked to the current requirements of the EnEV. There are currently six *KfW efficiency house standards* (KfW 55, 70, 85, 100, 115) for existing buildings whereby the energy performance target is determined by the respective number (numbers are the percent of primary energy consumption relative to a minimally compliant new home). Figure 1 illustrates the relation to the building code requirements for a KfW 55 and KfW 100 efficiency house standard. Specific investment subsidies granted are 17.5% for a retrofit to KfW 100 standard and 30% for a retrofit to KfW 55 standard. The KfW support programmes are financed by the Ministry of Economic affairs and the German Energy and Climate fund. The overall budget was increased to 2 billion Euros per year in 2015. Up to now, the KfW programmes has mainly targeted residential buildings as well as public and social infrastructure buildings. Since 2015, also commercial non-residential buildings are eligible for support.

In addition to the main regulations and financial support instruments, information policies are also relevant for the achievement of the long-term targets. These policies include the support of energy advice services, a new "heating system check" programme, a labelling programme for existing heating systems, and long-term renovation roadmaps for individual buildings. The national efficiency label for existing heating systems should increase the

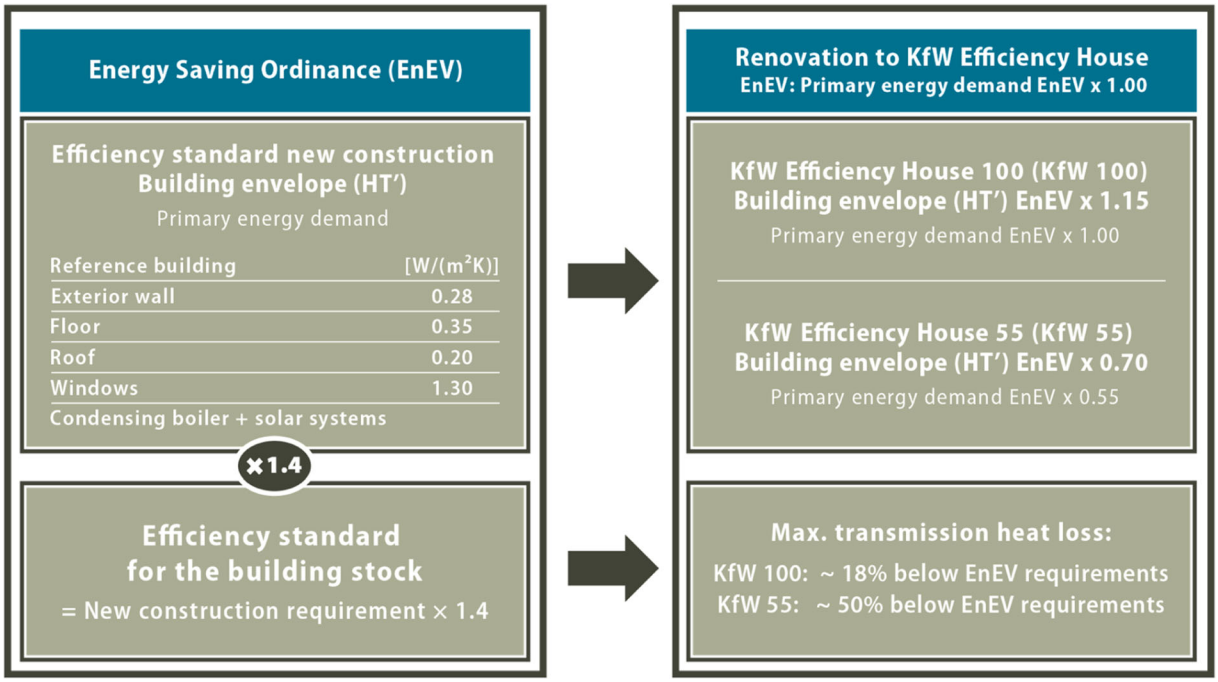

Fig. 1 Relation of building code requirements and financial support instruments in Germany

