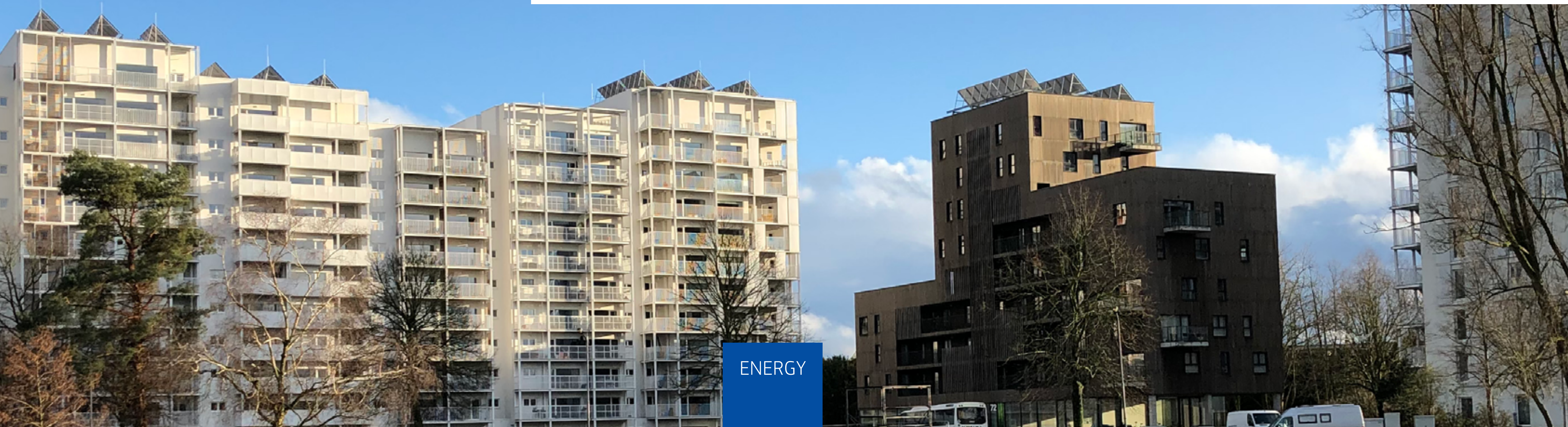
European Commission

BUILDING ENVELOPE RETROFIT SOLUTION BOOKLET

Smart Cities Marketplace 2023

The Smart Cities Marketplace is managed by the European Commission Directorate-General for Energy



ENERGY

Publisher Smart Cities Marketplace © European Union, 2023

Completed in: January 2023

Author: Smart Cities Marketplace managed by the European Commission Directorate-General for energy
smart-cities-marketplace.ec.europa.eu | European Commission | DG ENER

2023 version is written by: Paulina Rodriguez Fiscal, Han Vandevyvere (VITO/EnergyVille), Leen Peeters (Th!nk E)

2020 version is written by: Yixiao Ma, Han Vandevyvere (VITO/EnergyVille), Leen Peeters (Th!nk E)

Proofreading: Gabi Kaiser, Siora Keller (Steinbeis 2i)

Graphic design: Agata Smok (Th!nk E) for the Smart Cities Marketplace, European Commission DG ENER

Cover image ECO-life project in Kortrijk, Belgium where appartment buildings built orginally in 1970 were retrofitted to low-energy residences in 2021. © Agata Smok

Typeface: EC Square Sans Pro

interactive

WHAT IS THE SMART CITIES MARKETPLACE?

The Smart Cities Marketplace is an initiative supported by the European Commission bringing together **cities, industry, SMEs, investors, banks, research and other climate-neutral and smart city actors**. The Smart Cities Marketplace Investor Network is a growing group of investors and financial service providers who are actively looking for Climate-neutral and smart city projects.

WHAT ARE THE AIMS OF THE SMART CITIES MARKETPLACE?

The Smart Cities Marketplace has thousands of followers from all over Europe and beyond, many of which have signed up as a member. Their common aims are to **improve citizens' quality of life, increase the competitiveness of European cities and industry** as well as to **reach European energy and climate targets.**

WHAT CAN THE SMART CITIES MARKETPLACE DO FOR YOU?

