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High-Performance Retrofitting of Housing

ADEME recommendations to meet current challenges

Key information

1. At the level of housing, high-performance energy/carbon-efficient retrofitting, as defined under the French Building Code (*Code de la Construction*) amended by the French Climate & Resilience Act (*Loi Climat & Résilience*) of 2021, consists of **achieving the energy consumption and GHG emission thresholds designated by labels A and B in French Energy Performance Certificate (DPE, *diagnostic de performance énergétique*) ratings**. This requires a comprehensive approach and, in the vast majority of cases, the completion of large-scale work on the home. In practical terms, in order to achieve this kind of level of performance, it is necessary to deal with all **6 key components of the retrofitting**[1] of a home and their interfaces, to **conduct this work in a maximum of 3 stages, over a limited period** (of about 5 years) and to conduct this work according to a precise sequence (priority needs to be given to taking care of the building envelope and ventilation). If the need arises to tackle only one of the components of the retrofitting (e.g. in case of breakdown of a heating production system, etc.), the choice of system and its sizing need to be precisely studied in order to be compatible with the treatment of the building envelope at a later stage.
2. **In order to meet the climate targets for 2050 (carbon neutrality, French National Low Carbon Strategy 2 (*Stratégie Nationale Bas Carbone 2*)), the housing stock needs be made up of 80 to 90% of homes achieving the A and B labels[1], as compared with 6% today.** The remainder of the housing stock needs to have a C label rating, subject to use of a low-carbon energy (that is to say being below the B label carbon threshold). This limited proportion of homes ranked C means that as soon as low-energy building performance retrofitting (*Bâtiment Basse Consommation*, *BBC-rénovation*) is possible, it needs to be achieved, and that the target of a C rating should be reserved for homes that present technical or architectural incompatibilities with insulation of the building envelope. It will therefore also be a matter of progressively slimming down the exemptions currently provided for in the regulatory definition of high-performance retrofitting.
3. The insulation of certain buildings sometimes presents particularly complex technical issues. For these buildings, the achievement of class A or B may be simplified by making massive use of the most high-performance renewable energies (solar, geothermal etc.), as well as low-carbon district heating networks. In these cases, investment in renewable energies needs to be studied on a case-by-case basis, bearing in mind the objective of only compensating for lack of insulation and airtightness that cannot be corrected due to technical considerations or for heritage reasons.
4. Retrofitting also needs to be integrated into an **overall vision** of the issues confronting housing. High-performance retrofitting requires extensive work, it therefore provides an opportunity for mutualising costs by incorporating other issues connected with the permanence of the building, the heritage dimension, the occupants' health and safety (electricity, indoor air quality, etc.) and other environmental issues (reuse, water management, etc.). In particular, adaptation to climate change (e.g. summertime comfort) needs to be integrated into retrofitting work from now on. For this reason, housing surveys need to integrate broader issues.

[1] Insulation of walls, floor slabs (i.e. ground surface floor areas excluding walls), and rooves, replacement of external joinery, ventilation, and production of heating and domestic hot water.
[2] This estimate includes new homes. These proportions are different from those published in *Transition(s) 2050, Choisir maintenant, Agir pour le climat* (*Transition(s) 2050, Decide Now Act 4 Climate*) insofar as the definition of low-energy building-retrofitting has changed since the report was published. The minimum thresholds for rating labels A and B have been lowered.

5. In the vast majority of cases (with the exception of recent, well-insulated homes heated with electricity), **high-performance retrofitting is cost-effective in terms of its overall carbon impact**, since the carbon savings generated by retrofitting over a 50-year period are greater than the carbon emitted at the time of the work and contained in the products, materials and equipment. The more ambitious the retrofitting, the greater the total amount of carbon avoided. Insulation is the lever that provides the greatest carbon savings over a 50-year period, ahead of changes in heating methods.
6. The issues involved in speeding up the high-performance retrofitting market are for the most part not of a technical nature: with current technology, existing knowledge enables the completion of high-performance retrofitting. However, in 2022, there were only 43,000 homes officially undergoing low-energy building retrofitting. The figure is admittedly higher if homes that attain the low-energy building level of energy efficiency without applying for certification are taken into account. However, this figure needs to be seen in the context of the number of 600,000 to 700,000 high-performance retrofits required every year according to the foresight scenarios.
7. From an economic point of view, the expansion of the high-performance retrofitting market is both a challenge and an opportunity. **The challenge is twofold: on the one hand, increase in investment volumes, and on the other, large-scale recruitment in the retrofitting sector.** Current investment in retrofitting (in the order of 20 billion euros per year) needs to be reallocated to high-performance retrofitting and doubled. In terms of human resources, by 2030, the additional workforce needed for high-performance retrofitting of buildings is set to come to a Full Time Equivalent of between 170,000 and 250,000 (as against the current FTE of 230,000 employed in retrofitting). There are existent needs at all levels of the industry, from design to implementation and operation. **The expansion of this market represents a major opportunity** to boost growth for players in the construction of new buildings (currently a FTE of 350,000).
8. Expansion of the high-performance retrofitting market is based upon several key actions:
    - **The development of performance guarantees:** the model of comprehensive service providers capable of providing a package incorporating design, retrofitting work, financial engineering, financing and a guarantee of actual performance needs to be tested and then deployed. Its development will require the definition of a **comprehensive retrofitting contract** model guaranteeing the household or jointly-owned property a price, a deadline and an undertaking with regard to the actual energy performance achieved after the work.
    - **The development of support for households covering the whole of the aspects of a retrofitting project**, from the stage of reflection upstream of the project to the work implementation stage and post-retrofitting inspections.
    - **Continued investment in training.** Training henceforth needs to be given to the whole of the tradespeople who implement systems and materials on the worksites, with particular emphasis on coordination of the work and massive expansion of the provision of programmes dedicated to insulation techniques with so called old materials (timber framing, stone, earth, etc.).
    - **Reinforcement of quality control of work** (proportion of worksites inspected, on-worksite inspections, interfaces, etc.), in particular within the framework of the French RGE (*Reconnu Garant de l'Environnement*, "recognised guarantor of the environment") scheme for the accreditation of retrofitting contractors.
    - **Adaptation of the provision of finance to the considerable costs of high-performance retrofitting and the diversity of households' economic situations** (in particular in order to move towards the absence of expenses to be borne by the most precarious households). The development of Third-Party Finance Companies (*Sociétés de Tiers Financement*), providing an integrated service combining technical and financial expertise, needs to be encouraged. It is necessary to work on the matter in greater depth in order to make it possible to facilitate financing by players in the banking sector within the framework of the taxonomy of sustainable activities.
    - **Public policies making it possible to guide both demand and supply towards achievement of the highest possible level of performance.** Public communication needs to be aimed at creating a positive image of high-performance retrofitting, and the France Renov' information and advice scheme needs to be developed in order, on the one hand, to take broader issues into-account (adaptation to climate change, biodiversity, etc.) and, on the other, to guide households towards energy efficiency performance. Many existing obligations need to be more effectively monitored. A general obligation to undertake retrofitting at the time of change of ownership could accelerate the expansion of the market but requires investigation of all of its aspects.
9. The objectives of mass deployment can only be achieved via a **transitional phase of ramping up the schemes and increasing the number of qualified professionals.** It is necessary to plan this phase in the most effective possible manner, with a clear multi-year timetable (with progressive increase in both supply and demand) and support for the actors.

[3] Avoid shutting in bats under external thermal insulation, install nesting boxes in the insulation, etc.

1. Background and Issues

1.1. Retrofitting of homes: the need to address multiple issues

The retrofitting of homes[1] meets numerous environmental and energy-related challenges, including: saving energy (and therefore reducing household energy bills), reducing greenhouse gas emissions, conserving resources (materials, energy, soil, etc.), reducing emissions of atmospheric pollutants, improving the quality of use of homes, and the need to adapt our energy consumption to the capacity of the energy system to produce energy with a low environmental impact and reduce peak demand for electricity consumption.

Retrofitting also addresses economic, social and health issues. 79% of households restrict their heating consumption for financial reasons (*Médiateur national de l'énergie* [the French national energy ombudsman, an independent public authority whose role is to propose amicable solutions to disputes with companies in the energy sector and inform energy consumers of their rights], 2023), an increase of more than 10 percent as compared with 2022. Moreover, exposure to cold, excessive heat or humidity, and poor indoor air quality, have a major impact on the health, sociability and mental condition of people. By way of example, the retrofitting of all "energy sieves" (i.e. housing that consumes a large amount of energy due to poor thermal insulation) by 2028 would enable the avoidance of health costs of almost 10 billion euros per year (CGDD (the French State Commission for Sustainable Development), 2022).

Moreover, retrofitting also needs to include adaptation in order to make homes more resilient in the face of the impacts of climate change and to preserve their fitness for habitation, that is to say their capacity to protect their occupants from external conditions (heat in particular in the event of heatwaves).

Lastly, reduction of domestic energy consumption is a solution for both collective and individual resilience. It makes it possible to absorb the impact of geopolitical crises and uncertainties concerning the prices and supply of energy, while maintaining acceptable levels of thermal comfort.

How to integrate these multiple issues and aspects into retrofitting?