motivation of building owners to replace inefficient systems. Energy labels for existing boilers older than 15 years are required since 2016. Quite new instruments are so called long-term renovation roadmaps for individual buildings which are provided in combination with a comprehensive energy assessment. They aim to prevent lock-in effects if buildings are retrofitted step-by-step. A renovation roadmap considers not only the technical requirements and barriers but also the individual financial situation of the building owner and suggests a timeline for the retrofit of individual building components leading to a high efficient building which conforms to the target of an almost climate neutral building stock.

"Primary energy demand x 1.4" means that the minimum requirement on existing buildings is 140% of those of new buildings. Therewith, the primary demand of existing buildings after a retrofit should not exceed more than 40% of the requirements defined for new buildings in the building code (Source: Fraunhofer ISI).

Successes and challenges

The policies in place were successful in the past. The building code regulation has been tightened several times increasing the requirements for new and existing buildings at the same time. However, with the last recast of the EnEV, only the efficiency standard for new buildings has been adjusted. The further development of the building code regulation also focuses on new buildings with the introduction of the Nearly-Zero Energy (nZEB) standard. The major policy approach for the building stock is therefore the application of financial support instruments which have been effective in the past considering the number of implemented measures and the establishment of new market standards: energy efficiency measures in 2.3 million dwellings have been supported by the efficient retrofit programme of the KfW in the periods 2005 and 2015 (Diefenbach et al. 2016). That is, 5.7% of all dwellings have received support. The KfW efficiency house is meanwhile a well-established efficiency standard not only for construction companies and building professional but also for investors and private building owners. The same is true for RES-HC installations.

However, despite high financial support, these instruments have not been very successful in lowering the overall investment costs for the building owners. Furthermore, energy efficiency measures supported by current policies do not all conform with the medium- and long-term saving targets:

- The specific investment costs in small-scale RES-HC installations have not significantly changed in the last 10 years.
- 88% of the measures supported within the KfW energy efficiency retrofit programme in 2015 are single components not major or deep retrofits (Diefenbach et al. 2016).
- The KfW programme supports the installation of fossil fuel condensing boilers. In 2015, 84% of the financially supported heating systems were gas and oil boilers and not RES (Diefenbach et al. 2016).

This is confirmed by the recent monitoring report of the *Energiewende* which is prepared by an independent expert commission (Expertenkommission 2016). The commission states that Germany may reach the short-term building target for 2020 but that additional efforts are necessary with regard to the medium- and long-term targets for 2030 and 2050.

Furthermore, financial instrument for energy efficiency measures, heating technologies, and energy advice services are coordinated by different entities making access to building retrofits and financing rather complex for building owners. Standardized products for holistic deep retrofits including initial consultation, implementation, and financing offered by market actors are rare.

Future directions and savings

The most recent decisions of the German government in the field of energy and climate policy aim to achieve the long-term targets for 2050 and the new interim targets for 2030. This is true both for the overall target to reduce primary energy consumption by 50% by 2050 and for the sectoral targets aiming at buildings, transport, industry, agriculture, and the energy sector:

- With regard to buildings, the *Climate Action Plan 2050* from November 2016 (BMUB 2016) contains a road map towards an almost climate-neutral building stock. A key component here is the gradual further development of energy standards for new buildings and existing stock undergoing extensive refurbishment. Another important aspect is to focus funding on heating systems based on renewable energy sources.
- The Green paper on Energy Efficiency launched in August 2016 (BMWi 2016), asked how the existing range of instruments in energy-efficiency policy can be further developed and supplemented in order to enable Germany to reach its target of reducing primary energy consumption by 50% by 2050. Among others, the Green paper mentions price-based instruments (e.g. energy charges and taxes) and volume-based instruments (e.g. energy utility obligations).
- The new "support strategy for energy efficiency and renewable heating" of the Ministry of Economic Affairs (BMWi 2017) presents a plan on how the existing policies for the heating and cooling sector could be better integrated. The strategy comprises RES heat supply and energy efficiency in buildings and for industrial process and the transformation as well as district heating infrastructure. The goal is to reach a sound and well coordinate support framework. Therefore, a one-stop shop will be developed as a central information hub for energy efficiency and support programmes offered target group orientated guidance for investors.