Explore the possibilities, **shape** your project ideas, and close a **deal** for launching your Smart City solution! If you want to get directly in touch with us please use info@smartcitiesmarketplace.eu

© Oliver Cole on Unsplash

WHAT AND WHY

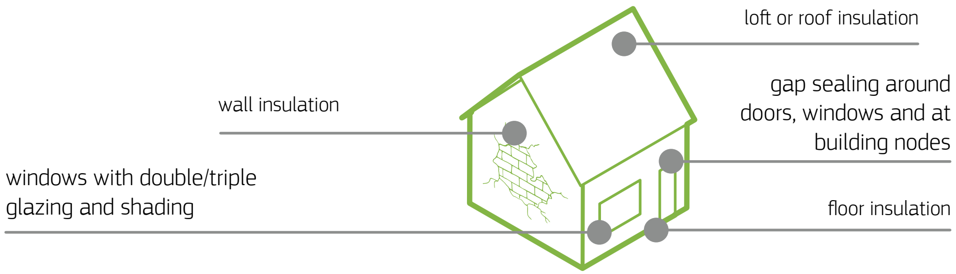
© Jesus Cardona

WHAT AND WHY

Buildings are the single largest energy consumer in Europe, accounting for approximately **40% of the EU's energy consumption**, while **75% of buildings' heating and cooling is produced from fossil fuels**. Nearly 35% of the buildings in Europe are more than 50 years old, and almost **75% of the building stock is considered inefficient**.

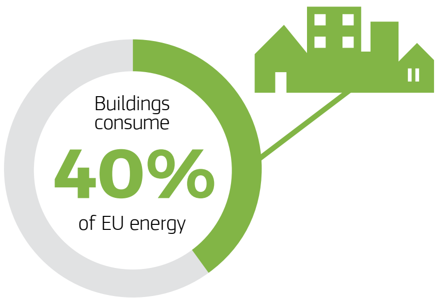
At the same time, the building renovation rate stays rather low, averaging around 1% per year. Increasing this renovation rate can contribute to the more efficient use of energy and the reduction of CO_2 emissions while improving indoor thermal comfort.

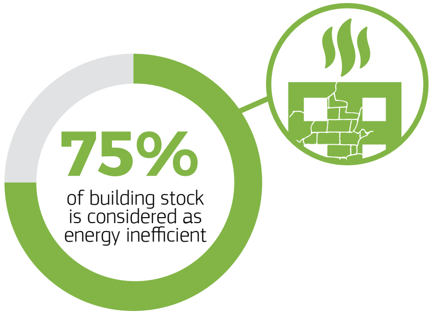
Various energy retrofit measures can be considered, targeting the **building envelope** on the one hand and the building's thermal and electrical systems on the other hand. Building envelope retrofit, **reducing the thermal losses** from **transmission** and **infiltration**, is a logical and impactful first step.

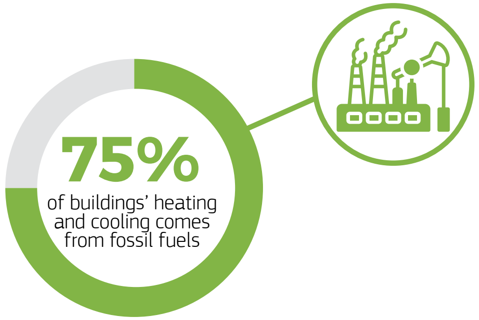


This booklet focuses specifically on envelope retrofit and considers it from a **technical, financial, social and governance perspective**.

Implementation **barriers**, as well as the **upscaling potential**, will be discussed and illustrated by experiences from different European projects.







CITY CONTEXT

© Agata Smok

CITY CONTEXT

Given the importance of energy retrofit, the EU has supported many consortia to experiment with new techniques and operational procedures, financing schemes, end-user engagement strategies and governance process setups.

From the analysis of a set of nearly **50 building retrofit** demonstrators, it appears that half of the retrofit projects realise savings of 50-75% of the total final energy demand.

Some selected examples are shown below.

In Valencia, Spain 548 dwellings (62,243m^2 in total), including 536 privately owned houses and 12 social housing units are deeply retrofitted. Roof, façade, glazing and shaing measures are implemented beyond national regulation for refurbished buildings and normal practices. This retrofitting aims for 64% of energy savings (including through renewable energy integration).

In Valladolid, Spain, an intensive building envelope retrofitting plan was deployed for 398 dwellings (24,700m^2 of the conditioned area with 1,000 residents). The energy demand of these buildings is drastically reduced through the implementation of passive measures on walls, roofs, and windows. The energy saving is around 32%.

In Nottingham, Great Britain, a comprehensive retrofitting program was developed in the Sneinton area in order to achieve a low energy district (23,318m^2 of conditioned area, 411 dwellings with around 1,600 residents). The retrofitting intervention focuses on wall and roof insulation, especially on properties that are over 100 years old. The energy savings are around 40%.

A set of envelope-related interventions were implemented in Tepebasi, Turkey (9.110m^2, 57 dwellings for 400 residents). Through exterior wall insulation, triple glazing and attic insulation, 53% energy savings were achieved.