1.2. The need to speed up the process of energy and carbon-efficient retrofitting

1.2.1. Objective: a majority of the housing stock rated class A or B by 2050

Homes account for 30% of French final energy consumption, which represents 10% of its greenhouse gas emissions. The current rate of reduction of energy consumption and decarbonisation of housing needs to be greatly speeded up in order to achieve the targets France has set itself in order to comply with the Paris Agreements (HCC [French High Council for the Climate, *Haut Conseil pour le Climat*)], 2023).

In terms of energy and carbon, for Metropolitan France, the notion of the performance of a retrofit needs to be interpreted in the context of the achievement of France's environmental targets. It is a matter of bringing homes up to performance levels that are compatible with these targets, while ensuring thermal comfort in both winter and summer. For energy, these include the European Energy Efficiency Directive of 2023 (a 30% reduction in France's final energy consumption[2] by 2030 compared with 2012), and for carbon, the Fit for 55 objective (a 55% reduction in the European Union's emissions by 2030 compared with 1990 levels) and carbon neutrality by 2050 (French Energy and Climate Law (*Loi Energie Climat*) of 2019).

Historically, our awareness of the need to reduce our energy consumption was awakened before that of reducing our greenhouse gas emissions. With the emergence of climate issues, the definition of

[1] This document does not deal with building safety and structural issues, which need to be a precondition before any retrofitting.
[2] French national contributions to the European target are currently provided for information only.

performance has evolved to include both energy consumption[3] and emissions of greenhouse gases at the operational phase of a building[4]. This explains the adoption of the dual energy-carbon metric in French public policy tools such as the Energy Performance Certificates (DPE, *Diagnostic de Performance Energétique*) and Low-Energy Building-retrofitting accreditation (*label BBC-rénovation*).At the level of housing, high-performance energy/carbon-efficient retrofitting consists of achieving the energy consumption and carbon emission thresholds designated by labels A and B in French Energy Performance Certificate (DPE) ratings, as defined in the French Building Code (*Code de la Construction*) amended by the Climate & Resilience Act (*Loi Climat & Résilience*) of 2021[5], combined with the additional requirements of the decree (*arrêté*) of 3 October 2023 defining Low-Energy Building-retrofitting accreditation.

At the level of housing stock, in order to meet climate targets, by 2050, 80-90% of the stock needs to be made up of housing (main homes) qualifying for label A or B ratings[6]. The remainder of the housing stock needs to have a label C rating, subject to use of a low-carbon energy (that is to say being below the B label carbon threshold) (ADEME, 2024a). This limited proportion of homes ranked C means that as soon as low-energy building performance retrofitting is possible, it needs to be achieved, and that the target of a C rating should be reserved for homes that present technical or architectural incompatibilities. By way of comparison, 6% of French main homes currently have label A and B ratings, and 24% C ratings (SDES [French Department of Statistical Data and Studies], 2023).

Low-Energy Building-Retrofitting Accreditation

The French Low-Energy Building-retrofitting accreditation scheme (*Label BBC Effinergie rénovation*) applies to retrofitting projects for both residential (individual houses in areas not yet connected to public sewerage and energy supply networks, as well as in developed housing areas, and blocks of flats) and non-residential buildings (used for offices, education, retail, short-stay accommodation, catering, entertainment, sport, industry, etc.). These buildings have to be located in metropolitan France and may be under public or private ownership.

The accreditation concerns the elements of the thermal study produced in the course of the design phase, as well as the inspections and measurements conducted at the end of the work. If the requirements of the accreditation are met, it is awarded at the time of official acceptance of the completed work (after verification) by the certifying body.

For obtainment of the "BBC Effinergie" Low-Energy Building-retrofitting accreditation label, the building or the part of the building concerned must meet the two following requirements:

- Validate the requirements of the Decree of 3 October 2023 concerning the content and conditions for award of the accreditation label provided for under article R. 171-7 of the French Building and Housing Code (*Code de la construction et de l'habitation*). In particular, in terms

[3] The types of energy consumption considered are those connected with heating, domestic hot water production, lighting, cooling, and ventilation and heating auxiliaries.

[4] That is to say, without taking into account energy consumption and GHG emissions upstream, i.e. connected with the work, or downstream, i.e. connected with the processing of waste from the buildings.

5 The Climate & Resilience Act introduces exemptions to this basic definition. Article L111-1 thus provides that: High-performance retrofitting (*Rénovation énergétique performante*): the retrofitting of a building or part of a building used for residential purposes is said to be high-performance when the work, which takes care of ensuring satisfactory ventilation, enables compliance with the following conditions:

a) Rating of the building or part of the building as class A or B according to the meaning of Article L. 173-1-1;

b) Study of the following six components of retrofitting work: Insulation of walls, insulation of floor slabs, insulation of rooves, replacement of external woodwork, ventilation, production of heating and domestic hot water and associated interfaces.

However, by way of exception, retrofitting is said to be high-performance in application of the first or penultimate paragraph of 17a hereof:

-for buildings which, due to technical, architectural or heritage constraints or costs that are manifestly disproportionate in relation to the value of the property, cannot undergo retrofitting work enabling the achievement of a level of energy performance at least equal to that of class B, when the work enables a gain of at least two classes according to the meaning of article L. 173-1-1 and the six aforementioned work components have been dealt with;

-for buildings rated class F or G before the work according to the meaning of the same article L. 173-1-1, when they reach at least class C after the work and the six aforementioned work components have been studied.

A high-performance retrofitting project is described as comprehensive when it is completed within a maximum period of time that cannot be set at less than eighteen months for buildings or parts of buildings used for residential purposes comprising only one home, or at less than twenty-four months for other buildings or parts of buildings used for residential purposes, when the six aforementioned work components have been dealt with.

[6] This estimate includes new housing. These proportions are different from those published in *Transition(s) 2050, Choisir maintenant, Agir pour le climat* (*Transition(s) 2050, Decide Now Act 4 Climate*) insofar as the definition of low-energy building-retrofitting has changed since the report was published. The minimum thresholds for rating labels A and B have been lowered.

of energy performance, the decree stipulates that the housing must qualify for a class A or B rating.

- And validate the additional Effinergie (French association for promotion of the construction and retrofitting of low-energy buildings) requirements (for residential buildings: integration of thermal bridges, management of interfaces, checks and measurements concerning ventilation systems, building automation and regulation systems, commissioning in compliance with required standards and biodiversity) (Effinergie, 2024).

1.2.2. A process of high-performance retrofitting to be stepped up

The multiple meanings of the term "retrofitting", which can cover anything from the completion of a single act (changing a window, boiler, etc.) to the complete retrofitting of a home, make monitoring of the market difficult. By way of example, the French National Monitoring Centre for Retrofitting (ONRE, *Observatoire national de la rénovation énergétique*) documents homes on which acts of retrofitting have been completed, which is different from high-performance retrofitting (ONRE, 2023). 64,200 retrofits were financed via the MaPrimeRenov Sérénité (public funding for retrofitting work for households on low and very low incomes) and MaPrimeRenov Copropriété (public funding for retrofitting work on jointly-owned properties) schemes in 2022 and 2023 (ANAH [French National Housing Agency], 2022, 2023). However, these were not necessarily high-performance retrofits (the required energy saving of at least 35% does not guarantee the achievement of low-energy building status).

The figure that comes closest to the number of high-performance retrofits is that of the Monitoring Centre for Low-Energy Buildings (*Observatoire BBC*) run by Effinergie, the association responsible for the *BBC-Rénovatio*n Low-Energy Building accreditation label. In 2022, it listed 43,000 homes engaged in a low-energy building retrofitting process. The figure is admittedly higher if homes that attain low-energy building level without applying for certification are taken into account. **However, this figure needs to be seen in the context of the number of 600,000 to 700,000 high-performance retrofits required every year according to the foresight scenarios.**

Although the process is well underway among council or public housing (which account for 95% of low-energy building retrofits), it is still in its infancy in the private housing sector. Only 8,000 individual houses and 12,411 jointly-owned residential buildings (out of the 27 million main homes built before the French Thermal Regulations of 2012) have obtained the low-energy building retrofitting accreditation (Low-Energy Building Monitoring Centre).

Yet, between 70% and 90% of projected homes for 2050 have already been built[7]. It is therefore necessary to significantly speed up the pace of high-performance retrofitting of housing.

How to speed up high-performance retrofitting of housing in order to meet the 2050 targets?

2. The Keys to Success

2.1. First insulate, then decarbonise heat production

In order achieve performance, it is necessary to make use of two levers: in the first place, dealing with the building envelope, and secondly, decarbonisation of thermal practices (heating and domestic hot water).

2.1.1. Dealing with the building envelope and ventilation: a priority

[7] Estimates from the Transition(s) 2050 scenarios: the volume of new buildings varies from one scenario to another according to our capacity to mobilise the existing housing stock (vacant housing and offices, second homes, etc.) in order to meet our housing needs.

