Què funciona contra el canvi climàtic?

Report

What works to improve the energy efficiency of buildings?

Policies and programmes for encouraging the adoption and use of efficient technologies

ivàlua
Institut Català d'Avaluació de Polítiques Públiques

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COAMB
Col·legi d'Ambientòlegs de Catalunya

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Summary prepared by:
Jacint Enrich – Energy Research Group, Barcelona School of Economics (BSE)

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Steering group: Maria José del Blanco and Xavier Soto (Department of Economics and Finance); Leonardo Bejarano and Gabriel Borràs (Department of Territory, Housing and Ecological Transition); Salvador Samitier (Department of Agriculture, Livestock, Fisheries and Food); Maria Siuraneta (Col·legi d'Ambientòlegs de Catalunya); and Anna Segura and Cristina Ferrer (*Ivàlua*).

Expert group: Olga Alcaraz (Polytechnical University of Catalonia), Jeroen van den Bergh (Institute of Environmental Science and Technology - ICTA-UAB), Maria Crehuet (Associació de Micropobles de Catalunya), Irene González (Aliança contra la pobresa energètica), Albert Puigvert (Associació d'Iniciatives Rurals de Catalunya), Ana Romero (Àrea Metropolitana de Barcelona), Jordi Teixidó (University of Barcelona) and David Villar (Catalan Institute of Energy).

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Evidence synthesis and knowledge transfer project to improve climate change mitigation and adaptation policies.

A project by:

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1. Introduction

In 2015, at the United Nations Climate Change Conference in Paris (COP21), nearly 200 countries reaffirmed their commitment to limiting the increase in the global average temperature to 2 ℃ above pre-industrial levels by 2100, and to pursue efforts to limit this increase to 1.5 ℃. To achieve this, they called for action to reduce greenhouse gas (GHG) emissions in the coming years, with the aim of bringing global carbon dioxide (CO_2) emissions down by 45% compared to 2010 levels before 2030, and reaching net zero CO_2 emissions and achieving profound reductions in other GHGs before 2050.[1]

Energy consumption is by far the largest source of GHG emissions, and is responsible for approximately 75% of all emissions worldwide. Eleven per cent of this figure corresponds to the residential sector.[2] As far as Catalonia is concerned, energy consumption represents 71.6% of total GHG emissions, and energy consumption in the residential sector accounts for 13.8% (Catalan Energy Institute, 2022). In the residential sector, emissions are caused mainly by the consumption of electricity and heating. Therefore, increasing the energy efficiency of residential buildings and thus reducing household energy use is a prerequisite for moving towards a carbon-free economy.

With these aims in mind, both the European Union and Catalonia have established improving the energy efficiency of buildings as a priority issue in the fight against climate change. Examples of this commitment are the various programmes aimed at improving the energy efficiency of the housing stock financed by the Next Generation EU Fund and implemented in Catalonia, such as the PREE 5000 programme of subsidies for the energy rehabilitation of buildings in municipalities with fewer than 5,000 inhabitants,[3] or subsidies for rehabilitation projects at neighbourhood level[4], among others.

The present document aims to contribute to the design of effective policies and programmes by synthesizing the most recent empirical evidence on the effectiveness of various instruments designed to increase energy efficiency in the residential sector.

Specifically, the document compiles evidence from studies that use experimental or quasi-experimental methods, in order to evaluate the impact of interventions aimed at promoting the adoption of energy-efficient household appliances and for improving the building envelope and heating, ventilation and air conditioning systems in residential buildings. These interventions include information programmes aimed at improving individual decision-making regarding

[1] https://unfccc.int/sites/default/files/resource/cma2021_10_add1_adv.pdf
[2] Source: Climate Watch: https://www.climatewatchdata.org
[3] https://www.accio.gencat.cat/ca/serveis/cercador-ajuts-empresa/ajutsiserveis/21561-next-generation-eu-icaen-pree-5000-rehabilitacio-energetica
[4] https://habitatge.gencat.cat/ca/ajuts/ajuts-rehabilitacio/ajuts-europeus-millora-eficiencia-energetca-habitatges/index

investments, programmes to reduce or eliminate the cost of adopting efficient technologies or renovating homes (i.e., through subsidies) and programmes that make achieving certain levels of efficiency mandatory, such as building codes for new constructions.

The reviewed evidence includes interventions from countries that are, to a large extent, comparable to Catalonia. However, the idiosyncrasies of each particular context should be borne in mind when extrapolating the results. For example, factors such as climate and energy prices vary from country to country and at different times of year, and may thus affect potential savings in energy efficiency.

2. Motivation

The latest report from the International Energy Agency warns that, as a necessary condition for achieving the climate objective of limiting the global temperature increase to 1.5 ℃ by the year 2100, the annual rate of improvement in energy efficiency needs to be doubled, from the current figure of 2% to 4% by the year 2030 (International Energy Agency, 2023). The European Union has recently approved a directive on the energy efficiency of buildings with the aim of reducing energy consumption by 16% by the year 2030, and by between 20 and 22% by the year 2035.[5]

Improving energy efficiency requires consumers to use fewer energy inputs in order to achieve the same level of services (e.g., lighting, heating, cooling, washing clothes or dishes, etc.), mainly through the adoption of more efficient technologies. The appeal of investing in energy efficiency is clear: the investments needed can be self-financed by reducing consumption (and thus lowering energy bills) while maintaining a specific level of well-being. At the same time, lower consumption reduces the dependence on fossil fuels, which in turn brings about the desired GHG reductions.

The influential study by McKinsey & Co. (2009) estimated that the United States could save up to $1.2 trillion by making investments costing $520 billion, thus obtaining savings of approximately $2 for every dollar invested. Among the most cost-effective technologies were the installation of LED lights, the replacement of household appliances, and the rehabilitation of homes. Therefore, improving the efficiency of household appliances and homes can be one of the least expensive (and possibly even profitable) ways to reduce carbon dioxide emissions. However, the same study highlighted consumers' reluctance to adopt these technologies.

Given these missed opportunities for investments in which the future savings would exceed costs (what is known as the "energy efficiency gap"), a substantial body of literature has attempted to identify the mechanisms or market failures that have caused this reticence on the part of consumers (Gillingham and Palmer 2014, Gerarden et al. 2017, Gillingham et al. 2018).

[5] https://www.europarl.europa.eu/news/es/press-room/20240308IPR19003/eficiencia-energetica-de-los-edificios-nueva-ley-para-descarbonizar-el-sector

First, the literature has examined whether this reticence is due to the lack of information regarding future savings, or whether it is because this information is poorly distributed among the different market agents (e.g., between the owner of a rental property and the tenant). A second barrier to entry that restricts the adoption of energy-efficient technologies is the high cost of the initial investments, especially among the sectors of the population that have limited access to credit.