In San Sebastian, Spain, 156 residential buildings and 34 commercial buildings (totaling 18,350m^2) were retrofitted with façade, roof, and ground floor insulation and energy-efficient window replacement, resulting in a 35% reduction of primary energy consumption (in combination with a district heating network).

In Florence, Italy, 300 social housing dwellings with 700 residents, totalling 20,000m^2 of floor area, were retrofitted with envelope insulation, which results in an energy saving of around 30% (in combination with a district heating network).

In Vitoria-Gasteiz, Spain, 312 dwellings (23,110m^2) were retrofitted by insulating the envelope and installing double-glazed exterior windows. Additionally, those buildings were connected to a new biomass district heating network. This reduced heating demand by 52.5% and CO_2 emissions by 89%.

In Sonderborg, similar envelope retrofitting actions were implemented in the demonstration sites consisting of 51 buildings with 815 apartments and 66,181 m^2 of built area in total. The energy savings due to these district renovations have reached 2,980 MWh.

In Nantes, France, both multi-dwelling apartments and individual houses were retrofitted by the implementation of better thermal insulation and the installation of smart devices and renewable energy systems. Five multi-dwelling apartments (270 dwellings of 18,000m^2) achieved an average energy performance of 80 kWh/m^2/year (35-68% relative saving depending on the building), whereas 32 individual houses reduced energy use by 24% on average.

In Nice, France, two apartment buildings with 132 dwellings (10,684m^2) were retrofitted so that the energy savings are expected to be 900 MWh/year after renovation meaning a CO_2 reduction of 252 ton CO_2/year.

In Barcelona, Spain, 207 dwellings (over 14,000m^2) were retrofitted with external wall insulation and efficient shading. Natural gas consumption for space heating was reduced by 22% to 30% (depending on the building). In addition, 53% of the monitored dwellings have increased thermal comfort in winter, while there is also a 43% reduction in dissatisfaction due to temperature imbalance.

6 buildings with a total of 323 apartments were retrofitted in the area of Valla Torg in Stockholm, Sweden. The refurbishment measures consisted of the upgrade of the thermal envelope and many other active measures. Overall, the measures achieved a reduction of the total energy consumption of the buildings by 60%.

In Cologne, Germany, a large energy retrofitting project in 16 residential buildings with 687 rented dwellings was implemented in the Stegerwaldsiedlung neighbourhood. Similar measures are included – envelope insulation and window replacement. Combined with a few active measures (LED lighting, PV panels), the total final energy saving is up to 61% at the individual building level.

TECHNICAL SPECIFICATIONS

© Th!nk E

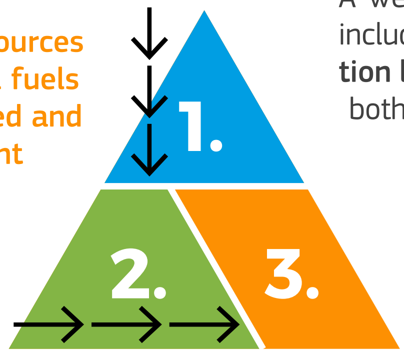
TECHNICAL SPECIFICATIONS

Classification of solutions

Trias Energetica

The **"Trias Energetica"** principle describes a logical three-step strategy for realising an energy-efficient building:

1. **Reduce the overall energy demand of the building by measures such as good insulation and airtightness;**
2. **With the energy demand being reduced, the next step is to use as many sustainable energy sources (e.g., solar, wind, geothermal...) as possible to supply the remaining demand;**
3. **If sustainable energy sources are not available, fossil fuels should only then be used and if so in the most efficient way possible.**



With the concept of the **Trias Energetica** in mind realising an energy-efficient building should always **start with reducing the heating (or cooling) losses** from the conditioned interior space towards the outdoors.

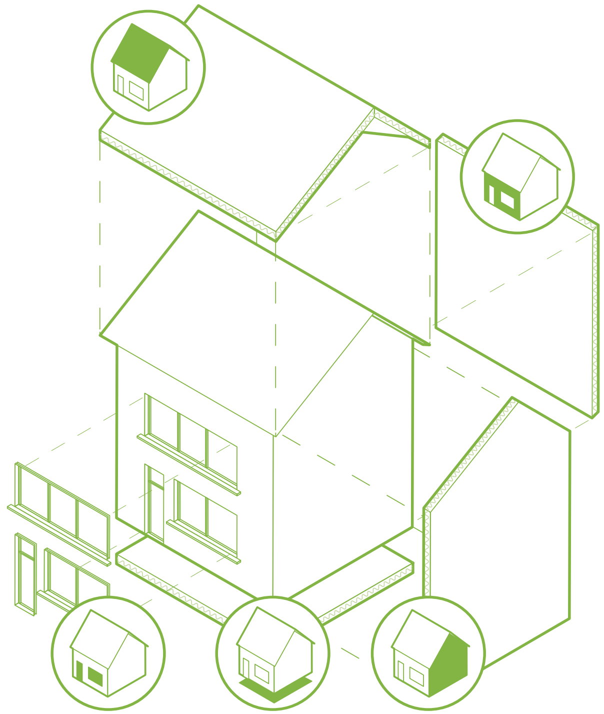
The building envelope is hereby defined as the physical barrier separating the interior spaces from the exterior. It consists of **roofs, walls, floors, windows and doors**.