There are numerous advantages to taking care of the building envelope (walls, rooves, floor slabs i.e. ground surface floor areas excluding walls, thermal bridges etc.), ensuring airtightness and changing the joinery:

- Properly executed and reducing the number of work stages to a minimum, this work is essential in order to achieve the A and B rating labels and reduce energy bills, and therefore fuel precarity, in the long term.
- This makes it possible to reduce the need for heating and therefore to install less powerful, and therefore less costly, heating equipment.
- **It makes homes more comfortable and less sensitive to external temperatures in both summer and winter.** This thus limits the temperature sensitivity of energy consumption for heating and the risks connected with peak demand on the electrical grid. It also contributes to the flexibility of demand for electricity. Indeed, it is easier to bring the time of heating consumption backwards or forwards in a well-insulated building: its interior temperature does not fall rapidly and the comfort of its occupants is preserved.

Treatment of the building envelope must be combined with the installation of effective ventilation for the home. Ventilation plays a number of roles: supplying fresh air; removing pollutants, CO_2 and humidity in order to ensure healthy air for the comfort and health of users; protecting the building from damage connected with excess humidity (pathologies and/or loss of performance); and lastly, limiting heat loss connected with replacement of air.

Bio-based materials and retrofitting

Thermal insulation using bio-based materials is often appropriate for buildings constructed using old materials (stone, earth, timber framing, etc.). Indeed, combined with a vapour barrier, for example, these materials make it possible to regulate moisture transfer and limit the risks of accumulation of water liable to damage walls.

In terms of summertime comfort, regardless of the type of insulation material used (whether or not bio-based), the first criterion of choice needs to be its thermal resistance, in order to prevent passage of heat. The densest insulation materials (as is the case for certain bio-based insulation materials) improve the phase-shifting capacity of the walls[8], but this effect is of secondary importance as compared with the thermal resistance of the insulation material.

Lastly, retrofitting is an excellent opportunity to store carbon by encouraging the use of wooden materials (joinery, cladding, interior fittings, etc.).

2.1.2. Decarbonising thermal practices: a necessary but not sufficient condition[9]

Decarbonisation of the use of heat in homes is based upon changing from equipment that uses carbon-based energy sources (boilers using heating oil and gas of fossil origin) to less carbon-intensive energy sources, and the development of renewable energy sources in networks. This involves switching to geothermal (water-to-water) and aerothermal (air-to-water or air-to-air) heat pumps, solar heating, log or wood pellet appliances, renewable gas from methanation, district heating networks powered by renewable or recovered energies, and electricity from renewable energies such as wind power and photovoltaics.

Decarbonised energy production capacity is limited, and for this reason, reducing the energy consumption of buildings is an essential prerequisite for the decarbonisation of energy carriers. For example, the use of wood for energy needs to be complementary to its other uses (building materials, insulation materials, green chemistry, etc.), biogas production capacity depends on the availability of

[8] Phase-shifting refers to the time taken for heat to pass through a material.

[9] See also ADEME expert opinion "*Décarboner le chauffage : quelle place pour les pompes à chaleur ? Décarboner les consommations d'énergie en phase d'usage des logements pour atteindre nos objectifs 2030 et 2050*".

primary resources (e.g. agricultural products and by-products for methanation) as well as on needs in other sectors (industry, transport, etc.), and electricity production capacity depends on capacity for development of renewable energies and/or nuclear power (ADEME, 2021a).

Certain blocks of flats with individual gas heating currently have few alternatives to gas. **It is possible for them to retain their heating and domestic hot water production systems, provided that the gas used to power them is decarbonised, and that their overall consumption is limited so as not to exceed biogas resources (which need to be allocated to the industrial and mobility sectors in priority).** This means, on the one hand, reducing the total proportion of homes heated with gas and, on the other, ensuring that homes heated with gas (for which no energy alternative exists) are retrofitted in the most high-performance manner possible, in order to reduce their consumption to the greatest possible extent.

Heat pumps (air-to-water and air-to-air) have a key role to play, but like all other thermal equipment, and in particular equipment operating at low temperatures, they need to be combined with insulation. In individual houses, the level of insulation of the house affects the performance of heat pumps. Semi-virtual laboratory studies on air-water heat pumps have shown that, for a properly sized, installed and adjusted heat pump, the Coefficient of Performance (COP) can remain at about 3 as a yearly average, even in a poorly insulated house in the climate of northern France (ADEME, 2024b). The use of measuring instruments under real conditions is in progress in order to validate these results. However, changes in the performance of heat pumps following improvements to the envelope of a house (i.e. their ability to maintain their annual COP despite wide modulation ranges) is still an area in which research and innovation are required. Moreover, it is still essential to conduct research to objectively assess the performance of heat pumps following the installation of insulation, both in terms of their lifespan and their COP. In blocks of flats, the reduction of the building's thermal needs made possible by insulation is all the more necessary in order to reduce the set temperatures of emitters (radiators) and therefore their size, reduce the power used, the space taken up and the noise pollution, and in order to enable the installation of renewable energies (Pouget Consultants, 2023a).

The replacement of a gas or fossil fuel boiler with a heat pump (without insulation of the home) therefore remains a sensitive act of retrofitting for which advice and support needs to be provided for the household. The replacement of a fossil-fuel heating system with a heat pump without first insulating the building admittedly brings about a rapid reduction in carbon emissions needed in order to achieve the 2030 targets, but leads to heat pumps being too big, and therefore additional cost. In addition, the replacement of fossil fuels with heat pumps in the absence of insulation has an impact on peak demand for electricity in winter. In this regard, the hybridisation of a system, in the form of combining two pieces of equipment, one of which may already be installed (e.g. heat pump and wood-burning stove, heat pump and existing gas boiler, etc.), may be appropriate when it is not possible to carry out high-performance retrofitting in the short term. The two systems will work together for a while, then once the insulation of the home has been completed, it will be possible to remove one piece of equipment (e.g. gas boiler, back-up electric convector heaters).

Because of their central role in the transition, it is also necessary to secure the strategy of deployment of (water-to-water, air-to-water and air-to-air) heat pumps in housing, especially since sales of this type of equipment are growing rapidly (in particular air-to-air heat pumps, of which 900,000 units were sold in 2023, as compared with 300,000 for air-to-water heat pumps and 3,500 for geothermal heat pumps) (Uniclima, 2024).

- In the first place, continue documenting the actual performance of heat pumps in order to gain a better understanding of the optimal conditions for their deployment (and to stabilise a protocol for the use of measuring instruments concerning the actual performance of air-to-air heat pumps).
- Secondly, give priority to the most energy-efficient systems, in particular by massively increasing the use of geothermal heat pumps.
- Lastly, support industrialisation in order to ensure a supply of French or European machines.

In addition, the transition to heat pumps using refrigerants with a low Global Warming Potential (GWP) needs to be speeded up, since these represent a non-negligible proportion of the carbon footprint of retrofitting.

Electric heating by means of Joule convector heaters is highly inefficient and responsible for part of the peak demand for electricity in winter. According to research by RTE (*Réseau de Transport d'Électricité*, the electricity transmission system operator of France), the condition for limiting the associated fluctuations in demand for electricity (and therefore for limiting the carbon impact of electricity) is to eliminate a proportion of Joule heating in homes (RTE, 2023). Moreover, it is not compatible with achieving the A and B rating labels of French Energy Performance Certificates (DPE). In individual houses currently heated with Joule convector heaters, and therefore without a water network for heating, air-to-air heat pumps are a more high-performance alternative than Joule heating. However, their use should be limited in summer in order to avoid contributing to urban heat islands.

The carbon impact of retrofitting

The question of the carbon impact of retrofitting is an emerging issue for which the data and methodologies used have yet to be consolidated (Cerema, 2023). To a large extent, the carbon impact of a retrofit depends on the nature and extent of the work conducted, and moreover on the energy performance and the initial energy used for heating and domestic hot water, and finally on the geographical location and the performance achieved after the work.

However, current knowledge nevertheless suggests the following conclusion (Pouget Consultants, 2023b):

- **In the vast majority of cases, retrofitting is profitable in carbon terms: the operational carbon savings generated by a retrofit over a 50-year period[10] are greater than the carbon emitted at the time of the work. The more ambitious the retrofit, the greater the total amount of carbon avoided.**
- **Insulation is the act that brings the most carbon savings, with little variability in connection with the nature of the insulating materials used.**
- Changing joinery has a higher carbon impact than changing insulating materials, but variability due to the type of joinery (wood, PVC, aluminium or mixed) is low, since windows are the principal carbon contributor of this element.
- For the same thermal performance, the use of bio-based insulating materials, that have not undergone much processing, made from co-products of agriculture or forestry (straw, hemp, cellulose, wood etc.) and wooden joinery are the preferred solutions from a carbon point of view.
- For homes that are fairly well insulated (in particular those built under French RT2012 thermal regulations) and heated with electricity, retrofitting is not very worthwhile from a carbon point of view, since it would be difficult to make the carbon impact cost-effective from a change in their existing set-up alone.
- Switching from fossil fuels (heating oil, and mains gas) to renewable or less carbon-intensive energy sources offers a good carbon return on investment. Heat pumps have a longer carbon payback time than treatment of the building envelope, in particular due to the impact of refrigerants. However, heating equipment has a shorter lifespan than insulation, and has to be replaced more often, which means regular incurrence of carbon costs, particularly in connection with refrigerants. Over a 50-year lifespan, insulation of the envelope thus remains the most carbon-efficient act.
- **For the same level of performance, the carbon impact of a retrofit may vary significantly depending on the materials and equipment used in particular for directly resulting and closely related work (bringing into compliance with standards, painting, sanitary fittings, etc.).** It is therefore possible to reduce the carbon impact of retrofitting by giving priority to sufficiency

[10] Conventional lifespan traditionally used in Lifecycle Assessment calculations in the building sector.

in material use, materials that are low-carbon or enable carbon storage (renderings, wood cladding, etc.) and reuse.