Even if the support strategy is a right step to more coordination in energy efficiency policy instrument, the crucial challenge will be to achieve a cross-sectoral approach for energy policy. The Green Paper on Energy Efficiency emphasizes not only the "Energy Efficiency First" principles, but also the importance of sector coupling options by using electricity from renewable energy sources (RES-E) for the transition of the heating sector.

With regard to the building sector, especially the following demands on future energy efficiency policies are identified (see, e.g. Thamling et al. 2015, Schlomann et al. 2015, Expertenkommission 2016):

- More orientation of the main building policies in place (especially EnEV and KfW programmes) at the medium- and long-term targets for 2030 and 2050;
- Abolition of support for fossil fuel technologies;
- Focus government support on deep renovations;
- Establish energy efficiency markets and standardized products for energy efficiency measures (e.g. by the introduction of an energy efficiency obligation system);
- Implementation of ambitious building code standards for existing buildings in line with the cost optimality;
- Develop policies to stimulate specific retrofit opportunities during the lifetime of a building (e.g.

property transfer, replacement of very outdated or broken boilers);
- Address target groups, which are not focused on in the current policy mix (especially low-income and aged home owners).

USA

Current efforts

Unlike in France and Germany where the national government leads retrofit efforts, most of the programmes and policies in the USA are at the state and local levels. The national government assists and supports these state and local efforts.

Hundreds of retrofit programmes exist in the USA, ranging from simple energy audit programmes to financial rebates for specific measures (e.g. attic insulation or new heating systems) to comprehensive retrofit programmes that seek to optimize the entire house as a system. The best programmes tend to have the following elements (Neme et al. 2011):

- Retrofit advice to consumers;
- Marketing to drive both the demand and the supply chain;
- Technical training and certification of retrofit contractors;
- Rebates and/or up-front cost discounts;
- Innovative financing;
- Quality insurance;
- Investment in research and development;
- Building-efficiency labelling.

No single programme covers every one of these points, but several include many of them. For example, the Home Performance with Energy Star programme is run by many states, utilities and cities with help from the US Department of Energy. Most of these programmes include contractor training and certification, energy audits, and quality inspections; usually some rebates or financing are also included, although in many cases these are modest. As of the second quarter of 2017, there were 44 active state and local programmes and over 640,000 homes had been retrofit since the start of the programme in 2002 (Grubbs 2017). While the highest performing programmes estimate a decrease in whole-house energy use by 30% or more, savings vary considerable depending on programme design and scope. Project energy savings have averaged about 22 million Btu per household per year (23 billion joules), which is 23–32% of total household energy consumption, depending on the region. Energy Star reports an average sponsor cost of $3500 per home retrofitted, with 57% of this amount going to homeowner incentives, 14% to contractor incentives, and 29% to administrative costs. Average homeowner retrofit cost was $5600, with a range from $600 to 17,000 (Jacobsohn et al. 2014).