Different retrofit measures can be carried out on both opaque and transparent components of the building. The resulting envelope retrofit can be realised at the **component level, dwelling level, building level** and even at an upscaled **district level**.

Adding **insulation material** is the most common measure for **improving the thermal resistance** of opaque parts of the building envelope, thus **reducing the number of thermal losses**.

The exact insulation measures depend on the type of structure, the type of insulation material, and the location of the insulation material within the structure.

A well-designed insulation addition includes measures to **reduce infiltration losses.** Good execution is key for both, but especially for the latter one.



The trade-off between the building envelope retrofit depth and the sustainable heat and cold supply level.

How much exactly needs to be insulated or to what extent the losses need to be reduced is to be seen from a system perspective. Sustainable heat (or cold) sources can be available locally and at various temperatures depending on their origin.

In the case where a high-temperature **local heat source** is available; a lower insulation level may be a responsible choice. A good example hereof is a heritage area where buildings present few possibilities for extra insulation but where the same area could be serviced by a sustainably sourced, high-temperature **district heating** network.

When **waste heat** at low temperatures is available, better-insulated envelopes combined with floor heating or low-temperature radiators could be opted for.

The balance includes a combination of building-level assessments and evaluations at a larger scale, requiring expert advice to lead to the most sustainable approach.

Local **heat zoning plans** play an important role in settling the outcomes of the said trade-off. Heat zoning plans define the urban areas where district heating and cooling networks will be rolled out, with given temperature regimes versus those areas where stand-alone systems such as individual heat pumps will be the standard solution for building installations. In other words, the urban area roadmaps and the individual building roadmaps (see also further) must be compatible with each other. All of this must be considered from the perspective of a decarbonised energy system, phasing out fossil fuel-sourced installations.

Read more about district heating and cooling as well as heat zoning plans here: smart-cities-marketplace.ec.europa.eu/insights/solutions

Thermal conductivity (k-value)

The basic measure of how much heat energy is conducted by any building material, including thermal insulation materials, is thermal conductivity. It is characterised by the lambda (λ) value, or k value (unit: W/m*K). As a rule of thumb, the lower the thermal conductivity the better, since the material conducts less heat energy. 'k' and 'λ' are material characteristics, whereas 'R' and 'U' as discussed below are building component characteristics.

Thermal resistance (R-value)

Thermal resistance is the inverse principle of conductivity. The lower the conductivity, the higher the resistance. To compare the relative performance of different thicknesses of materials (and composite building parts consisting of several layers of different materials) implies assessing their thermal resistance (unit: m^2*K/W). Thermal resistance is calculated by dividing the thickness of the material by its thermal conductivity, giving an R value specific to that thickness. As a rule of thumb, the higher the thermal resistance the better, as there is a greater resistance to heat transfer. Resultantly, the thermal resistance can be increased by selecting a material with a lower conductivity and/or by providing a thicker layer of that insulation material. In a composite wall, the thermal resistances of the different layers add up.

Thermal transmittance (U-value)

A U-value is a measure of thermal transmittance, or the amount of heat energy that moves through a floor, wall or roof, from the warm (heated) side to the cold side (unit: W/m^2*K). As a rule of thumb, the lower the U-value the better. In this way, U is the inverse of R.

NZEB Flanders:

Roofs: U_{roof} = 0.24 W/m^2*K

External walls: U_{wall} = 0.24 W/m^2*K

Windows (profiles and glazing):

U_{window} = 1.5 W/m^2*K and glass: U_{glass} = 1.1 W/m^2*K

Doors: U_{door} = 2.0 W/m^2*K

Floors: U_{floor} = 0.24 W/m^2*K

U-value requirements for renovated buildings in Sweden:

Roofs: U_{roof} = 0.13 W/m^2*K

External walls: U_{wall} = 0.18 W/m^2*K

Windows (profiles and glazing):