2.2. Adapting the strategy of high-performance retrofitting of the housing stock to each type of home

2.2.1. Individual houses: promising results

The monitoring and use of measuring instruments on 106 individual houses retrofitted to low-energy building standard during the Perf in Mind project confirms that it is possible, with current technology, to complete high-performance retrofits of individual houses (Enertech, 2021):

- **The vast majority of retrofits fulfilled the intended low-energy building energy target.**
- **Households are highly satisfied with the retrofit, their bills after the work and their comfort (in winter and summer).**
- Indoor air quality is good overall, or even very good.
- **There is no observed rebound effect**. Thanks to the comfort provided by the quality of the building envelope, the set temperatures and therefore the energy consumption remain circumscribed. This is the result of the retrofitting of the whole of the retroffiting components, the quality of the work and the performance of the envelope (absence of the effects of cold walls and draughts). In fact, any poor performance in terms of the envelope and/or systems may erode the target consumption level and increase the importance of user behaviour in the achievement of proper performance (which is one of the causes of the rebound effect).

The study also stresses the importance of providing support to households, which is decisive both for undertaking the decision to carry out the work and for achieving proper performance.

2.2.2. Blocks of flats: the need to improve the design and execution of retrofitting work

Measurement campaigns (Rénovons collectif & al, 2023) concerning the energy performance of retrofitted blocks of flats show that, with current techniques, they can be retrofitted to a level of consumption and carbon emissions enabling them to achieve classes A or B of French Energy Performance Certificates.

The measurements also highlight the fact that, despite significant savings as compared with their initial state, the target is not always achieved in reality. Indeed, certain recurring technical issues concerning the quality of the work and the fine-tuning of the technical facilities remain to be improved. This is the case in particular with regard to insulation of the whole of the walls, dealing with thermal bridges (including structural thermal bridges) and optimisation of the production and distribution of heating. The measurements also illustrate the importance of regulation, highlighting the difference in consumption between housing without regulation, housing equipped with thermostatically-controlled valves, and lastly housing equipped with thermostats enabling greater control over temperatures by the occupants. Lastly, it is necessary to deal with communal domestic hot water, whose consumption (due to circulation loops) may exceed that of heating.

Decarbonisation of thermal practices in blocks of flats in which the apartments are individually heated with gas generates major constraints for heat distribution, with the creation of hot water networks circulating in the building in order to distribute heating and domestic hot water. In an insulated building, consumption from circulation loops may be higher than that from heating, therefore, the switch from individual to centralised production of domestic hot water needs to be studied on a case-by-case basis. Hybrid systems are also conceivable (for example, communal heating and individual hot water). On the other hand, in dense blocks of flats, the noise generated by heat pumps is a major issue that is difficult to overcome.

Lastly, in jointly-owned properties, the challenges of collective decision-making intersect with technical issues, in particular with regard to the coordination of work in private and communal areas.

2.2.3. Old and/or heritage buildings: differentiating between situations

Certain categories of buildings require special attention:

- **Buildings constructed with materials that require special precautions with regard to insulation (raw earth, timber framing, cob, stone, etc.).** These types of building represent about 11 million homes (according to the typology of the housing stock established by the PROFEEL programme), that is to say a third of the housing stock. It is therefore inconceivable not to retrofit them in a high-performance manner. The principal challenge for this type of building is to guarantee its permanence and prevent damage, which entails proper training for designers and building contractors, use of appropriate materials, and higher retrofitting costs. Internal insulation is one solution for these buildings, but external insulation using capillary materials that are open to water vapour should not be systematically ruled out. A certain number of these buildings have been covered with non-capillary or scarcely capillary rendering (cement renderings), and external insulation could make it possible to combine preservation of the building with thermal improvement. Support for innovation needs to continue in order to place technical solutions on the market (including external insulation) appropriate to each situation.
- **Listed buildings and registered Historical Monuments, as well as buildings with Remarkable Contemporary Architecture accreditation (*Architecture contemporaine remarquable*) represent about 200,000 buildings (according to the Mérimée database).** Their retrofitting is not a priority for the achievement of France's environmental targets, although the *Effinergie patrimoine* experiment has shown that it is possible to drastically reduce their energy consumption to levels close to low-energy building retrofitting. Connection to district heating networks (where available), wood-fired boilers and/or partial insulation (e.g. rooves) are among the most appropriate solutions.
- **Buildings located within heritage protection areas (areas surrounding historic monuments, and "SPR" remarkable heritage sites (*Sites Patrimoniaux Remarquables*)) but not falling into the two preceding categories:** TFor the latter type of homes, the principal challenge is not of a technical nature, but rather concerns the need to work in close consultation with the official French planning body for heritage buildings (*Architectes des Bâtiments de France*), local and regional authorities and the Ministry of Culture in order to reconcile preservation of architecture, reduction of energy consumption (external insulation, etc.) and adaptation to new climatic conditions (incorporation of solar protection, etc.). The regional level appears to be the most appropriate, since it is positioned at the interface between the rich variety of buildings and the establishment of a large-scale retrofitting policy. Moreover, systematisation of heritage surveys, as well as the encouragement of work in close consultation between architects and engineering and design consultancies, constitute essential building blocks for the retrofitting of these buildings.

Incorporation of renewable energies to compensate for the difficulty of insulating certain buildings

Certain buildings in the above three categories are sometimes particularly complex to insulate. For these buildings, the achievement of class A or B status may be simplified by making massive use of the most high-performance renewable energies. For example, the installation of a geothermal heat pump enables improvement of the COP by between 1 and 3 as compared with aerothermal systems. Similarly, the installation of photovoltaic panels – whose self-consumed output is deducted from final energy consumption – is capable of significantly improving the French Energy Performance Certificate rating. In both cases, these investments in renewable energies need to be studied on a case-by-case basis, bearing in mind the objective of only compensating for lack of insulation and airtightness that cannot be overcome for technical or heritage reasons.

2.3. Scheduling work and limiting the number of stages

Achievement of the A, B (or even C) label of the French Energy Performance Certificates rating requires a comprehensive approach and the completion large-scale work on the home. In practical terms, it is a matter of:

- **Limiting the number of stages of work to a maximum of 3 over a limited period (of about 5 years), giving priority to the reduction of needs** by dealing with the envelope and then via the installation of efficient systems using renewable energies (see text box below).
- **Fully dealing with the whole of the 6 key retrofitting components for a home[11], and their interfaces (physical points of junction between these work components ensuring airtightness and continuity of the insulation), installing a mechanical system for ventilation, in order to avoid thermal bridges and deal with airtightness. Completing this work according to a precise sequence.**

In the case of retrofits completed in uncoordinated stages, the final stages will probably remain incomplete since they would make it necessary to correct previously completed work on the interfaces and interactions, as well as reinsulating any parts of buildings that had not been sufficiently insulated. These buildings would then have reached a **retrofitting dead end**, since the cost of the final stage would be prohibitive, **it would not be completed, and the only way to reduce household energy consumption would be to reduce winter and summer comfort.** Although the completion of high-performance retrofitting in stages is conceivable (subject to certain conditions), the retrofitting project needs to be an integral part of an overall approach in order to avoid retrofitting dead ends of this kind. The work needs to be thought out as a whole within the framework of a comprehensive roadmap, enabling description of the ultimate objective aimed at, and the different realistic/relevant stages making it possible to achieve it. In particular, if the need arises to tackle only one of the components of the retrofitting (e.g. in case of breakdown of a heating production system, etc.), the choice of system and its sizing need to be precisely studied in order to be compatible with the treatment of the building envelope at a later stage.

Retrofitting sequencing: case studies

Low-Energy Building Retrofitting cannot be achieved without dealing with the interfaces between different elements of work (and therefore dealing with thermal bridges and airtightness). For this reason, "stage-by-stage low-energy building" retrofitting is only consistent with the grouping together of parcels of work so as to deal with the interfaces between these elements in the most effective possible manner. The first stage of the work is the cornerstone of the project. It needs to prioritise the work elements which, if not completed jointly, would compromise the capacity of the home to achieve low-energy building level, and which, on the other hand, reduce the risks of defects. This generally leads to the prioritisation of elements of work concerning the building envelope and ventilation.

For example, in individual houses, the postponement of certain work elements to the second or third stage of the work, or failure to complete them in a joint manner, can have a significant impact on the final energy consumption of the home. **This is principally the case for insulation of walls and replacement of joinery (dealing with these two components separately can lead to a 20-100% increase in heating requirements for the dwelling at the end of the retrofitting process, as compared with a home retrofitted "in the right order"), and, to a lesser extent, insulation of rooves (which leads to a difference of 8 to 15% in heating requirements).** Conversely, postponement of the insulation of floor slabs, for cellars or unheated premises, and replacement of heating systems, does not have any impact on final consumption. It is therefore conceivable for this work to be completed at a later stage (ADEME, 2021b).