A good example of a multifamily housing programme is the Chicago Energy Savers programme run by Elevate Energy. The programme offers "one-stop shop" services to multifamily building owners in Chicago including an energy audit, reduced cost financing, arranging for and overseeing contractors, and quality control inspections. Since 2005, about 800 buildings with nearly 35,000 apartments have been retrofitted (Elevate Energy 2016).[2]

In the commercial sector, the predominant type of programme is prescriptive rebates for particular types of energy-efficient equipment such as efficient lighting or heating, ventilating, and air-conditioning (HVAC) systems. A major initiative seeking to improve whole buildings is the Energy Star Buildings programme run by EPA. The programme encourages building owners to benchmark their buildings on a 1–100 scale; buildings with a score of 75 and above earn the Energy Star designation; those with lower scores are encouraged to pursue a multistep upgrade strategy (the score is based on primary energy use but adjusted for building size, occupancy, and weather). As of the end of 2016, nearly 500,000 properties, representing about half of US commercial building floor area had been benchmarked (EPA 2017). EPA conducted a study looking at buildings that were benchmarked annually over the 2008–2012 period, finding that on average these buildings had reduced their weather-normalized energy use by 7% over this 4-year period (EPA 2012). More than 7500 buildings earned the Energy Star in 2016, bringing the total to 29,500. EPA estimates that on average, Energy Star-certified buildings use 35% less energy than typical buildings nationwide. In addition, EPA works with local utilities, states, and other local partners to encourage benchmarking and whole building retrofits. As of the

[2] Participation information through Dec. 31, 2017, from Abigail Corso, Elevate Energy, email to S. Nadel dates Jan. 26, 2018.

end of 2016, about 40 Energy Star utility partners are providing streamlined access to the energy data their commercial customers need for benchmarking and 23 local governments and two states use EPA's benchmarking tool as the foundation for their energy benchmarking and transparency policies (EPA 2017).

At this point, most comprehensive retrofit programmes in the USA are funded by electric and gas utilities, although some states and localities provide funding. Utilities fund these programmes for a variety of reasons but the most important are generally: (1) energy efficiency is often less costly per unit of energy than new power or natural gas resources; and (2) regulators support these programmes and often provide some inducements for utility efficiency investments. These programmes are relatively expensive as opposed to other energy efficiency programmes that simply address individual measures such as lighting. For example, a review by Lawrence Berkeley National Laboratory of utility programmes covering the 2009–2013 period found that whole-home retrofit programmes cost an average of $0.094/kWh saved, more than twice as much as the average utility energy efficiency programme ($0.046/kWh). Commercial custom programmes (which includes whole-building programmes as well as individual custom measures) cost an average of $0.052/kWh. These are total costs; the utility typically pays about half and the building owner the rest (Hoffman et al. 2015). Another recent trend is growing interest in "pay for performance" programmes in which contractors are paid based on measured energy savings. A few pilot programmes are now underway.[3]

The US Department of Energy (DOE) also provides some funding in three ways: (1) full funding for the Weatherization Assistance Programme that serves low-income households; (2) grants to all 56 state energy offices (states and territories) that can be used for many activities, including building retrofits; and (3) competitive grants for innovative programmes, such as the Better Buildings Neighborhood programme which worked with more than 40 competitively selected state and local governments to develop sustainable programmes to upgrade the energy efficiency of homes and buildings.[4]

In addition, there are a variety of federal programmes that provide assistance including:

- Federal tax credits for some specific home weatherization measures such as insulation and new heating and cooling systems and windows. This tax credit covered 10% of the measure cost, up to a maximum of $500. It expired on Dec. 31, 2016, but there are discussions in Congress about renewing it;
- Federal tax credits for commercial building improvements, but due to the structure of the credits, the only retrofit measures it really covers involve full lighting system retrofits. This also expired on Dec. 31, 2016, but could be renewed;
- A variety of discounted loan programmes offered by such agencies as the Department of Housing and Urban Development, the Federal National Mortgage Association (generally known as *Fannie Mae*), and the Rural Utility Service;
- A simple Home Energy Score programme developed by the DOE that rates the efficiency of existing homes on a 1–10 scale. Some state, utility, and local government programmes use this tool;
- A deep energy retrofit programme run by the General Services Administration that seeks to reduce the energy use of federal buildings in half at the time they undergo substantial renovations. In the first round, they worked with energy service companies on 23 buildings; initial results from the first ten buildings show average savings of 38%, about double the savings of a normal GSA building remodeling project (Shonder 2014).