U_{window} = 1.2 W/m^2*K

Doors: U_{door} = 1.2 W/m^2*K

Floors: U_{floor} = 0.15 W/m^2*K

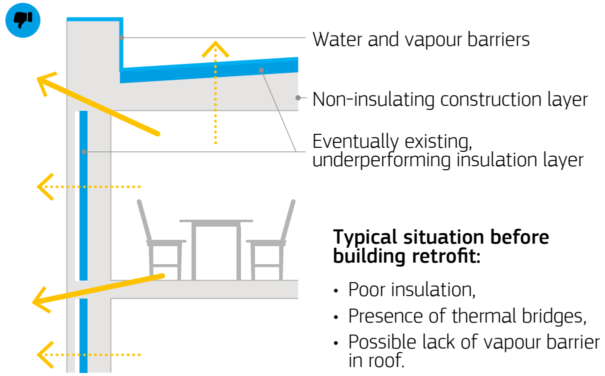
Façades/external walls

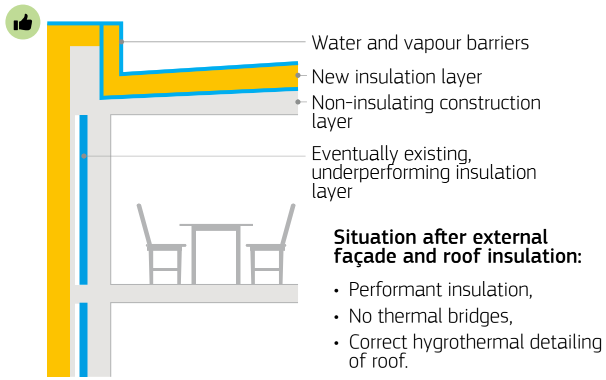
For façades, the insulation layer can be placed externally, internally or in the wall cavity.

External insulation

External insulation implies that **one or more insulation layers are applied to the external surface of the wall**. The extent to which the existing wall is dismantled depends on its state of conservation and the type of insulation. The existing rendering or cladding of the external surface sometimes needs to be removed before putting the new insulation layers. Most often, a **new façade finish will have to be applied on top of the newly added insulation layer**. A common example is rendering, but light façade systems and even a new outer stone or brick blade are possible, as far as the right support systems are put in place (support frames attached to the existing façade or new foundations).

From a building physics perspective, external insulation is the preferred option because (1) it provides the **most guarantees for realising a continuous insulation coat around the building without 'thermal bridges'** (interruptions in the insulation that provoke accrued thermal losses and lead to risks like condensation) and (2) it completely **'packs' the thermal mass of the building structure so that the latter can work as heat (or cold) storage within the protected volume**, reducing the temperature fluctuations and hence improving the thermal comfort.





Situation before insulation. © Th!nk E

Insulation works. © Th!nk E

New outer brick blade. © Th!nk E

Internal insulation

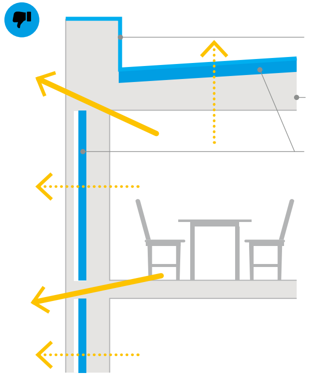
Internal insulation means adding an insulation layer on the inside of the external wall.

The most common method is to **build a new stud wall and add the insulation layer into its structure.** However, internal insulation can be disruptive, and it requires the removal and re-fixing of indoor items or equipment. It is also sub-optimal from a building physics perspective.

Three bottlenecks are:

1. **unavoidable thermal bridges (for example, where concrete floors are fixed into the external walls);**
2. **loss of the thermal capacity of these external walls; and**
3. **thermal stress on the latter, which is now fully exposed to heat and cold shocks from the outside.**

In addition, the useful floor area is decreased by the internal insulation package. Internal insulation must, therefore, be regarded as an option to choose when other solutions are **not possible or judged too complex or expensive** to realise.



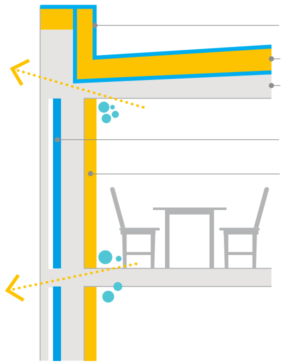
Water and vapour barriers

Non-insulating construction layer

Eventually existing, underperforming insulation layer

Typical situation before building retrofit:

- Poor insulation,
- Presence of thermal bridges,
- Possible lack of vapour barrier in roof.