However, a growing body of literature is questioning whether this energy efficiency gap actually exists (Allcott and Greenstone 2012). First, as we will see later in the evidence review, many studies find that the savings obtained are significantly lower than the initial technical estimates suggested, since the conditions under which energy consumption is simulated (e.g., meticulous installation and maintenance) differ significantly from the real-world situation. In addition to the difference between technical estimates and actual savings, changes in household behaviour after installation can also reduce the effectiveness of energy-efficient technologies. For example, if an investment reduces the cost of energy and consumers increase their consumption, it will appear to be less effective than initially projected, a phenomenon known as the rebound effect (Gillingham et al. 2016).

Nonetheless, even if there is no gap between private costs and benefits, public intervention to improve household energy efficiency would still be justified by the negative externalities of consuming a source of pollution such as energy. Likewise, even if household energy consumption increases after the investment is made due to the rebound effect, policies aimed at encouraging the adoption of energy-efficient technologies can be a good adaptation tool if it is the most disadvantaged households that are responsible for the extra consumption, because this reflects an increase in their well-being and also addresses to some extent the problem of energy poverty.

3. Questions that guide the evidence review

This literature review is motivated by the desire to understand the effect that different policies and programmes have had on the rates of adoption of efficient technologies in residential buildings, on household energy consumption, and on other indicators of well-being. The review sets out to answer the following questions:

1. What are the main public policy instruments that have been used to promote energy efficiency in the residential sector?

2. Which instruments have been found to be most effective, and what are the key features of their design that contribute to their effectiveness?

3. Do the effects depend on the type of household or other relevant factors?

4. Do some interventions have counterproductive or undesired effects?

5. Are there examples of good practices that can be taken as models for improving the design of energy efficiency policies in our country?

4. Policies included in the review

This evidence synthesis will focus on policies and programmes aimed at reducing household energy consumption by improving the energy efficiency of buildings, such as:

- The adoption of more energy-efficient household appliances.
- The rehabilitation of the existing housing stock to improve their heating, ventilation and cooling systems.
- The construction of more energy-efficient buildings.

Thus, the review does not include policies and programmes that aim to reduce household energy consumption through changes in consumption habits, i.e., either by reducing it or by distributing it more efficiently over the course of the day. Programmes of this kind will be the subject of the second evidence review entitled "What works to improve energy consumption habits of households? Policies and programmes for reducing and shifting demand".

The first set of policies under review are **information and educational programmes**. In essence, they consist of informing households about the savings that can be made by enhancing energy efficiency, given that the lack of information is one of the main barriers that prevent households from making the investments required.

The second block of programmes revolves around offering economic **incentives** to increase investment in energy efficiency, either by encouraging the purchase of efficient appliances or by promoting improvements to home heating, ventilation and cooling systems. While these incentives may include subsidies, favourable loans, or tax incentives, based on the available evidence this synthesis includes only **direct subsidies**. Theoretically, subsidies should be reserved for cases where investments are not profitable at an individual scale but are socially desirable, or for situations where households would benefit from increasing their energy efficiency but lack the financial capacity to cover the upfront costs.

Finally, the third type of programme involves the establishment of mandatory environmental **standards**. This type of instrument is also suitable in cases where there is no individual incentive to invest in energy efficiency, or when information on profitability is costly or difficult to provide. In addition, these measures come into play at the time that the appliances in question are being manufactured, or when the buildings are being constructed, but their effects extend throughout its entire useful life. Thus, the synthesis includes evidence on the effectiveness of **building codes**, which aim to improve climate control systems in new constructions and, more recently, to incorporate renewable energy generation systems such as photovoltaic and aerothermal technologies.

Given the scarcity of rigorous impact evaluations on the effectiveness of these energy efficiency policies in Catalonia and Spain (only one was identified), the review includes evaluations and syntheses conducted in other contexts, primarily in the United States and, to a lesser extent, in Europe.

In total, six reviews and 25 primary studies were included, of which eleven evaluate programmes that incentivize the adoption of energy-efficient appliances (seven based on the provision of information and four based on subsidies; one of the studies combines the two approaches). As for the energy efficiency of buildings, six studies analyse the effectiveness of establishing building codes in new constructions, while eight studies address the problem of home renovation.

5. Measures of effectiveness

In our assessment of the effectiveness of the policies and programmes reviewed, first, we will examine the extent to which they encourage the **adoption of energy-efficient technologies**, either by promoting the choice of more efficient household appliances or by encouraging investments to improve the efficiency of the home.

Second, when possible, we will explore how these investments affect **household energy consumption**. This is our real variable of interest, since the ultimate goal is the reduction of GHG emissions.

It may be that certain households decide to take advantage of gains in energy efficiency to increase their energy supply, while consuming the same level of energy as before, instead of obtaining the same supply using a lower energy inputs. So, whenever possible, we will also include variables related to **household well-being**, for example, ambient temperature, or the price or floor space of homes.

6. Literature review

6.1. Programmes for promoting the use of energy-efficient household appliances

The provision of information on the costs and benefits of investing in more efficient appliances, together with the granting of **direct subsidies** for their purchase, are the two main public policy instruments for encourageing households to buy more energy-efficient appliances and thus reduce their energy consumption. Below, we present evidence regarding their effectiveness.

Are information programmes effective in promoting the adoption of efficient household appliances?

There is a first group of programmes that promote the purchase of more energy-efficient appliances by providing information on their benefits at the time of purchase, either through **labelling** or by expanding the **information provided by the salesperson**. When we talk about benefits or savings, we refer to reductions in the useful lifetime cost of the appliances.

> The **lifetime cost** is the purchase cost plus the operating cost of the appliance, i.e., the cost of the energy consumed during the appliance's useful life.

Seven of the studies reviewed analyse the effect of labelling and the provision of information at the time of purchase on decisions to adopt more energy-efficient appliances (Table 1).[6]

Table 1. Evidence of the effectiveness of the provision of information

Study	Country	Intervention	Variable	Result
Blasch et al. (2019)	Switzerland	Information in kWh or in monetary terms.	Identification of the light bulb or refrigerator with the lowest lifetime cost.	Information on savings in monetary terms increases the likelihood of selecting the most efficient appliance.
Newell & Siikamäki (2013)	US	Information in kWh, in monetary terms, in CO2 emissions or in efficiency category with the EnergyStar logo.	Selection of efficient boilers.	• Information on savings in monetary terms and the EnergyStar logo as the most relevant elements. • Information in kWh or CO_2 emissions increases adoption whenever it is accompanied by the previous elements.
Allcott & Taubinsky (2015)	US	Information on the useful life cost.	Choice of fluorescent lights.	+12% in the market share of fluorescent lights.
			Willingness to pay for fluorescent lights.	Higher than the market price of this type of bulb.

[6] In all the studies analysed, in accordance with previous estimates we assume that the efficient alternative is also the most economical in terms of lifetime cost.