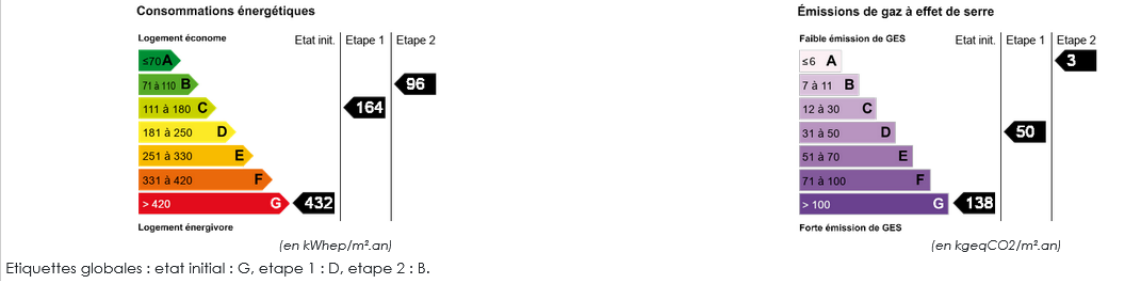
Example 1: Reconstruction period (1948-1974) house of 80m² located in Doubs[12]

[11] Insulation of walls, floor slabs, and rooves, replacement of external joinery, ventilation, and production of heating and domestic hot water.
[12] The following examples are simulated using the https://www.bbc-par-etapes.fr/ tool.

Building characteristics: solid stone (vast majority) rubble masonry, parpen, solid or hollow brick, generally with rendering.Low to medium levels of glazing. Span roof, attic, flat roof (rare). On earth platform or over cellar. Unheated ground floor.

Initial situation: absence of thermal insulation, heated with heating oil, single glazing wooden joinery, individual heating with heating oil.

The first stage of retrofitting enables the building to pass from the G label to the B label according to the French Energy Performance Certificates rating (while more than halving carbon emissions). The second stage enables achievement of a B energy rating and a residual level of carbon emissions[13].



Etiquettes globales : etat initial : G, etape 1 : D, etape 2 : B.

RECOMMENDED STAGES OF WORK

Stage 1:

- External Thermal Insulation of walls using insulating materials with a thermal resistance of greater than 4.4 m².K/W
- Insulation of inconvertible attic space using insulating materials in loose-fill or roll format with thermal resistance of greater than 8.5 m².K/W
- Replacement of joinery with double-glazing with a Uw value of less than 1.3 W/(m².K) and installation of solar protection for the east, west and south-facing windows.
- Installation of adjustable mechanical hygro-control of ventilation

Stage 2:

- Double service heat pump ηS ≥ 111% (medium and high temperature) ηS ≥ 126% (low temperature) producing hot water and heating.
- Emission through existing wall emitters (after verification of their sizing) and installation of thermostatic valves with a time variation of less than 0.3 K.

Elements not dealt with: floor slab insulation

INTERACTIONS TO DEAL WITH

Parcels concerned	Risks	Work to be planned
Stage 1		
Wall / Joinery	Thermal bridge + airtightness	With regard to joinery, provide for L-shaped linear insulating material (R>0.4m².K/W) to deal with the thermal bridge (lintel, jamb & sill). Ensure airtightness between the new joinery and the wall.
Roof slab	Thermal bridging & airtightness	If there is an airtight hatch, insulate the hatch and ensure that the junction between the hatch and the floor is airtight.
	Airtightness	Provide for the use of suitable accessories for airtight sealing of perforations, including flues (eyelets, adhesive tape, mastic, etc.).
	Condensation	In the absence of a high water vapour permeability type of underlay under the roof, provide ventilation underneath the underlay of the soffit or roofing.

[13] The calculations presented here are based on the methodology of the former French Energy Performance Survey rating labels applied prior to the 2021 reform.

	Thermal bridge	Provide for L-shaped linear insulating material at the top of the interior bearing walls at least 60 cm high at the interface with the roof slab.
	Airtightness	Provide for the use of suitable accessories for airtight sealing of perforations connected with ventilation (eyelets, adhesives, mastic, etc.).
	Airtightness	Anticipate the passage of networks and provide for appropriate means of airtight sealing.
Stage 2		
Domestic hot water	Airtightness	Provide for the use of suitable accessories for airtight sealing of network perforations (eyelets, adhesives, mastic, etc.).
	Comfort & over-consumption	Install devices to reduce hot water consumption (flow reducers for example).
Heating	Overconsumption	The size of the heating appliance needs to be planned in relation to the final project. Provide for the use of simple back-up heaters for intermediate conditions.

Breakdown of consumption by use				
	Initial condition	Stage 1	Stage 2	Unit
Heating	319	94	55	kWhPE/m²total net floor area.year
Domestic hot water	34	34	16	
Cooling	0	0	0	
Lighting	5	5	5	
Auxiliaries	1	4	4	
Total	360	137	80	
	34 091	12 988	7 559	kWhPE.year

Example 2: Large block of flats, in urban area, either on its own or in a housing estate, elongated rectangular form, built between 1948 and 1974, in the Côte d'Or region.

Building characteristics: massive construction in shuttered concrete or with prefabricated panels, with or without external rendering.High level of glazing. Single-glazed wood or aluminium joinery. Flat roof. With basement (car park). Unheated ground floor.

Initial situation: No thermal insulation.

The first stage of retrofitting makes it possible to pass from a D energy rating to a C rating[14] and reduce carbon emissions by 40%. The second stage makes it possible to reduce conventional energy consumption still further and, thanks to replacement of the heating and domestic hot water system, to achieve a residual level of carbon emissions.

[14] The calculations presented here are based on the methodology of the former French Energy Performance Survey rating labels applied prior to the 2021 reform.

R

Stage 1:

- External Thermal Insulation of walls (any type of insulating material accepted) with an external facing open to water vapour (rendering with Sd<2m), the R needs to be ≥ 4.4 m².K/W.
- Retrofitting of the waterproofing and insulation of the flat roof using an insulating material with PV and DTA (i.e. the "*Document Technique d'Application*" procedure for assessing non-traditional products in France) approval compatible with flat roofs, R needs to be ≥ 6.5 m².K/W
- Change of joinery. Uw value needs to be ≤ 1.3 W/(m².K)

Stage 2:

- Sprayed insulation of the floor slab with mineral wool with binder or PUR with a thermal resistance of greater than 3m²/K/W
- Installation of a Double Service heat pump ηS ≥ 111% (medium and high temperature) ηS ≥ 126% (low temperature) using existing emitters and thermostatic valve with time variation of less than 0.3 K
- Insulation of hydraulic networks (heating and DHW) in class, and insulation of junction points of the heating and DHW network in unheated volume, With: R insulating material ≥ 1.5 m².K/W (at T network = 50°C)

INTERACTIONS TO DEAL WITH

Parcels concerned	Risks	Work to be planned
Stage 1		
Wall / Joinery	Thermal bridge + airtightness	With regard to joinery, provide for L-shaped linear insulating material (R>0.4m².K/W) to deal with the thermal bridge (lintel, jamb & sill). Ensure airtightness between the new joinery and the wall. The blinds or shutters etc. need to be appropriate for new external insulation and joinery.
Roof slab	Thermal bridge + airtightness	If there is an abutment, ensure the continuity of the insulation of the airtightness system. If there is a rooflight or skylight, insulate the skylight frames and install high-performance infill and flashing. Install an airtight seal (membrane, adhesive tape, etc.) around the perimeter of the through elements. Provide for L-shaped linear insulating material at the top of the interior bearing walls at least 60 cm high at the interface with the roof slab.
Wall / Heating	Integrated thermal bridge	If there is an existing network, provide for its rerouting in order to avoid reducing the thickness of the insulating material in these areas.
	Airtightness	Provide for the use of suitable accessories for airtight sealing of perforations, including flues (eyelets, adhesive tape, mastic, etc.).
	Thermal bridge	Provide for L-shaped linear insulating material at the top of the interior bearing walls at least 60 cm high at the interface with the roof slab.
	Ventilation malfunction	Sealing or blocking (without asbestos removal) of rubbish chutes if they open into the housing.
	Ventilation malfunction	Ensure the airtightness of the landing door.
	Airtightness	Provide for the use of suitable accessories for airtight sealing of perforations connected with ventilation (eyelets, adhesives, mastic, etc.).
Ventilation	Airtightness	Anticipate the passage of networks and provide for appropriate means of airtight sealing.
Stage 2		
Floor / Heating	Integrated thermal bridge	If there is an existing network, provide for its rerouting in order to avoid reducing the thickness of the insulating material in these areas.

Domestic hot water	Airtightness	Provide for the use of suitable accessories for airtight sealing of network perforations (eyelets, adhesives, mastic, etc.).
	Comfort & over-consumption	Install devices to reduce hot water consumption (flow reducers for example).
Domestic hot water / Heating	Comfort & over-consumption	Check that the DHW system is balanced.
Heating	Overconsumption	The size of the heating appliance needs to be planned in relation to the final project.