With the change in federal administration in early 2017, budget cuts to some of these programmes were proposed by the new administration. However, Congress decides on the budget, and as of this writing, it appears that Congress is contemplating only modest cuts to these programmes.

At the state level, energy efficiency loan programmes are now run by more than 30 out of the 50 states.[5] In addition, some electric and gas utilities offer on-bill finance programmes in which utility or third-party capital is lent to utility customers for energy efficiency retrofits, with the loan payments put on the utility bill. Generally, the energy savings will offset the loan

[3] See https://www.nrdc.org/experts/merrian-borgeson/can-paying-performance-increase-energy-savings .

[4] See https://www1.eere.energy.gov/analysis/pdfs/bbnp_volume_1_final_evaluation_072215.pdf .

[5] http://www.naseo.org/state-energy-financing-programs .

payments, so the homeowner sees no increase in their bill. Zimring et al. 2014 discuss many of these programmes.

Another innovative financing programme that is becoming more popular is Property-Assessed Clean Energy (PACE) finance. PACE involves putting the cost of an energy efficiency loan on the property tax for an individual building. The advantages of this approach are that the loan passes from one owner to another, and due to the high rate of payments for property taxes, interest rates may be lower. Such programmes are run by a number of states and municipalities. As of the end of 2017, more than $4.8 billion of financing had been provided, with a little over half of this for energy efficiency (renewable energy is much of the balance). About 89% of the financing provided has been in the residential sector, primarily in California.[6]

The USA also has a vibrant ESCo market, but most of their business is in the public or quasi-public sector—municipalities, universities, schools, hospitals, and state and federal facilities. Of ESCo business, less than 10% of revenues in 2014 was in private-sector buildings (Stuart et al. 2016).

As noted above, one of the keys for driving more demand for home and building retrofits is a building labelling and disclosure policy. In the USA, there is no national labelling programme like those in place in most European countries. Instead, annual energy use disclosure policies have been adopted for large commercial buildings (over about 5000 m^2 in floor area), and often large multifamily buildings, in 26 cities[7] and also two states (California and Washington). Every year, a few more cities adopt such a policy. Residential efforts are more limited as these only apply at the time of sale. A total of six states and eight cities had a residential disclosure policy as of 2013, requiring the disclosure of one of the following (varying by state): (1) utility bills; (2) an energy use benchmark score; (3) an asset rating such as an energy audit; or (4) a list of specific energy efficiency features (Cluett and Amann 2013). More recently, Berkeley, California, and Portland, Oregon, have required owners to obtain a Home Energy Score (a rating on a 10-point scale) when single-family homes are put on the market (Portland) or the sale is closed (Berkeley).[8]

There are also a few mandatory retrofit programmes in the USA that typically require energy upgrades before a home or building can be sold or rented. At present such programmes are in place in Austin, Texas; Berkeley and San Francisco, California; Boulder, Colorado; Burlington, Vermont; and Memphis, Tennessee. These programmes require modest retrofits to homes and/or rental properties (Neme et al. 2011).[9] New York City is requiring that lighting systems in large commercial buildings be upgraded and that these buildings undergo a commissioning process for existing buildings (often called *retrocommissioning*), both by 2025.[10] And Los Angeles is requiring that most buildings of about 2000 m^2 or more have an energy audit and undergo retrocommissioning by 2019–2023 and every 5 years thereafter (date varies as a function of tax identification number in order to spread the work out).[11]

Successes and challenges

In the residential sector, York et al. (2015) document nine whole-home retrofit programmes that have served more than 1% of eligible customers annually including two programmes (Austin, Texas and Mid-American Energy in Iowa) that have served more than 25% of eligible customers since they began in the 1980s and 1990s. Even higher participation rates have been achieved in multiyear campaigns targeting specific communities. The first such programme was the Hood River Conservation Project which intensively marketed retrofits in the town of Hood River, Oregon during the 1980s. Hood River is a town with about 3500 eligible homes about an hour from Portland. The programme paid most of the cost of retrofits, contributing up to the avoided cost of a new coal power plant. The retrofits on average reduced electricity use by 9%, generally at no cost to the homeowner. Ultimately 91% of eligible customers received energy audits and 85% of eligible homes were retrofit (Results Center 1992a).[12] These results show

[6] http://pacenation.us/pace-market-data/ (visited Jan. 21, 2018).