Water and vapour barriers

New insulation layer

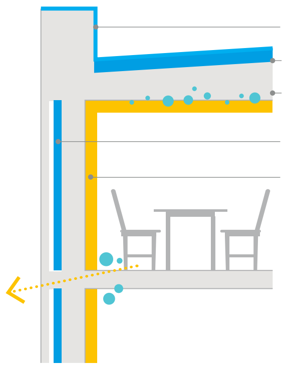
Non-insulating construction layer

Eventually existing, underperforming insulation layer

New inside insulation layer

Situation after internal façade and external roof insulation:

- Performant insulation,
- Correct hygrothermal roof detailing but remaining thermal bridges and condensation risks.



Water and vapour barriers

Eventually existing, underperforming insulation layer

Non-insulating construction layer

Eventually existing, underperforming insulation layer

New inside insulation layer

Situation after internal façade and roof insulation:

- Performant insulation, but remaining thermal bridges and internal condensation risks (critical in roof).

© Smart Cities Marketplace

Cavity wall insulation

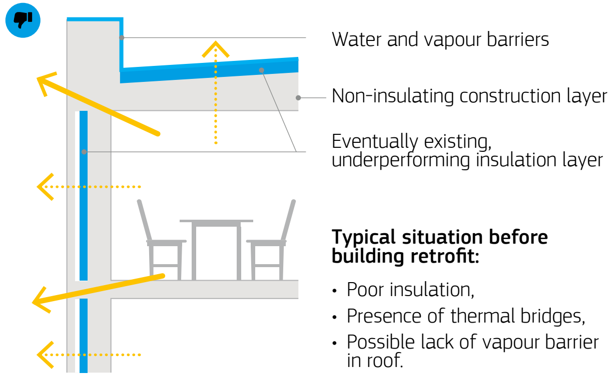
If the external wall has an empty cavity and the cavity is wide enough (at least 50 mm), the latter can be filled with appropriate insulation material to improve the thermal properties of the external wall.

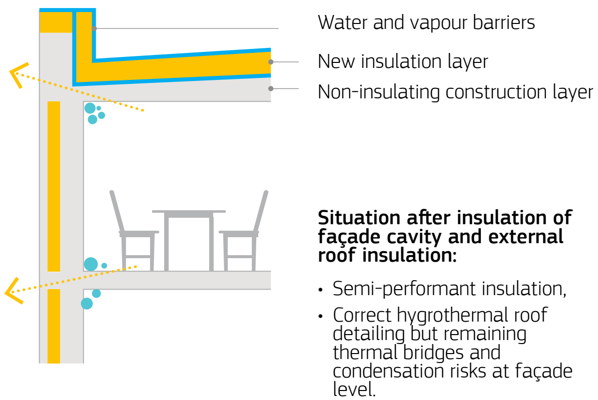
While most brick walls are suited to glazed bricks, some painted façades, as well as older porous bricks, cannot be combined with cavity wall insulation. The insulation layer thus reduces the heat losses through the cavity by **removing the air layer with more performant insulation material.** Although this is a very convenient solution (few disruptions, relatively cheap), it has some disadvantages, like internal insulation.

Unavoidable thermal bridges are the main challenge with this solution, depending on how much the internal cavity is continuous or not.

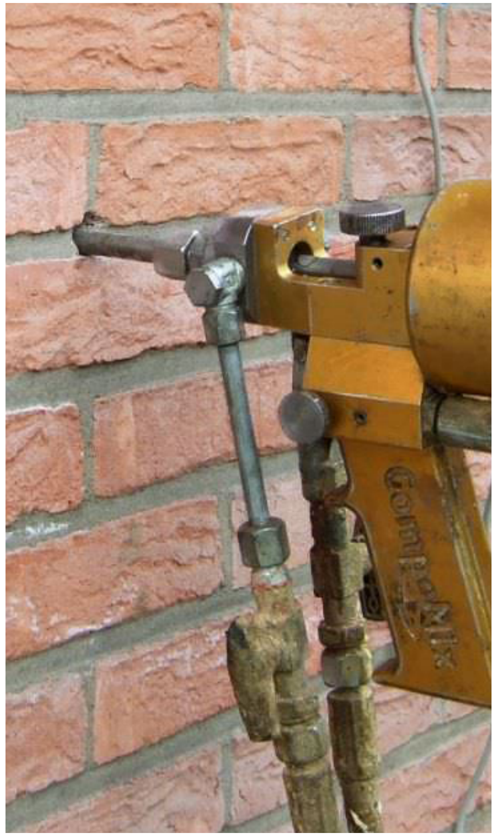
The potential improvement of the thermal performance is also limited by the width of the cavity. However, the thickness will be just enough to overcome the typical thermal discomfort that comes with cold exterior walls.