Davis & Metcalf (2016)	US	Information in monetary terms based on state prices versus national prices.	Selection of air conditioners with a lower lifetime cost.	Selection of appliances with a lifetime cost of $10 lower.
Kallbekken et al. (2013)	Norway	Information on the useful life cost + personnel training.	Selection of efficient refrigerators.	No statistically significant effects.
			Selection of efficient dryers.	• Information: no significant effects. • Staff training: selection of dryers 3.4% more efficient. • Combination of the two treatments: selection of dryers 12% more efficient (falling to 4.9% after one year).
Blasch et al. (2017)	Switzerland	Presentation on how to calculate useful life cost.	Selection of refrigerators with a lower lifetime cost.	Significantly increases the likelihood of choosing a refrigerator with a lower lifetime cost.
		Online calculator to calculate the cost.		The online calculator is two to four times more effective than the presentation.
Allcott & Sweeney (2017)	US	Information on life cycle cost + sales incentives.	Probability of adopting efficient boilers.	No statistically significant effects.

Regarding the text that appears on labels, several studies have sought to identify the messages are most effective in influencing consumer behaviour. In general, providing information about the economic savings that accrue from investing in an appliance with a lower lifetime cost tends to be the most effective way to encourage its purchase. Blasch et al. (2019) find that providing information about monetary savings expressed in euros is more effective than providing information about energy savings expressed in kWh. Along the same lines, in an analysis of boilers in the US, Newell and Siikamäki (2013) find statistically significant effects when the information is provided in the form of a logo that certifies the product's efficiency.

Information about energy savings expressed in kWh or possible CO_2 reductions also increases sales, provided that it is accompanied by the information mentioned above. In the case of lighting, Allcott and Taubinsky (2015) point out that providing information on the lower lifetime cost associated with the use of compact fluorescent bulbs (more efficient than traditional incandescent ones, but far less efficient than LED) increases their adoption by 12%. Those authors also calculate that the provision of information increases consumers' willingness to pay for more efficient bulbs by between $3 and $5, thus exceeding the market price of this type of bulb (valued at $4 per pack), but far below the savings over its useful life ($40).

However, two studies did not find statistically significant effects of the provision of information on the lifetime cost when it is not combined with other interventions. In the first, Kallbekken et al. (2013) found that labelling alone does not significantly increase sales of more energy-efficient refrigerators and dryers, but the efficiency of the purchased goods after three months improves by around 12% when the sales are made by staff who have undergone a training programme; unfortunately, this effect wears off over time, falling to 4.9% after one year. In the second study, Allcott and Sweeney (2017) found that information does not encourage the purchase of efficient boilers even when complemented by a monetary incentive for sales staff.

Given that providing information on monetary savings is more effective than demonstrating energy efficiency, it is likely that the mechanism behind these inefficiencies stems from consumers' limited ability to calculate and compare benefits with costs – whether due to a lack of rational attention or simply the fact that people make unintentional mistakes. If this is so, educational tools can be a good complement to labelling policies. Blasch et al. (2017) showed that a four-slide presentation on how to calculate life cycle cost significantly increases the likelihood of choosing a refrigerator with a lower life cycle cost. Furthermore, simply providing an online calculator for consumers to calculate life cycle cost is between two and four times more effective than a presentation.

The main practical problem involved in providing information on potential savings in monetary terms is that any attempt to do so must be able to accurately estimate the energy price in the long term. In an online experiment in the US, Davis and Metcalf (2016) analysed how more accurate information can induce the adoption of more efficient goods. In the US, the price of electricity can double from one state to another, so messages based on aggregate prices cannot be considered useful information. The authors find that providing specific information on monetary savings for each state (which in turn determines which appliance has the lowest lifetime cost) leads households to select appliances most in line with the energy price in their location. As a result, states with higher energy prices adopt more efficient technologies, and vice versa. Therefore, although the average efficiency of the appliances purchased does not change (some states adopt less efficient technologies than in the pre-intervention period because energy prices are low), the aggregate welfare increases. This result suggests that a pricing mechanism that reflects the true cost of energy, such as a carbon tax that takes environmental externalities into account, can be an effective measure to incentivize households to make the necessary investments.

Do subsidies represent an effective way of promoting the adoption of efficient household appliances? Are they able to reduce household energy consumption?

The second instrument to encourage the adoption of energy-efficient appliances is **subsidies**. Subsidies are a valid option in situations where the acquisition of efficient appliances is not individually profitable but is socially desirable, as well as in cases where the provision of information is not possible or is expensive.

Table 2. Evidence on the effectiveness of subsidies

Study	Country	Intervention	Variable	Result
Allcott & Sweeney (2017)	US	Subsidies of 20-50% of the price difference with a standard model.	Likelihood of adopting efficient boilers.	+1% / +4%
		Subsidies + sales incentives.		+4% / +22%
Houde & Aldy (2017)	US	Subsidies of varying amounts depending on the state.	Sales of efficient refrigerators, washing machines and dishwashers.	+7% / +15% (only 10% are additional sales).
La Nauze & Myers (2023)	Australia	Subsidies for purchases.	Optimal subsidy to encourage the purchase of LED lights valued at $20 (instead of traditional ones).	$12
		Subsidies for information searches.		$9
Davis et al. (2014)	Mexico	Subsidies of between 10 and 40% for replacing refrigerators.	Electricity consumption.	-8%
		Subsidies of between 10 and 40% for replacing air conditioning systems.		+2%

Generally, studies conclude that subsidies tend to promote the purchase of efficient appliances (Table 2). Allcott and Sweeney (2017) found that subsidies increase the probability of choosing energy-efficient boilers by 1 to 4%, and that this rate increases significantly (by between 4% and 22%) if the subsidies are combined with financial incentives for sales staff to inform customers about the benefits of choosing more efficient appliances. For their part, Houde and Aldy (2017) evaluated the effects of a policy implemented in the US that subsidizes the purchase of appliances with a certain level of efficiency. The authors found that this programme increased sales of efficient appliances by between 7% and 15%.

However, the main problem with the use of subsidies to promote the adoption of efficient technologies is that, to be effective, they must induce the potential beneficiaries to make investments that they would not otherwise have made; this phenomenon is known as additionality (Gillingham et al., 2009). Unfortunately, the empirical evidence for this type of measure is not encouraging; the study by Houde and Aldy (2017) mentioned above concluded that 70% of these new sales would have occurred without the subsidy, and that an additional

20% correspond to consumers who postponed their purchase only in order to benefit from the subsidy. This means that the subsidy is responsible for only 10% of the additional sales.

The issue of additionality is exacerbated by the fact that subsidies do not reach those who need them most. Assessing the characteristics of recipients of subsidies from different energy efficiency programmes in the US, Allcott et al. (2015) reported that most of those who benefit are wealthier or more environmentally conscious than the average population – not poorer households, or individuals with rental contracts. A possible reason for this is the lack of information in these households about the existence of the subsidies themselves. The authors argue that limiting subsidies to specific sectors of the population is vital if these incentives are to address the externalities for which they are designed.