[7] See http://www.imt.org/resources/detail/map-u.s.-building-benchmarking-policies (visited Sept. 27, 2017).

[8] https://www.cityofberkeley.info/BESO/ and https://www.portlandoregon.gov/bps/71421.

[9] Also see https://bouldercolorado.gov/plan-develop/smartregs.

[10] See http://www1.nyc.gov/assets/buildings/local_laws/ll88of2009.pdf .

[11] See https://www.ladbs.org/docs/default-source/publications/ordinances/ord_184674_12-15-16.pdf?sfvrsn=4 .

[12] Somewhat similar results were achieved in 1990 in the Town of Espanola in Ontario, Canada (Results Center 1992b).

what can be achieved with concentrated effort and high budgets. However, such high participation rates are rare and most programmes are reaching only a fraction of 1% of eligible customers each year (e.g. after 12 years of operation, Home Performance with Energy Star has only served 0.6% of the single-family homes in the USA).[13] Furthermore, as shown by the Hood River example, many programmes are not achieving 20% energy savings per home, let alone the 30–50% savings needed to achieve long-term energy and climate goals (more on this later).

In the commercial sector, whole building programmes are rarer but the Energy Star buildings programme has benchmarked nearly half of commercial building floor area, leading to significant energy savings. In addition, Kwatra and Essig (2014) looked at 25 whole building programmes offered by utilities and state agencies, finding a total of more than 10,000 retrofits. Energy savings are provided in absolute and not percentage terms, but from the data, we estimate that savings range from about 5–25% in each building served, again, less than is needed.

Reasons for the low participation and modest savings are many-fold (Ungar et al. 2012) and include:

- Lack of awareness by building owners of what they can do and how much they can save;
- Complexity of retrofits, which make it difficult for a home or building owner to undertake a retrofit or trust those who purport to help them;
- Retrofit costs, which many homes and businesses cannot afford, and make retrofits more expensive than many other efficiency measures, reducing interest in running retrofit programmes;
- Shortage of affordable financing; and
- Split incentives—the party making energy efficiency decisions (landlords and builders) are often not the same people who pay the energy bills (home owners and building tenants).

Future directions and savings

Nadel (2016) examined whether it is possible for the USA to use energy efficiency to reduce its energy use and greenhouse gas emissions by 50% by 2050, achieving a large share of the 80% greenhouse gas reduction that the USA (and many other countries) are targeting. He concluded that this target is achievable by aggressively pursuing 13 energy efficiency measures, one of which is home and building retrofits. He specifically examined savings achieved by 2040 for each strategy (the official US forecast used only extended to 2040) and found that building retrofits alone could reduce total US energy use by about 11%. Achieving these savings would require retrofits to 50% of existing homes and 75% of existing commercial buildings, with average savings per building of 30%. He also found that significant additional energy can be saved in existing buildings through minimum efficiency standards on replacement equipment, application of intelligent efficiency strategies to homes and buildings (use of sensors and big data to identify and address energy waste) and through improved building occupant behaviour. When these additional measures are added, savings in existing buildings could more than double. However, with current efforts, at best a third of these savings will be realized, with the majority of savings happening in the commercial sector.