Breakdown of consumption by use				
	Initial condition	Stage 1	Stage 2	Unit
Heating	122	42	15	kWhPE/m²total net floor area.year
Domestic hot water	61	61	49	
Cooling	0	0	0	
Lighting	5	5	5	
Auxiliaries	2	6	6	
Total	189	114	76	
	2 387 771	1 438 979	955 111	kWhPE.year

Photovoltaic production

Investment in photovoltaic technology should not be made at the expense of other investments contributing to the reduction of energy consumption (insulation and switching to a more high-performance system). This investment can even (in case of positioning of panels on the roof) be concomitant with roof insulation work.

Self-consumption of photovoltaic energy by the homes makes it possible to limit demand for electricity from the grid and reduce energy bills. In terms of the building's carbon emissions, it makes a non-negligible contribution[15].

Lastly, priority should be given to use of photovoltaic production in order to cover the ancillary section of electricity consumption (equipment in continuous operation: cooling in particular), specific controllable electricity uses (dishwashers, washing machines, etc.) or enabling energy storage (mobility, domestic hot water).

2.4. Adopting a comprehensive vision of performance

2.4.1. Integrating other dimensions into retrofitting (health, precarity, air quality, biodiversity, adaptation to climate change, etc.)

In order to successfully conduct high-performance retrofitting of the housing stock, it is necessary to adopt a comprehensive vision of the technical issues connected with buildings. High-performance retrofitting requires large-scale work, it is therefore an opportunity to mutualise costs by incorporating other issues connected with the permanence of the building and the health and safety of occupants (electricity, asbestos, indoor air quality, acoustics, etc.). It also needs to take other environmental issues into account, such as outdoor air quality (replacement of domestic wood-burning heating equipment enables a sharp reduction in the quantities of pollutants emitted), biodiversity (maintenance/creation of shelters to provide habitats for wildlife, planting vegetation, review of lighting in order to avoid disturbing nocturnal species, etc.), sustainable water management (reduction of the amount of water drawn,

15 The kWh produced by a PV module has zero direct emissions and indirect emissions equal to 44g if produced in China, 32g if produced in Europe and 25g if produced in France. These indirect emissions are steadily decreasing with the improvement of technologies and module efficiencies. The average content in the electricity mix (direct emissions) in mainland France was 52g per kWh in 2022 (Base Empreinte® database).

storage on the plot, etc.), and the impact of climate change (drought, heatwaves, flooding, hail, etc.).Moreover, special attention needs to be paid to limiting the environmental impact of retrofitting (e.g. reuse, waste management, preservation of the habitat of protected species at the time of insulation work, integrated rainwater management, etc.). Furthermore, retrofitting can also provide an opportunity for rethinking the density of occupation of the housing: indeed, a third of low-energy building retrofits involve extensions. However, apart from consumption per square metre, it is also important to bear in mind the overall consumption of the housing.

Other issues and aspects need to be taken into account, in particular the health and safety of occupants, and moreover their comfort (feeling at home, adapting one's home to ageing, keeping energy costs under control and compatible with income, etc.). Retrofitting that protects the occupants' health and the building needs to comply with best practices in terms of ventilation and diffusion of water vapour in walls, in order to avoid phenomena of condensation that give rise to the growth of moulds and various pathologies for the building, which are also detrimental to the quality of indoor air and therefore to occupants' health.

2.4.2. Adaptation to climate change: the right time to act

Adaptation to climate change henceforth needs be incorporated into retrofitting projects. It is a matter of making use of the synergies between retrofitting and adaptation (e.g. geothermal energy, which makes it possible to provide high-performance summertime comfort) and avoiding potential conflicts (e.g. not planting trees too close to walls whose roots could alter the water balance of the foundations). Adaptation issues include:

- **The phenomenon of Clay Shrinkage and Swelling (CSW), connected with increase in the variability of water content in clays as a result of major droughts, may give rise to major structural damage to individual houses.** The acceleration of climate change is exposing more and more homeowners to this phenomenon every year.
- **Summertime comfort: insulation and the installation of solar protection and ceiling fans are henceforth essential.** In view of climate change, the number of dwellings that will need to be air-conditioned is set to increase (due to lack of through passages, or their location in attics or urban heat islands), although it is not currently possible to identify the exact number. It is therefore necessary to plan ahead in order to ensure that air conditioning consumption is as low as possible: on the one hand, through high-performance retrofitting, which contributes to improving summertime comfort while protecting homes from cold waves, which are still probable in the context of climate change, and, on the other, through reduction of the heat input from equipment (refrigerators, screens, etc.).

Retrofitting and "heat traps"

Retrofitting should be an opportunity for putting in place strategies for managing overheating. In the first place, this needs to begin with the systematic installation of external solar protection. **Insulation of buildings (externally if possible, in order to preserve the building's inertia) limits the amount of incoming heat and makes it possible to limit discomfort.** Super-ventilation at night makes it possible to evacuate excess heat, which means, on the one hand, anticipating this need when designing retrofitting work (e.g. by installing mosquito nets in infested areas to enable opening of windows at night), and, on the other, mobilising the occupants (e.g. opening windows at night). Ceiling fans are particularly effective, while limiting energy consumption (Peuportier & al, 2023).

In certain areas (cities with urban heat islands, etc.) and for certain homes (absence of through passage, difficult to ventilate at night, etc.), specific cooling equipment needs to be envisaged: this therefore needs to be anticipated and highly energy-efficient active cooling systems deployed (ground-coupled heat exchangers, geocooling, geothermal heat pumps, adiabatic cooling, dual-flow systems, etc.), incorporating appropriate cold diffusion systems (air blast, fan coil units, underfloor cooling, etc.) into the retrofitting work.

2.5. Structuring the high-performance retrofitting market

2.5.1. Limited supply, which remains to be expanded

Supply refers to the whole of the goods and services necessary for the dwelling to achieve proper performance. In addition to the work itself (and therefore building contractors), it therefore includes supply of goods from manufacturers and supply of the services associated with design and monitoring of the project, and moreover its financing.

At present, the supply of both high-performance retrofitting work and support remains limited. The French RGE scheme for accreditation of retrofitting contractors has made it possible, on the one hand, to identify companies with the necessary skills ready to work in the subsidised market and, on the other, to train a large number of companies in the field of retrofitting. However, the number of companies with RGE Comprehensive Retrofitting accreditation is still very small (around 200), and while their dynamism is encouraging, technical (e.g. retrofitting using prefabricated off-site systems such as EnergieSprong) and organisational innovations (e.g. groups of tradespeople) still remain limited in scope. By 2030, the available projections (ADEME-Build Up Skills 2, France Stratégie, négaWatt, etc.) estimate that the additional need for labour dedicated to high-performance retrofitting work will amount to an additional full-time equivalent of between 170,000 and 250,000 (depending on the assumptions and scenarios considered), i.e. double the current full-time equivalent of 230,000[16]. By way of comparison, it is estimated that in 2021, employment in new construction represents an FTE of 350,000. There are existent needs at all levels of the industry, from design to implementation and operation (Paruelle et al, 2023).

It is therefore necessary to put an action plan in place in order to ensure the availability of the labour required for retrofitting throughout the country. This could include actions such as communication initiatives aimed at young people in order to improve the attractiveness of the trades (e.g. the "*T'es Refait*" ["You've reinvented yourself"] campaign), which could be extended to new audiences (retraining, jobseekers, etc.). It could also include actions to improve quality and productivity on site (e.g. off-site retrofitting), bring in new workforces (e.g. assisted self-retrofitting would make it possible in particular to keep tradespeople close to retirement in work and compensate for the unavailability of professionals in certain areas), and to retrain part of the workforce currently employed in new construction (given that this business is set to slow down in the future due in particular to demographic changes). Other actions will be necessary in order to meet these needs.

Self-retrofitting: a practice to consider with caution

Self-retrofitting refers to practices in which households take part in completion of the work. It covers a wide range of different practices: autonomous self-retrofitting, in which the household completes the whole of the work itself; mixed self-retrofitting, in which the household completes certain pieces of work and entrusts others to contractors; and assisted self-retrofitting (ARA, *auto-rénovation accompagnée*), in which the household contracts out work that it has defined with the help of an assistant – often a tradesperson – and completes a part of it itself (ARA may be social or activistic in nature).The 2018 TREMI survey on retrofitting work in individual houses highlights the very widespread nature of self-retrofitting: while 61% of retrofitting work was completed by professionals alone, 6% was completed by a combination of professionals and self-retrofitting, 18% by self-retrofitting making use of professional building skills, available in the family circle, and 15% by self-retrofitting without any specific skills.

With regard to the various different forms of self-retrofitting, there is a need to produce knowledge about the quality of the work completed, the conditions under which it is carried out and the possibility of coordination with professionals, in order to enable these practices to be more effectively integrated into public retrofitting policies.

[16] Estimate from the Build Up Skills 2 project. These estimates only concern needs connected with retrofitting, rather than home maintenance and improvement work as a whole.

Assisted self-retrofitting has great potential. While it is attractive to households that want to be involved in the work for a variety of reasons (of which financial issues are often far from being the only consideration), its deployment would require the introduction of systematic quality control.