In relation to this problem, and since the provision of information can be an effective way to promote the purchase of efficient appliances, La Nauze and Myers (2023) suggest that subsidies aimed at encouraging consumers to compare the prices and potential savings of different appliances may be more effective than direct subsidies for their purchase. In particular, they find that the optimal product subsidy in the case of LED light bulbs is $12 for a package valued at $20, while the optimal information subsidy is $9 per package.

Good practices

The government of Victoria, Australia, offers discounts on energy bills if consumers compare the cost of different electricity tariffs on its regulator's website: https://compare.energy.vic.gov.au/

The programmes studied so far have incentivized the adoption of more efficient goods, which, conditional on their effectiveness, improve the energy efficiency of households. However, since the ultimate goal is the reduction of emissions, the variable that interests us is the final consumption of households once these technologies have been adopted. Since efficient goods reduce the price of consuming energy, it is possible that consumers who buy these appliances decide to increase their consumption. One of the first influential studies in this area was by Davis et al. (2014), who evaluated the impact of a large-scale appliance replacement programme implemented between 2009 and 2012 in Mexico, in which two million users benefited from subsidies for replacing refrigerators and (to a lesser extent) air conditioning units. The authors conclude that replacing refrigerators reduces electricity consumption by 8%, but that replacing air conditioning systems increases consumption. This latter result is explained by the fact that the replacement units were larger, and the subsequent rebound effect offset any efficiency gains. Nevertheless, replacing air conditioners may have improved household well-being, as the programme was targeted in areas with high temperatures.

6.2. Programmes for improving energy efficiency in buildings

Regulating the construction of new buildings to make them more energy-efficient, **providing information** on the energy efficiency of homes and **subsidizing** purchases to improve efficiency are the three main instruments currently in place. The measures outlined below go beyond the adoption of efficient appliances, and include improvements to the building envelope (facades, windows, etc.) and heating, ventilation and cooling systems.

Are building codes effective in reducing energy consumption in new constructions?

A key instrument for improving the energy efficiency of buildings consists of imposing minimum requirements on new constructions, through **building codes or energy efficiency standards**. These measures aim to promote the installation of more efficient heating and cooling systems or improve the insulation of buildings by adapting facades, windows, and doors.

Six of the studies reviewed analyse the effect on electricity consumption of introducing standards for new constructions. Four of them also measure the impact on gas consumption (Table 3).

Table 3. Evidence on the effectiveness of building codes

Study	Country	Intervention	Variable	Result
Aroonruengsawat et al. (2012)	US	Building codes.	Electricity consumption.	-0.3% / -5% per capita.
Jacobsen & Kotchen (2013)	US (Florida)	Building codes.	Electricity consumption.	-4%
			Gas consumption.	-6%
Kotchen (2017) – Review of the previous study (long-term effects)	US (Florida)	Building codes.	Electricity consumption.	The effects disappear in the long term.
			Gas consumption.	The effects endure over the long term.
Levinson (2016)	US (California)	Building codes.	Electricity consumption.	No statistically significant effects.
			Gas consumption.	No statistically significant effects.
Bruegge et al. (2019)	US (California)	Building codes.	Electricity consumption.	-1%
			Gas consumption.	-0.6%
			Floor space of the house.	-5% of the lowest quintiles.

			Price of the house.	-10% of the lowest quintiles +2% of the high quintiles.
Novan et al. (2022)	US (California)	Building codes.	Electricity consumption of air conditioning systems.	-8% / -13%

The results of these studies suggest that this type of instrument can help to reduce energy consumption in buildings, especially gas consumption. Aroonruengsawat et al. (2012) compared the introduction of codes in several US states at different times and find that electricity consumption fell by between 0.3% and 5% per capita, depending on the state. Jacobsen and Kotchen (2013) compared buildings built just before and after the introduction of stricter requirements in Florida in 2002, and estimated annual savings of 4% in electricity consumption and 6% in natural gas consumption. Finally, Novan et al. (2022) found that electricity consumption for air conditioners fell by between 8% and 13% in homes located in areas with stricter codes. The authors take these figures to reflect the upper limit of the reduction, because they correspond to the time of day when consumption is highest (afternoon/early evening), and the appliance that consumes the most. However, other studies have not found these effects (see Levinson 2016; Kotchen, 2017), and question the effectiveness of codes in reducing electricity consumption.

The main problem with these studies is the difficulty of comparing the effects of the codes, given the variations in the requirements imposed in different geographical areas and at different times. The most reliable evidence today comes from Bruegge et al. (2019), who studied the change in regulations in the building codes in California in 1982.[7] The study focuses on single-family homes, and the authors took care to standardize all requirements for insulation, roofing, and windows across different climate zones with different demands. The study is the first to assess the distributional effects, exploring how these codes may affect residents in different ways depending on their income. At the aggregate level, the authors find that electricity consumption falls by 1% per household, while gas consumption falls by 0.6%.

The same authors also suggest that building codes lead builders to reduce the floor area of homes in the lowest income quintiles by between 4% and 6%. What is more, the increase in construction requirements reduces the price of housing by between 8% and 12% for the two lowest income quintiles: half of this effect is due to the reduction in surface area, and the other half to changes in the attributes of the homes (for example, the number of rooms) compared to similar homes where no requirements are imposed. In contrast, homes in the highest income quintiles that comply with building codes increase in value compared to similar homes that do

[7] These codes required builders to demonstrate that the building would use less energy than a set maximum, a situation that introduced a considerable amount of flexibility. Builders could adopt minimum requirements for roof and wall insulation, the energy efficiency of windows and glazing, and the wall-to-window ratio.

not. Overall, it is possible that lower-income households are more negatively affected by the distortions caused by these standards, as they end up with smaller homes, lower value per square metre, and without a corresponding reduction in energy consumption per square metre. Regarding the relationship between investment costs and savings, the comparison between present costs and future benefits is more complicated in the case of buildings than in the case of household appliances, given their longer useful life. Assumptions about future energy prices, annual discount factors and possible environmental benefits mean that forecasts range from a total recovery of the investment after six years (Jacobsen and Kotchen, 2013) to a partial recovery of only 50% after 40 years (Novan et al., 2022).

Are energy audits effective in improving the energy efficiency of existing buildings?

A second group of programmes aim to promote reforms in the building envelope and in heating, ventilation and cooling systems by providing information on potential gains in energy efficiency through **energy audits**. These audits can be used to provide information on possible **investments** or to issue **technical certificates** that record the level of efficiency of the building.

Energy audits reflect the situation of a home with regard to energy use, and can help to identify measures that may improve it. During a visit to the home, technical experts record information about the structure of the building, the heating and air conditioning systems, the appliances used, and the insulation and ventilation. Combining this information with local climate conditions, energy audits conclude with a series of recommendations regarding suitable investments, bearing in mind their cost.