Thus, to achieve these aggressive savings, the USA needs to substantially ramp up its retrofit efforts, following all the steps recommended at the beginning of the "USA" section of this paper. A big question is who will lead these efforts. The most likely candidates in the USA are electric and natural gas utilities (with the electric and gas utilities serving a region working together), with support from federal, state, and local governments. Utilities are the biggest supporter of efficiency programmes in the USA and their budgets are growing while government budgets tend to be tight (Berg et al. 2016). But where utilities do not want to lead, states and localities will need to lead. States and localities will need to find a source of funding for homes and buildings that use fuel oil and propane for heat[14] (electric and natural gas utilities will generally not fund heating savings in these homes), and should either lead or assist in developing financing programmes. And likely higher incentives will be needed to achieve higher participation rates, as concluded by a recent review of the Vermont Home Performance with Energy Star programme (Gamble

[13] Author's calculation based on 450,000 participants and 78.5 million attached and detached single-family homes in the USA in 2009 (from https://www.eia.gov/consumption/residential/data/2009/#structural).

[14] For example, the state of Vermont uses a portion of revenue from sales of allowances in a regional greenhouse gas cap and trade programme to fund retrofits to these homes.

2014). At same point, states and utilities may need to consider requiring retrofits before sale or rental, as France and a few American cities are now doing. Given the current and foreseeable national political situation, the federal government is unlikely to lead such a programme, but instead will play a supporting role. One area worth focusing on more is research to better document the non-energy benefits of home and building retrofits—these benefits, such as improved comfort, rents and worker productivity, can play an important role in encouraging home and building owners to undertake retrofits.

Discussion and conclusion

France and Germany both have established formal goals to renovate 2% of buildings each year as part of efforts to reduce energy use in 2050 by 50% relative to 2012 (for France) and 2005 (for Germany) levels. France and Germany have extensive nationwide programmes and policies promoting public sector and residential retrofits, with more limited efforts in the private commercial sector. In France, 1.75% of residences were retrofitted in 2013. In Germany, in the past decade, nearly 6% of residences have participated in a large retrofit loan programme, an average of nearly 0.6% per year. Additional renovations have been done outside this programme. In both countries, there is more emphasis on residences and less on the commercial sector. In the USA, most of the building retrofit programmes are run by states, utilities, and municipalities, often using tools developed by federal government. Several local programmes are achieving comprehensive renovations on more than 1% of homes each year, but nationwide, annual renovation rates are much lower. Nearly half of US commercial buildings have been benchmarked and about 1/8 of these certified as Energy Star (in comparison, in France, nearly 15% of non-residential building are certified and registered in the EPC database—ADEME, Observatoire DPE). The USA has more emphasis on the commercial sector than the other two countries, likely in part because the commercial sector is a higher portion of US building energy use (44%) than in the other two countries (around average 33% (IEA 2017 and ODYSSEE 2017). In all three countries, single-measure retrofits are most common; comprehensive retrofits are more limited. All three countries want to substantially ramp up renovation activity. The emphasis in Germany and the USA is on technical support and financing. France also has technical support and financing, but in France, retrofits are mandated by 2020 and 2025 for the lowest efficiency buildings, although many details still need to be worked out. Major strategies in each of the countries are summarized in Table 1.

Each of these countries, as well as other countries, can learn from each other. Germany probably has the most comprehensive national technical support and financing programme. France is a leader in mandating renovations. Both France and Germany are developing programmes and policies to encourage phased retrofits. In the USA, there have been some very successful local programmes and the Energy Star programme has reached a large portion of the commercial sector. The USA is also a leader in utility funding of energy efficiency, including building retrofits.