2.5.2. Structuring the market around performance and quality

It appears essential to reinforce quality control of retrofitting work, in particular within the framework of the French RGE accreditation scheme for retrofitting contractors. The proportion of on-site inspections should thus be significantly increased and correlated with the number of projects completed by contractors. The inclusion of inspections concerning interfaces (airtightness) and ventilation (permeability of networks) for high-performance retrofits also appears essential. Innovations should also be introduced in inspection procedures, in order to enable the inspection of work in progress (for insulation in particular). This on-site inspection could be extended to self-retrofits in order to validate the receipt of subsidies.

Although considerable training efforts have been made in recent years for current and future building professionals (FEEBAT, renewable energy training, etc.), training remains central to the retrofitting workforce management strategy. These efforts need to continue:

- By continuing to train the whole of the tradespeople who install systems and materials on site, in order to ensure that each act of the work is completed in compliance with best practices and without interfering with the work of other trades.
- By improving training for work on occupied sites.
- By ensuring that there are a high enough number of technical systems maintenance contractors with the required skills to fine-tune systems and maintain their performance over time.
- By stressing the coordination of retrofitting work completed all at once or in stages, including within the framework of assisted self-retrofitting, and by helping professionals to take broader issues than retrofitting into account (adaptation to climate change, waste management, etc.). Via mass dissemination of programmes dedicated to techniques of insulation using so called "old" materials (timber framing, stone, earth, etc.).

Beyond quality of work, high-performance retrofitting requires high-quality design and worksite monitoring. **Supply of engineering services (auditing, project management, quality control, etc.) is still inadequate for the individual house and jointly-owned property sectors.** Solving the difficult equation of quality of supply and quantity of professionals will require:

- Obligations and funding to ensure that high-performance retrofits are conducted by qualified and competent contractors and that the essential independent quality control is conducted (airtightness test, ventilation inspection, etc.). The development of supply of services incorporating a contractual undertaking with regard to heat consumption. Confidence in the reality of energy savings and the quality of the work carried out is one of the key factors in the growth of the high-performance retrofitting market. The knowledge acquired in recent years has enabled a better understanding of the causes of discrepancies between estimated and actual consumption (uncertainties about the situation before completion of the work, characteristics of the calculation engines, quality of implementation, home occupancy patterns, climatic conditions, equipment maintenance, etc.). However, they can be controlled or supervised. **This makes possible the development of performance guarantees, that is to say commitment by contract to a real level of performance to be achieved post-retrofit.**

It is necessary to experiment with a model of comprehensive service providers capable of providing a package incorporating design, retrofitting work, financial engineering, financing, and a guarantee of actual performance. Its development will require the definition of a comprehensive retrofitting contract model guaranteeing the household or jointly-owned property a price, a deadline, and a commitment on the actual energy performance achieved after the work. The method of organisation of this model needs to leave room for a diversity of players (project managers, cooperatives and groups of tradespeople,

general contractors, etc.). Such a model will enable trust to develop, on the one hand, to reassure households and, on the other, to secure financing from the banking sector. Public funding for comprehensive retrofitting could thus be made conditional on contracts of this kind.

2.5.3. Structuring the demand for high-performance retrofitting through the supply of support to households and jointly-owned properties for their project as a whole.

In recent years, the organisation of the France Renov' network and the creation of the MonAccompagnateurRénov[17] retrofitting advisory scheme have enabled the provision of information, advice, and support to all households. However, the support needs to progressively evolve in order to cover all of the aspects of a retrofitting project (architectural, energy, climate, health, materials and waste, suitability for the life household's project, etc.), from the reflection phase upstream of the project to execution of the work, taking charge of the equipment and carrying out post-work inspections if necessary.

Furthermore, support for buyers needs to be systematically provided at the time of purchase or extension of a property. These moments indeed constitute opportunities for undertaking large-scale work. The players in real property transactions (estate agents, notaries, managing agents of jointly-owned properties, etc.) therefore have a major role to play.

In the case of individual houses, support is not currently provided either financially or by the France Renov' network for project management services during the work phase (monitoring and official acceptance of completed work after verification). Yet, this is a key moment for achieving proper performance: it is a matter of supporting households in the monitoring of work and ensuring compliance with good practices (e.g. choice of materials, and methods of storage of insulating materials, which has an impact on humidity levels and indoor air quality, etc.), as well as making sure that the correct settings are in place at the time of official acceptance of completed work ("water law" weather compensation for heat pumps, DHW storage temperature, unbalanced mechanical control of ventilation, etc.).It would therefore be useful, in the case of high-performance retrofitting, to systematise the use of a mode of organisation (project management, general contractor, grouping, etc.) that includes support for the household during the work and at the time of official acceptance of completed work.

2.6. Volumes of investment devoted to retrofitting to be raised in order to match needs

I4CE (2022a) estimates total investment in retrofitting of housing (by both public authorities and homeowners themselves) at 19.8 billion euros in 2021, for the most part devoted to non-comprehensive retrofitting work. In order to achieve the required rates of performant and comprehensive retrofitting, these sums would need to be reallocated to high-performance retrofitting and doubled, thus reaching an annual level of between 38.4 and 43.4 billion euros by 2030 (depending on the scenario considered, in constant euros). To this must be added a considerable amount of inextricably connected (finishing) and intimately related work (e.g. bringing electrical installations into compliance with standards), which can represent 50% of the total cost of work (Effinergie, 2019), as well as investment requirements for the adaptation of homes to both climate change, which are the subject of initial estimates ranging from 1 to around ten billion euros per year depending on the clay shrinkage and swelling risk management strategy (I4CE, 2024), and to ageing of the population (1.7 billion euros per year from now until 2030) (France Silver Eco and Filière Silver Economie, 2023). French housing is thus reaching a point in its history at which massive investment is becoming necessary in order to avoid its obsolescence.

The volumes of investment required make it imperative to think about the balance between public and private funding. In terms of the investment volumes to be provided for, there is a need for better calibration of the respective roles of public subsidies (in the form of direct incentives via subsidies and indirect incentives via subsidised loans), households' own funds or their contribution via debt, and private capital contributions by third-party investors.

[17] There are 380 accredited bodies today, that is to say 2,900 Rénov' Advisers.

2.7. Financing schemes adapted to the high cost of high-performance retrofitting

High-performance retrofitting represents a considerable cost, and all the more so as it is not part of most people's "dreams" and real property plans. Research by Effinergie (Effinergie, 2019, 2022) estimates the cost of low-energy building retrofitting (excluding project management) at €21,000 exclusive of tax per home for blocks of flats, and €56,000 for individual houses. These figures need to be updated in order to take the cost increases of recent years into account[18]. Generally speaking, annual monitoring of prices and costs would be necessary.

Funding of retrofitting for owner-occupiers involves a combination of public support (via direct subsidies of the MaPrimeRenov type and subsidised loans such as the Eco-PTZ scheme) and private funding. Subsidies can act as an incentive and/or facilitate the establishment of financing packages.

The cost-effectiveness of retrofitting is often put forward as a justification for investments. However, the notion of cost-effectiveness calculations as applied to retrofitting covers a variety of aspects, both monetary and non-monetary (pursuit of comfort, etc.), and the question of cost-effectiveness does not exhaust the budgetary issues involved in a retrofit (beyond "is it profitable for me?", other questions arise, such as "is it possible to finance the work under current borrowing conditions?"). **For this reason, priority should be given to approaches making it possible to focus on the economic viability of the project, rather than cost-effectiveness. In other terms, finding the equation to enable the project to be at once affordable (the resources to finance the work need to be obtained (subsidies) or borrowed (loans) in such a way as to limit the remaining outlay), beneficial (households need to receive a tangible benefit, in the form of savings on bills, comfort, green value and aesthetics, justifying the cost of the work) and solvent (retrofitting projects need to avoid placing a burden on household incomes, or exposing them to the risk of over-indebtedness) (I4CE, 2022b). This requires an individualised approach to the financing plan, and the resources and expenditure that make up households' monthly budgets, in order to assess their ability to contribute to the financing of their project.**

The increase in subsidies for high-performance retrofitting in 2024 will make it possible to reduce the remaining outlay for all categories of households. However, the current supply of financing options does not provide a solution tailored to the diversity of households' economic situations:

- For households with sufficient debt capacity and ability to cover their expenses (what is "left for living on"), éco-PTZs (subsidised interest-free loans) are the most suitable option. At present, they are still for the most part used to finance packages of individual pieces of retrofitting work (for which coupling with *MaPrimeRenov'* is organised and therefore facilitated). The changes planned for 2024 to more closely associate the *éco-PTZ* loans scheme with the new *MaPrimeRénov' Parcours accompagné* retrofitting assistance programme are therefore welcome.
- For low-income and very low-income households, for whom taking out a loan (or adding one to their existing mortgage) is not an option, the remaining outlay (that is to say the difference between the cost of the retrofitting work and the subsidies received) remains prohibitive despite a higher rate of financial assistance. It often represents more than a year of household income (I4CE, 2023). However, the new terms of the MaPrimeRenov' scheme from 1st January 2024 make it possible to envisage a remaining outlay of 10% for certain households (excluding local authority grants), according to criteria that need to be assessed. The impact of these regulatory changes also needs to be analysed. It is necessary to move towards nil remaining outlay for the most disadvantaged households, which can be achieved through high rates of assistance, additional funding (particularly from local authorities), and in any case without the need to take out a bank loan.