Table 4. Evidence on the effectiveness of energy audits

Study	Country	Intervention	Variable	Result
Holladay et al. (2019)	US	Information on energy consumption.	Conduct a $50 energy audit.	+1.5% to 3%
		Subsidy.		• $20: no significant effect • $50: +1.5% to +3%
		Energy audit.	Investments.	No significant effects.
Fowlie et al. (2018)	US (Michigan)	Information and assistance.	Conduct an energy audit.	Increase in participation from 1% to 6%
Myers et al. (2022)	US (Austin, Texas)	Mandatory certified audit.	Applications to access energy	+30%

			efficiency subsidies.	
			Price of housing.	Increase in the relation between price and energy efficiency.

Two of these studies examine interventions designed to encourage households to voluntarily undertake energy audits. In the US, Holladay et al. (2019) found that sending letters to households promoting energy audits, at a cost of $50, and providing information on the household's energy consumption in the previous year does not increase participation. However, if the information is complemented by social comparisons of consumption, households are more likely to decide to undertake an audit in order to increase their energy efficiency. Similarly, subsidies to cover the cost of the audit have the same effect as comparative consumption information: a subsidy for the full cost of the audit increases participation from 1.5% to 3%. However, these audits do not always lead to energy-efficient durable goods upgrades (Holladay et al., 2019).

For their part, Fowlie et al. (2018) randomly incentivized participation in the US Weatherization Assistance Programme (WAP). Widely analysed in the literature, this programme was designed to subsidize efficiency improvements in lighting, windows, ventilation systems and metal duct sealing in low-income households, and to date has benefited more than seven million of such households. The authors found that providing information and assistance during the application increases the demand for an audit by only 1% to 6%, with an average cost of $55 per household.

In the case of mandatory energy audits, a technical report on a home's energy use is issued and made public. The aim is to increase transparency and encourage owners to make improvements, either to reduce their own energy consumption or to make buying or renting a home more attractive. Along these lines, Myers et al. (2022) evaluated the effects of urging property owners who want to put their properties up for sale to provide information on the energy efficiency of their homes, based on information obtained from certified audits.[8] The authors found that after an audit, participation in energy efficiency aid programmes increases by around 30%; thus, the conclusion is that these certificates encourage investments in efficient technologies, although the authors did not specify what types of investment are made.

Additionally, for a given level of efficiency and without any additional investment, these certificates increase the correlation between the energy efficiency of the home and its price. That is, in the case of a home with a high level of energy efficiency, its price increases after the audit. The authors argue that this effect is the result of incomplete information, on the part of both the buyer and the seller: on receiving the information they need, the buyer is willing to pay

[8] In Myers et al. (2022), the technical report after the audit comprises not just all the measures carried out, but also a list of recommendations. Energy efficiency certificates of buildings (mandatory in our country) represent a similar measure; they also contain an additional report that evaluates the characteristics of the home in comparison with the standard in its climate zone, as well as information on the economic savings to be obtained if measures are applied to reduce energy expenditure.

more for an efficient home, and the seller can raise the price of the home in accordance with the quality. In short, an audit that can cost between $100 and $300 can lead to an increase in the price of the home of between $2,000 and $4,000.

Do subsidies represent an effective way of improving the energy efficiency of existing buildings?

Subsidies for housing renovation constitute a third way to promote energy efficiency in buildings. Although subsidies may be granted directly, they are often preceded by an energy audit which identifies potential future investments that merit either partial or full subsidy. In fact, four of the five studies reviewed analyse the effectiveness of the subsidized investments after the audit has been carried out.

Table 5. Evidence on effectiveness of air conditioning programmes

Study	Country	Intervention	Variable	Result
Peñasco & Díaz (2023)	UK (England and Wales)	Subsidies for roof and wall insulation.	Gas consumption.	• Reductions of 1.8% for roofs and 6.9% for walls. • No statistically significant reductions for the lower quintiles. • The effects disappear after four years.
Zivin & Novan (2016)	US (California)	Audit + assessment + total subsidy (average $1,700)	Electricity consumption.	-7% for renovation -31% adding advice on energy conservation.
Fowlie et al. (2018)	US (Michigan)	Audit + total subsidy (average $4,000).	Energy consumption.	-20% (mainly in gas consumption).
Alberini & Towe (2015)	US (Maryland)	Audit + partial subsidy (average $400).	Electricity consumption.	-5%
Ministry of Inclusion, Social Security and Migration (2024)	Catalonia	Audit and investment (average 5,000 €).	Energy consumption.	No statistically significant effects.
			Energy expenditure.	No statistically significant effects.
			Perceived quality of housing conditions.	+4%
			Perceived quality of life and health.	No statistically significant effects
		Audit + investment (average 5,000 €) + assessment	All.	The same effects as investment alone.

The exception, in which the effect of improving air conditioning in buildings is directly assessed without a prior audit, is found in Peñasco and Díaz (2023). The authors analyse the effectiveness of a series of subsidies for roof and cavity wall insulation in England and Wales between 2005 and 2017. They estimate a reduction in gas consumption of 6.9% in the first year after wall insulation and one of 1.8% after roof renovation. Unfortunately, these reductions disappear after four years. However, the authors conclude that subsidies may have had positive effects in mitigating the effects of energy poverty, since the reductions in consumption are smaller in homes located in more disadvantaged areas.

In general, studies of the impact of subsidy programmes that incorporate a prior energy audit suggest that these programmes tend to be effective in reducing energy consumption. In the Weatherization Assistance Programme in the US, Zivin and Novan (2016) found that improvements in the efficiency of lighting and thermal insulation brought about a 7% fall in electricity consumption in homes with air conditioning. Surprisingly, advice on conserving energy (while obtaining the same services) resulted in an additional reduction of 24%. It should be noted, however, that these effects are concentrated in the summer, when air conditioning use is highest, so it can be assumed that the average effect over the course of an entire year would be lower. Analysing the same programme in a different state, Fowlie et al. (2018) estimated that the renovations reduced energy consumption by 20% per month, mostly due to a fall in the consumption of natural gas.

Finally, Alberini and Towe (2015) studied the combination of energy audits and subsidies for better home air conditioning, finding that a subsidy of around $400 for the installation of a heat pump (at a price between $2,000 and $20,000), reduces electricity consumption by some 5%.

Despite these reductions in consumption, and as in our analysis of building codes, it is unclear whether these reductions are sufficient to cover the costs of the investments. An example of this discussion can be found in Fowlie et al. (2018), in which the authors conclude that the benefits of the programme only exceed the costs after twenty years, or after sixteen if the gains from avoided emissions are included.

Recently, in one of the first attempts in our country to evaluate public policies using experimental methods, the Ministry of Inclusion, Social Security and Migration, in collaboration with the Department of Social Rights of the Catalan government, set in motion the Project of Training and Improvements in Housing to Address Energy Poverty (2024). This project evaluates two instruments designed to improve the energy efficiency in homes of families at risk of social exclusion: a) investments in insulation, heating, boilers and appliances, and b) advice to improve efficiency and reduce energy expenditure, and c) a combination of the two.