In order to reach long-term climate and other national goals, substantial energy use reductions in existing buildings will be needed. More than half of existing homes and commercial buildings will need comprehensive renovations combining many different energy efficiency measures. Building renovation programmes and policies in France, Germany, and the USA have made substantial strides, but much more work is needed, both to increase the number of participants (no one is yet serving 2% of homes and buildings each year) and to move from single-measure to comprehensive retrofits. In order to increase the renovation rate substantially, further target groups have to be considered, which are not in the main focus of the current policy mix in all three countries. The landlord-tenant dilemma still remains unsolved. For Germany, finding suitable policies to solve this problem is even more important than for France and the USA, since the German building stock is characterized by a high rental rate of 55%, which is unique in Europe. Bürger (2012) suggest different approaches to tackle the investor-user dilemma, including one that France is starting to implement—mandatory retrofits of inefficient buildings. Another option being explored in Germany is legislation that would allow for rent reduction claims if property owners do not conduct retrofits that are required by building code regulation. Tigchelaar et al. (2011) suggest cost allocation rules (e.g. higher share of the investment to the rent) between tenant and property owner whenever better energy performance is achieved after the retrofit (e.g. achieved energy class).

Table 1 Summary of building renovation strategy elements in the three countries

Strategy element	France	Germany	USA
Retrofit advice to consumers Marketing to drive both demand and the supply chain	Provided by the national one stop shop PRIS programme	Provided by the consumer agencies and certified energy consultants supported by federal state and local government	Provided by some states, utilities and municipalities; national efforts particularly work with these more local programmes
Technical training and certification of retrofit contractors	National supports dedicated to train building professionals	Industry associations	Same as above; a few voluntary certification programmes
Programmes for individual measures	Many via government	Federal government via KfW and other agencies, RES-H use obligation in new buildings	Many states and utilities offer
Programmes for comprehensive retrofits	PRIS helps homeowners retrofit their homes	Federal government via KfW (KFW efficiency houses)	Many states and utilities offer; residential efforts use Home Performance with Energy Star
Rebates and/or up-front cost discounts	Many grants or support programmes offered by the French government.	Many grants or support programmes by national or state governments, mostly managed by KfW bank	Commonly provided by utilities
Special financing			Many states and some municipalities and utilities offer
Quality assurance	Included in some programmes	Included in some programmes	Included in some programmes
Investment in research and development	Governmental grants for R&D (including retrofitting)	Federal government programmes	DOE has large programme; some states and utilities also invest
Building-efficiency labelling and energy use disclosure	Label and grants for high energy performance (or nZEB) retrofit (BBC renovation-targeted maximal consumption of 80 kWh/m^2). EPCs also apply in France including for property advertising.	Energy Performance Certificates for new buildings, sale or rent. Property adverts are required to include EPC.	Energy Star and LEED common for commercial sector; residential efforts more limited; growing number of cities requiring annual disclosure of commercial building energy use
Retrofit mandates	As of 2025, must be "E" or better in order to sell or lease a home		Comprehensive retrofit requirements in just a few municipalities.

In all three countries, high upfront investments are required in order to achieve a high amount of energy savings in the building sector (Ecofys and Fraunhofer ISI 2011, BPIE 2012, Eichhammer et al. 2012). Since public budgets are limited, more use of private capital is necessary. Here, the USA with their utility programmes is more advanced than France (where utilities are obliged to meet energy saving targets in the frame of the white certificate scheme) and especially Germany, where almost all of the financial policies for building renovation are financed from state budgets. Considering the existing regulations and overall budget of financial schemes, the policy framework and government funding for building energy efficiency investments is quite strong in France and Germany, but weaker at the national level in the USA. However, with regard to the involvement of utilities, France and Germany are lagging—investments in clean technology by utilities are mainly renewable electricity and CHP installations. And even in the USA, utility funding is modest in about half of the states. Business models to sell energy services and energy-efficient retrofits are weak for the private sector in the three countries. The development of energy efficient retrofits as standardized product could attract additional capital from institutional investors such as financing long-term energy service contracts offered by utilities or housing agencies. In order to incentivize these stakeholders to develop suitable products and business models, an energy saving obligation scheme could be a sound instrument complementing the current policy mix in Germany. Expanded obligation schemes could also be useful in the other countries.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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