Moreover, delays in grants payment can hinder a projet: advance financing of subsidies is therefore essential. It is provided by ANAH (the French National Housing Agency) for low-income and very low-income households. Lastly, the *Prêt Avance Rénovation* scheme, which provides a loan that is ultimately repayable (at the time of sale of the property or on the death of the borrower, with only the repayments of interest being subject to gradual repayment), secured by mortgage and offering the possibility of

[18] By way of indication, the French Building Maintenance and Improvement Price Index (IPEA) stood at 124.5 for residential buildings at the end of 2022 (with base 100 in 2015) (INSEE, 2023).

recourse to the French guarantee fund for retrofitting (mobilised in case of default by the borrower), is designed as a solution of last resort, and remains little used.

Third-Party Finance Companies, providing an integrated combination of technical and financial skills, have demonstrated their ability to simplify the process for individuals, pool resources and change the rules of financing in terms of supply of credit. They generally conduct an assessment of repayment capacity, taking energy savings in particular into account. They contribute to facilitating the integration of different sources of finance tailored to the needs of project owners (smoothing of cash flow, advance financing of grants, and management of regulated loans). **Their development therefore needs to be encouraged.**

There are a number of avenues that need to be explored in order to facilitate financing by the banking sector, in particular to qualify loans allocated to retrofitting as being in line with the European taxonomy of sustainable activities and/or other more specific sustainability criteria and promote the green asset ratio (ratio measuring the share of so called green production in the total production for the year). Moreover, it may be useful to reduce the cost to banks of putting in place a proactive support strategy for the high-performance retrofitting market. This would make this activity more attractive for banks. It is also a matter of putting in place mutualised guarantee systems and specific guarantee funds to encourage the provision of credit. Lastly, there is a need to facilitate verification of the genuineness and accuracy of information and documents attesting to the completion and performance of work conducted.

2.8. Bringing public policy into line with performance

Public policies aimed at both the demand for and supply of retrofitting encompass a wide range of instruments: communication, information and advice, financial incentives, and regulation (obligation, prohibition), etc. In terms of high-performance retrofitting, the principal advances in recent years have been the introduction into financial aid packages of the possibility of financing project engineering (auditing, and the MonAccompagnateurRenov retrofitting advisory scheme) and high-performance retrofitting. Overall, however, the corpus of public retrofitting policies has difficulty in creating the necessary market conditions for speeding up high-performance retrofitting. *"Public policy on the retrofitting of buildings has not been able to define a precise economic model encouraging households to undertake high-performance retrofitting"* (Estrosi Sassone and Gontard, 2023).

In addition, many existing obligations (obligatory work involved in joint-ownership of properties, compulsory surveying of products, equipment, materials, and waste, etc.) need to be monitored. Putting in place the necessary support (funding, recruitment, and training of professionals, etc.) for the implementation of current obligations therefore remains a challenge.

Nevertheless, the development of this market needs to be supported by public policies making it possible to orient both demand and supply towards the achievement of the highest possible level of performance. **Public policy instruments as a whole need to be brought into line with the objective of performance.** For example:

- **Public communication needs to be aimed at creating a positive image of high-performance retrofitting.**
- **The France Renov' information and advice scheme needs to evolve in order to take broader issues into account (old buildings, adaptation to climate change[19], indoor air quality[20], potential for reuse of materials, etc.), and to guide households towards a first stage of retrofitting consistent with the requirements of low-energy building accreditation.** Housing surveys need to evolve in order to take into account the issues of adaptation to climate change (e.g. Clay Shrinkage and Swelling surveys). With regard to summertime comfort, an indicator could be incorporated into the French Energy Performance Certificate making it possible to characterise "heat traps" and include them in the criteria for decent housing.

[19] For example, the R4RE tool (Resilience for Real Estate, https://www.resilience-for-real-estate.com) and the research on the Resilience Performance Surveys (https://www.mrn.asso.fr/resilience/diagnostic-performance-resilience/).
[20] The ECRAINS® method (Building Commitment for Healthy Indoor Air), developed for the construction of new buildings, can be adapted to retrofitting.

- **Funding mechanisms (financial aid and loans) need to incentivise limitation of the number of stages and appropriate sequencing and ensure that interfaces are taken care of at the right time, to avoid the risk of their treatment at a later date representing a prohibitive cost.** Incentives could be put in place to subsidise the financing of the second and, above all, third stages, in order to avoid leaving homes in the middle of the retrofitting process, particularly in the case where hybrid heat production systems are put in place in the first stage in order to ensure the elimination of carbon-based systems after insulation. Moreover, the funding needs to take the various dimensions of performance into account. For example, funding for measures to prevent the Clay Shrinkage and Swelling (pavements around the perimeter of houses, geomembranes, anti-root screens, etc.) is essential in order to avoid the destruction of part of the investments in retrofitting due to disruption created by this phenomenon.
- **Under current regulations, retrofitting of buildings classed F or G under article L.173-1-1 of the French Building Code can be considered as high-performance retrofitting if, after the work, they achieve at least class C and the six categories of work have been studied. ADEME recommends that these regulations should be revised in order to ensure that retrofitting of homes that have not achieved an A or B label after completion of the work can only be considered to be high-performance retrofitting in the case of buildings for which technical, architectural or heritage constraints, or costs that are manifestly disproportionate to the value of the property, can be demonstrated and justified.** The achievement of energy and climate targets necessitates a significant reduction in the energy consumption and carbon emissions of these homes. Moreover, the French Thermal Regulations for existing homes need to be revised in order, on the one hand, to make them consistent with environmental regulations making it possible to take the carbon content of building materials into account as well as summertime comfort and, on the other hand, to review the method of calculation in order to make it more robust (CIBLE project).

The articulation of measures for provision of information and funding aimed at performance has great potential to accelerate the pace of high-performance retrofitting. Pioneering local initiatives articulating supplementary subsidies and national aid, in order to reduce remaining outlay, advances and subsidised loans, information desks and communication campaigns have, for example, resulted in a 3.5-fold increase in the rate of high-performance house retrofitting as compared with the national rate (Desquinabo, 2024).

Public policy tools other than those already in existence may be envisaged to develop the high-performance retrofitting market. **If a general obligation to retrofit in the event of change of ownership is to be envisaged, all of its potential consequences need to be examined, in order to document the benefits and limitations of the measure in a transparent manner, as well as the conditions of its economic, technical and social feasibility.**

The objectives of mass deployment can only be achieved via a transitional phase of ramping up the schemes and the number of qualified professionals. It is necessary to plan this phase in the most effective possible manner, with a clear multi-year timetable (with progressive increase in both supply and demand) and support for the actors. Similarly, the accompanying regulatory changes need to be defined and concerted sufficiently in advance of their application to enable the professionals concerned to adapt. Lastly, mechanisms (particularly insurance measures) need to be provided for in order to manage the inevitable occurrence of occasional shortcomings generated by a rapid expansion of the high-performance retrofitting market.

2.9. Continuing research, development and innovation

Support for research, development, innovation and industrialisation is necessary in order to:

- **Explore technical issues that are still little documented:** achievement of performance in blocks of flats, adaptation to climate change, analysis of the old and/or heritage building stock, development of in situ methods for measuring the characteristics of building envelopes and the performance of equipment, ways of dealing with buildings that are already partially insulated,

quality of work conducted by self-retrofitting (whether or not assisted), methodology for calculating the carbon impact of retrofitting, etc.

- **Support technical innovation and standardisation,** particularly for heat pumps capable of adapting to phased retrofitting with high power modulation (5 to 100%), phased insulation systems enabling the handling of interfaces, prefabrication of systems combining insulation and ventilation, low-energy cooling systems (adiabatic systems, ceiling fans, etc.) and systems for measuring actual performance (on official acceptance of completed work, and in use).
- **Support organisational, financial and legal innovations to develop new business models** (for example comprehensive service providers) capable of making the retrofitting procedure easier and faster for households, facilitate the financing of projects (sale of right to maximum surface area that can be built on within a plot of land, income from production of renewable electricity, green value, taxonomy, etc.) and provide confidence in real energy savings.
- **Support the development of industrial production of products (cladding, insulating materials, joinery, etc.), equipment and the components thereof (heat pump compressors, ceiling fans, etc.) in France.**
- **Integrate retrofitting of housing on a wider scale (housing block, district) in order to take advantage of synergies with other policies, in particular environmental policies (air quality, urban consolidation, No Net Land Take, district heating network, etc.).** Lastly, there is a need to be able to base innovation and retrofitting policy on data that is accessible to all. Making all French Energy Performance Certificates conducted available as open data has enabled the ecosystem to improve its knowledge of the housing stock. Initiatives such as the French National Building Database (*Base de Données Nationale du Bâtiment*) and the National Building Monitoring Centre (*Observatoire National des Bâtiments*), which combine and cross-reference a wide range of data, are complementary, and need to be supplemented by all types of information (data on subsidised retrofitting work, etc.) enabling increased knowledge of the development of the housing stock.

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