First, investment in energy efficiency improves a home's certification, partly in a mechanical way due to the investment itself, even though the technical difficulty of maintaining a comfortable temperature does not decrease. However, in terms of energy consumption, and in contrast to the effects found in the literature, the study carried out by the ministry does not find a significant reduction in consumption in any of the treatments evaluated.

It may be that the lack of statistically significant effects on consumption is due to an improvement in the comfort of homes, especially in the case of vulnerable families. In fact, the study mentioned finds significant effects of investments in terms of quality of life related to housing conditions (e.g., the use of household appliances or possibility of maintaining the home at an adequate temperature), although this was not reflected in an improvement in the quality of life and health indicators reported by the participants themselves. However, the study stresses that the lack of significant effects may be due to the difficulty of monitoring participants once the intervention has ended.

Another possible explanation for the lack of significant effects is that the study was carried out from May to November, since most investments were related to the replacement of heating systems and household appliances. For this reason, although the report does not specify whether air conditioning is included (as we have seen, air conditioning is responsible for a large part of the effect in the interventions evaluated during the summer months) it is expected that the results will not be significant. That is why, if possible, it would be interesting to be able to evaluate the effects of this intervention in the months when more intensive use of heating is made.

6.3. How do the energy consumption reductions observed compare with initial projections?

After assessing the savings and costs of different policies, many of the studies reviewed compare the reductions observed in energy consumption with previous estimates. This comparison allows us to assess the magnitude of the energy efficiency gap, if any in fact exists.

These studies note that, in practice, the observed reductions are significantly smaller than the initial technical estimates. There may be several explanations for the discrepancies between the initial projections and the savings observed. First, the conditions under which the potential energy consumption or savings achieved by these technologies are simulated may differ significantly from the actual conditions of use, for example, because they may assume perfect installation and maintenance (Christensen et al., 2023). Alternatively, this difference between technical estimates and the actual savings achieved may derive from changes in household consumption patterns, which capitalize on the increased efficiency to obtain more energy services at the same cost, something known as the rebound effect (Gillingham et al., 2016).[9]

Table 6. Evidence on the divergences between planned and realized savings

Study	Country	Intervention	Variable	Result
Davis et al. (2014)	Mexico	Subsidies between 10% and 40% to replace refrigerators.	Percentage of consumption reduction achieved compared to the estimate.	30%
		Subsidies between 10% and 40% to replace air conditioning units.	Percentage of consumption reduction achieved compared to the estimate.	0%

[9] The "rebound effect" is the increase in household energy consumption after installation. We leave aside other indirect rebound effects caused by the increase in consumption of other polluting goods thanks to the increase in the family budget.

Jacobsen & Kotchen (2013)	US (Florida)	Building codes.	Percentage of consumption reduction achieved compared to the estimate.	100%
Levinson (2016)	US (California)	Building codes.	Percentage of consumption reduction achieved compared to the estimate.	0%
Fowlie et al. (2018)	US (Michigan)	Audit + subsidy (average $4,000).	Percentage of consumption reduction achieved compared to the estimate.	30%
Christensen et al. (2023)	US (Illinois)	Audit + subsidy.	Percentage of consumption reduction achieved compared to the estimate.	50%
Zivin & Novan (2016)	US (California)	Audit + subsidy (average $1,700) + information.	Percentage of consumption reduction achieved compared to the estimate.	50%

The studies reviewed contain several cases in which the benefits of adopting more energy-efficient technologies are overestimated. Focusing on household appliances, the study by Davis et al. (2014), in Mexico, in which old refrigerators and air conditioners were replaced by more efficient ones, found that the reductions in consumption in refrigerators amounted to only 30% of the predictions made by the World Bank, while with regard to air conditioners the final consumption actually increased, invalidating any previous estimates of a decrease in consumption. The explanation may lie in the age of the household appliances; their average age was twelve years (the policy required that the appliance to be replaced was at least ten years old) and the estimates were based on the replacement of much older, less efficient units. Regarding air conditioners, the authors believe that a large proportion of the units exchanged were not working and that the replacement units were larger, a circumstance that counteracted any improvement in efficiency. Although the purchase of air conditioners certainly increased the well-being of families (especially since this programme was limited to geographical areas with high temperatures), this was not the goal of the policy.

As far as **building codes** are concerned, Levinson (2016) found no significant effects in terms of a reduction in electricity, while the California Energy Commission had predicted a reduction of 8%. On the other hand, Jacobsen and Kotchen (2013) concluded that the reductions of 4% in electricity consumption and 6% in the case of natural gas coincided with the estimates made by the regulators. However, Kotchen's 2017 study found that the reduction in electricity consumption achieved with the same programme disappeared in the long term, and so, once again, we see an overestimation of the savings.

Finally, these three studies of the effects of the Weatherization Assistance Programme analyse the difference between the savings actually obtained by the rehabilitation investments and the predicted figures. Fowlie et al. (2018) found that the savings amounted to only 30% of the projections, while in the studies by Zivin and Novan (2016) and Christensen et al. (2023) the figure rose to 50%.

Two of the studies reviewed try to identify possible rebound effects of the policies assessed, and conclude that these effects do not explain the differences between the estimated and actual rates of consumption. Using data extracted from thermostats, Fowlie et al. (2018) found no increase in indoor temperature, and concluded that the rebound effect was not significant. For their part, Christensen et al. (2023) estimated that the rebound effect was responsible for only 10% of the estimated differences.

Therefore, if the differences between the estimates and the real savings are not due to the rebound effect, the reason must be that the initial projections of the benefits of adopting efficient technologies were excessively optimistic. Indeed, breaking down the difference into component parts, Christensen et al. (2023) found that 40% of the discrepancy is due to biases in the model used for the preliminary calculation of the potential benefits. These authors observed the most significant discrepancy in the case of thermal insulation, while in the case of windows, duct sealing and boiler replacement the forecasts of the technical model did not differ significantly from the actual savings made. The other important factor causing the gap between estimates and actual savings is the difference in the standard of workmanship.

7. Conclusions

Improving energy efficiency at all levels, from the appliances we buy to the buildings we construct and live in, is a necessary precondition for achieving climate goals. If the measures applied are effective in incentivizing the adoption of technologies with lower life-cycle costs, they can be one of the most costefficient ways to reduce carbon dioxide emissions.

This article reviews the literature that has evaluated programmes designed to incentivize investments in energy efficiency and the effects of these programmes on final energy consumption. The study assesses interventions designed to encourage the adoption of more efficient instruments and appliances and to promote the rehabilitation of existing homes and the construction of more efficient buildings. Among the public policy instruments analysed are information provision programmes, energy audits, subsidies and building codes. The selection of studies has been restricted mainly to those that evaluate programmes implemented in countries similar to ours and that use rigorous estimation techniques to examine the causal effects of the various interventions. In total, 25 primary studies and six reviews have been included.