© ugent.be

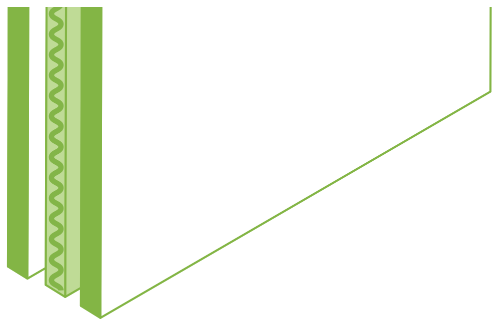




For any of the above insulation measures, it is strongly recommended to **get advice from a building expert** to realise a durable set-up that fulfils the proper hydrothermal prerequisites. Expert advice is equally recommended for solving the building nodes, as explained below.



© ugent.be



Building envelope nodes and avoiding future lock-in effects

To be effective, the insulation layer around the protected volume of the building must be continuous. Where external walls meet roofs, windows, or floors, this may imply that substantial adaptations to those specific building nodes must be carried out.

For example, **extending the roof surface and its insulation layer so that these connect well to the newly added external insulation layer and finishes on the façades**.

When a building is retrofitted in phases, one must already **consider future interventions** in order not to jeopardize the principle of continuous insulation.

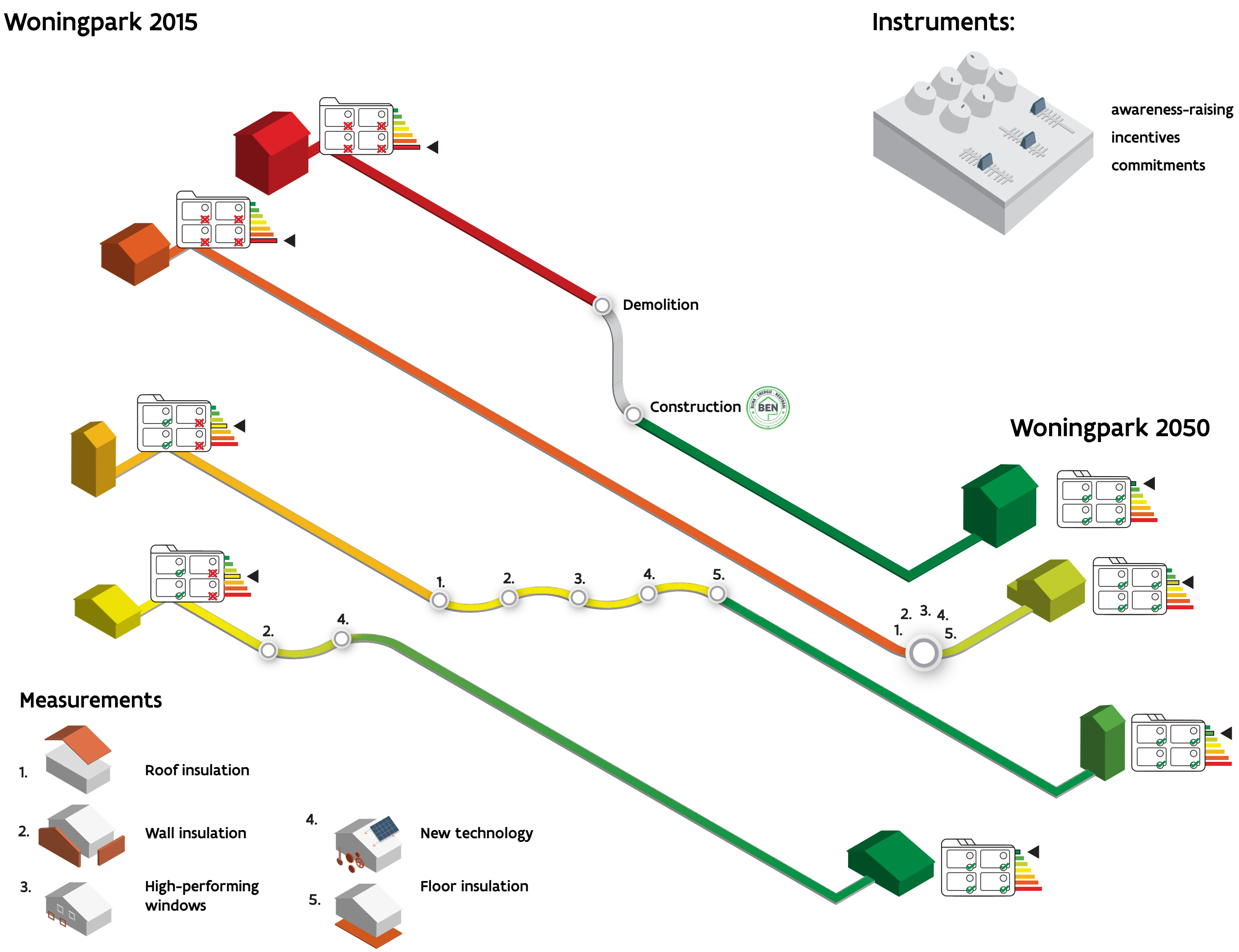
An example is window replacement: it must be considered that, at a later stage, the façades may be insulated and hence must properly connect to the new window profiles.