According to the evidence reviewed, the effectiveness of the different instruments varies significantly depending on the characteristics of the target population, the design of the programme and the technology adopted. However, certain characteristics of the programmes and patterns of effectiveness have been identified that should be taken into account when implementing policies in our country. To each conclusion we have added a level of confidence that reflects the degree of agreement between the various studies analysed and the robustness of the results they find.

Regarding **policies to encourage the adoption of more energy-efficient appliances**, the main conclusions are the following:

- Providing information on the energy or environmental benefits of purchasing efficient appliances moderately increases adoption rates (confidence level = low).
- Providing information on the monetary savings obtained by adopting an appliance with a lower life-cycle cost is more effective than providing information on energy savings (confidence level = medium).
- Educational tools or sales staff training that encourage customers to calculate the life-cycle cost can be a good complement to effective labelling (confidence level = high).
- Subsidies tend to promote the adoption of efficient appliances (confidence level = high).
- The main problem with subsidies is targeting: if they are not aimed at people who are not initially disposed to adopting energy-efficient practices, they may eventually finance purchases that would have been made anyway even if the subsidy had not been available (confidence level = high).
- The effectiveness of subsidies can be increased if they are combined with information on the life-cycle cost of household appliances (confidence level = medium).
- The extent to which the purchase of more efficient appliances translates into reductions in household energy consumption depends on the potential rebound effect of each appliance. For example, it is more difficult for a household to adjust the consumption of a refrigerator than that of an air conditioner (confidence level = high).

In relation to **policies for improving the energy efficiency of buildings**, the main conclusions are the following:

- Building codes contribute to reducing gas consumption and, to a lesser extent, electricity consumption (confidence level = medium).
- Evidence on the distributional effects of these policies is scarce, but one study found that the existence of building codes may lead to reductions in the size and attributes of smaller homes, which would harm the most disadvantaged classes (confidence level = medium).
- Interventions aimed at encouraging households to contract energy audits voluntarily, either through the provision of information or in the form of subsidies, have been found to be unpromising (confidence level = high).

- In contrast, mandatory audits may represent an effective way to incentivize investment and provide information to enable both sellers and buyers to make optimal decisions (confidence level = high).
- Subsidies for investments in improving the air conditioning of homes can contribute to reducing household energy consumption. However, of the appliances analysed, air conditioning units are the ones that are associated with the largest rebound effect (confidence level = high).
- In the case of both building codes and investments in renovation, studies differ with regard to the period of time needed to recover the investment. This is due to the long useful life of these investments, and to the fact that the calculation of this useful life must make assumptions about the price of energy and environmental benefits (confidence level = high).

Two final **points relevant to all the programmes** that encourage investments in energy efficiency are:

- The savings made are lower than the previous estimations (confidence level = high).
- According to the evidence reviewed here, this divergence is due more to the conditions under which the effects of the investments are simulated and the suboptimal installation process (due to the involvement of different auditors and installers) than to the rebound effect of household consumption. A review of the installation carried out prior to the granting of the subsidy can help to limit the expected effects (confidence level = high).

8. Discussion and practical implications

Institutions such as the International Energy Agency have stressed the importance of improving energy efficiency as a key step in the fight against climate change. In Catalonia, one of the objectives of PROENCAT 2050 (the government's strategy for carrying out the energy transition) is the reduction of the country's energy consumption without negatively affecting the well-being of the population. Energy-efficient homes have lower household energy consumption and, consequently, fewer GHG emissions when the energy used does not come from renewable sources; in addition, their lower expenditure contributes to alleviating the problem of energy poverty. Therefore, the achievement of a fair energy transition requires the deployment of effective policies that bring us closer to fulfilling this dual objective. Many of the conclusions of this synthesis suggest ways of rising to this challenge.

With regard to the **labelling of household appliances**, Catalonia is governed by European regulations on energy labelling, which for the most part require the inclusion of information on the appliances' energy efficiency category (from A for the most efficient to G for the least efficient) and the energy consumption for each cycle of use. Thus, public interventions that help calculate the life cycle cost of the different options and facilitate the translation into monetary terms of the information provided on the labels may be a good way to make this labelling more effective. However, the energy efficiency improvements required will not be achieved with information programmes alone; clearly, more instruments are needed.

Secondly, subsidies to encourage the **purchase of efficient household appliances** should be aimed at the segments of the population which, either due to lack of information or lack of financing, do not make the investments that are actually in their interests.[10] If this does not happen, these subsidies are regressive and do not incentivize additional purchases.

For example, in the case of aerothermal energy – a more efficient climate control technology that is expanding in Catalonia –[11] the barriers to its installation may vary depending on each household's economic profile. For lower-income households, the total investment cost may be the main obstacle, and in such cases, subsidies can be an effective tool to encourage adoption. In contrast, households with greater financial capacity may be willing to invest, given that it is economically profitable in the long term; however, they may be held back by the high upfront cost. In these situations, offering loans under favourable conditions may be sufficient to overcome short-term liquidity constraints, without the need for subsidies.

The problems of additionality and regressivity of poorly designed subsidies are not limited to household appliances; in fact their effects are well documented across products and across various sectors of the economy. For this reason, there is a high risk that GHG emissions will not be sufficiently reduced if energy efficiency policy is based on subsidies, and, if it is achieved, that the price will be far higher than if a policy based on carbon taxes is applied. Although no studies evaluating the effects of a tax programme on the gross alternative have been included in this review, these effects will be assessed in depth in the second evidence synthesis of this project, which deals with changes in household energy consumption patterns and programmes based on price mechanisms. In general, subsidies are usually well received by the general public, and so, though insufficient on their own, they have a part to play in the attempts to achieve climate goals. That said, they must be designed with great care.

As for the **energy efficiency of homes**, in Catalonia a great deal of work remains to be done. According to data from the Catalan Energy institute, 80% of buildings that have official energy efficiency certificates have ratings of E or lower;[12] significantly, 60% of the housing stock was

[10] In Catalonia, the new CAES system (Certificat d'Actuacions d'Estalvi Energètic) allows energy companies to propose energy efficiency investments in homes in exchange for reducing their participation in the National Energy Efficiency Fund. This may be a good way to avoid unnecessary procedures and to publicize the existence of possible subsidies, all to the benefit of the final consumer. Further information available at: https://icaen.gencat.cat/ca/energia/ajuts/certificat-dactuacions-destalvi-energetic-cae/

[11] https://icaen.gencat.cat/web/.content/10_ICAEN/17_publicacions_informes/08_guies_informes_estudis/informes_i_estudis/arxius/20200930_Estudio-Evolucion-Mercado-BdC_Acc.pdf

[12] https://icaen.gencat.cat/ca/energia/usos_energia/edificis/certificacio/observatori-de-la-certificacio-deficiencia-energetica-dedificis/index.html

built before the 1980s.[13] For new constructions, the Technical Building Code establishes basic requirements that must be met, including energy saving. This certificate establishes an upper limit for energy consumption, depending on factors such as geographical location and measures related to insulation and heating, cooling, and hot water production systems. Compliance with all these requirements obtains a high grade (A or B) in the energy certificate. Clearly, it is important to distinguish between the measures designed to improve the energy efficiency of new constructions and those aimed at the rehabilitation of existing buildings.

The literature concludes that **building codes for new constructions** reduce domestic energy consumption, especially gas consumption. The reason is that the requirements affect heating and cooling systems and focus especially on the efficiency of boilers, which mainly use gas as an energy source. The effects on electricity consumption are expected to be more significant in a future in which all these systems are electrified.

When extrapolating the results of these studies on building codes to the Catalan context, the problem we encounter is the lack of comparability between the policies: the long list of requirements varies widely according to both time and place. This is one of the cases in which a rigorous evaluation of the effects of current requirements in our country may prove particularly valuable.[14]

Technical energy efficiency certificates have been mandatory for homes that are sold or rented in Catalonia since 2013.[15] This requirement is important, as this certification helps to redress the situation of asymmetrical information in the rental market, where the landlord may have an incentive to buy cheap and inefficient appliances if it is the tenant who pays the electricity bill; in this situation, the tenant has no way of checking the quality of the appliances. What is more, if information on the landlord's energy efficiency is available, he or she can pass on the cost of the investments made to the rental price (Davis 2012). In fact, though further evidence in this area is scarce, Myers (2020) concludes that, given an energy-efficient housing envelope, tenants can save up to 24% in energy costs simply by installing efficient appliances. Furthermore, the cost of the **audit** to obtain the technical certificate of energy efficiency is very low compared to the price in the US, and so we do not believe that this is an area that requires any great changes.

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[13] https://analisi.transparenciacatalunya.cat/Energia/Certificats-d-efici-ncia-energ-tica-d-edificis/j6ii-t3w2/about_data

[14] The Practical Booklet 10 published by the Catalan Energy Institute presents a very full description of the different energy efficiency measures available. It reports their economic profitability depending on the type of housing and the climatic zone. It is beyond the scope of this publication to compare the measures described in the programmes analysed, but this booklet provides an essential guide to making these investments in Catalonia, comparing them with the literature and even analysing whether the subsequent savings coincide with the initial forecasts. For more information:
https://icaen.gencat.cat/web/.content/10_ICAEN/17_publicacions_informes/04_coleccio_QuadernPractic/quadern_practic/arxius/10_rehabilitacio_edificis.pdf

[15] https://analisi.transparenciacatalunya.cat/Energia/Certificats-d-efici-ncia-energ-tica-d-edificis/j6ii-t3w2/about_data

Therefore, efforts should be focused on the rehabilitation of existing buildings. Currently, there are several programmes that subsidize investments in energy efficiency, either through direct subsidies, tax deductions or soft loans. As explained above in this review, the most appropriate instrument for each case depends on the specific barriers that each household faces when undertaking the necessary improvements.

At the same time, it must be taken into account that the condition of buildings in Catalonia varies widely depending on the income of the municipality; for example, a study for the Metropolitan Area of Barcelona found a correlation between the average income of each neighbourhood and the level of efficiency of the certificates.[16] Therefore, if one wants to partially or fully subsidize these investments, great efforts must be made to focus on the segments of the population that need it most.

Subsidies are already targeted in most of the programmes analysed in this summary, and also in the case of the programme aimed at vulnerable households designed by the Ministry of Inclusion, Social Security and Migration. If the ministry's programme is to be maintained in the future, it will need to establish which aspects can be improved in order to reduce energy consumption or to improve households' quality of life.

On this latter point, the rebound effect in the acquisition of household appliances or in the investments to improve residential air conditioning would not be an undesirable effect in itself if these policies are justified by other objectives: for example, increasing the comfort of the population, especially if these subsidies are aimed at households that suffer from energy poverty. In fact, a study recently published by the Metropolitan Area of Barcelona, jointly with the Metròpoli Institute, concluded that more than 30% of people vulnerable to excessive heat suffer from energy poverty, and that half of households that have air conditioning are unable to use it.[17]

However, although in the past the economic literature tended to be pessimistic about the profitability and cost-effectiveness of these investments, if these policies are well targeted and take into account the long useful life of homes and the rising social cost of carbon, they can contribute to achieving the climate goals set.

The **social cost of carbon** is the cost borne by society of emitting an additional tonne of carbon dioxide (or equivalent), i.e., the cost of polluting. As the effects of climate change become more evident, the consensus among economists, international institutions and governments is that the social cost of carbon currently assumed is excessively low.

[16] https://recyt.fecyt.es/index.php/CyTET/article/view/93025/71949

[17] https://docs.amb.cat/alfresco/api/-default-/public/alfresco/versions/1/nodes/40cfd632-fb42-4bf2-a254-9f698c684343/content/InformePercepcionsCalor_CP5.2.3_rev2024.pdf?attachment=false&mimeType=application/pdf&sizeInBytes=13318054

The social cost of carbon assumed is key to determining which of the measures described above pass a cost-benefit analysis when the environmental benefits of energy efficiency investments are included. This cost is currently $51 in the United States, although the US Environmental Protection Agency has recently proposed that it should be raised to $190. (Environmental Protection Agency, 2022).[18] It is also important that cost-effectiveness analyses should be based on accurate prior estimates that take into account the quality of installation processes, the previous condition of the housing and possible changes in household behaviour.

A final aspect to consider when assessing the cost-effectiveness of the policies analysed in this summary is the energy source used by the residential sector, especially with regard to air conditioning. Bearing in mind that in the future electricity will represent a higher proportion of total energy consumption, it is reasonable to assume that reductions in electricity consumption due to investments in energy efficiency will also increase, while the effects on gas consumption will fall. Furthermore, as the percentage of electricity from carbon-free renewable sources increases, the reduction in GHG emissions for a given level of investment in energy efficiency will be lower. At the same time, energy expenditure savings will also be reduced, as renewable energies have a lower production cost.

However, this scenario is still some way off. It is important to design the path towards electrification (and the energy transition in general) with great care in order to ensure that climate policies do not promote inequality; during the transition period, disadvantaged households are likely to use dirty and expensive energy sources, while more affluent households will adopt cleaner, more energy-efficient technologies. Therefore, it is vitally important to develop measures that lead to efficient and fair electrification of the residential sector. Unfortunately, the literature in this regard is scarce.

Finally, this synthesis has brought together evidence on the effects that specific energy efficiency policies have in isolation. In practice these interventions act in conjunction with other factors. It Is important to assess how the combination of these instruments can complement or replace individual effects. And in addition to the synergies that may arise between different interventions aimed at improving the energy efficiency of households, these programmes will have to be complemented by other mitigation measures such as carbon pricing, or by adaptation to the new situation.

[18] For Europe, the European Commission's guidance advises member states to set the carbon price at €148/tonne of carbon. Source: https://ec.europa.eu/regional_policy/sources/guides/vademecum_2127/vademecum_2127_en.pdf

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