If the reduced net window opening resulting from this future intervention is not considered beforehand, the window replacement will lead to a lock-in where no technically correct solution is possible without replacing the windows again, this time with a smaller glazing area.

Illustration of the need to redesign building nodes, e.g., where retrofitted roof and façade meet. © Smart Cities Marketplace

The best way to avoid sub-optimal lock-ins while future-proofing the building in phases is to revert to the use of a **building roadmap**.

This roadmap envisages the desired end-state of the building and articulates the possible scenarios to reach that end-state step by step.



Example of building road mapping: use this image from © [Energiesparen/VEKA]()

Roof/Attic

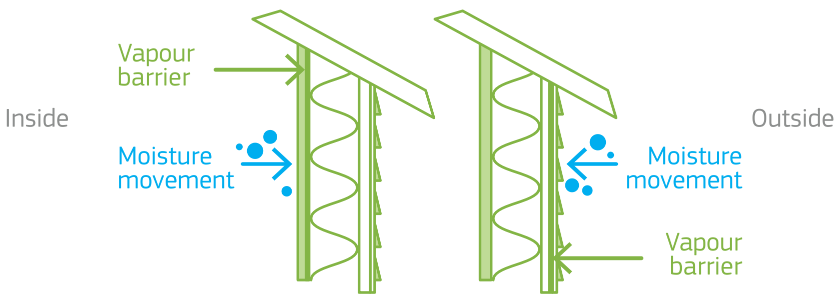
Roof insulation

Roof insulation is generally more critical than wall insulation and will most often be the first measure to apply when prioritising retrofit interventions.

At the same time, the payback time for roof insulation is generally (much) shorter than for wall insulation. How the roof is insulated depends on the roof type. The appropriate techniques for flat roofs are substantially different from those for pitched roofs.

When insulating a roof, one must be careful to install **vapour barriers** where needed and in the appropriate position, to avoid internal condensation **in the roof structure and hence future stability issues.**

Cold climates: Warm humid climates:



The importance of vapour barriers

If excessive amounts of water vapour were to get accumulated into the wall, roof or floor structure and the corresponding insulation layers, this would reduce the insulation properties and potentially lead to defects such as dampness, mould and/or rot. The resulting damages may be far-reaching, up to the structural failure of building components. Properly placed vapour barriers prevent these effects.

A vapour barrier is a continuous foil or sheet which is impermeable to water vapour. As warm air can contain more vapour than cold air and condensation may thus occur where there is moisture transport towards the colder air zones, the foil is always installed on the warm side of the insulation layer. This shield prevents the moisture from migrating toward the colder parts of the wall, roof or floor.

On the cold side, the insulation is not covered with a similar vapour sheet. The reason is that e.g., temperature changes can lead to increased humidity in the insulating material, and an open side enables it to dry. An exception occurs with the use of a water – and vapour-tight outer finishing layer, such as the waterproofing sheet on most flat roofs. Here one must make sure that upon installation, the insulation material is perfectly dry while it is being embedded in between the inner vapour barrier and the outer water-vapour proofing sheet. As such, no humidity can ever get into the sealed insulation package.

Vapour barriers must not have air leaks letting moisture to seep in, just like roofing foils should not have perforations letting water pass through.

Insulating the roof to future-proofed standards will often imply that the **roof thickness increases**:

→ It will not be the case in a pitched roof where the insulation can be added between the rafters and inwards into the attic space;

→ It will however be the case in pitched roofs where the sarking technique is applied. Hereby a new, continuous insulation package is added on top of the existing rafters;

→ And it will mostly be the case for flat roofs where the insulation layer on the outside is thickened and a new waterproofing membrane is added.

In this way, a similar challenge, as discussed for the façades will occur at the building nodes, for example, at the connections between roofs and façades. Roof borders may require substantial reworking.

Insulating a flat roof inward under the roof structure brings **high risks of internal condensation** and must only be done in specific setups with the approval (and control of execution) of a building expert.

For most **pitched roof types**, in contrast, the solution works very well if certain conditions are fulfilled (for example, the proper installation of a vapour barrier where interior climate conditions require such). The insulation of pitched roofs is commonly the first and most evident measure to increase a building's energy efficiency, as it is easy to execute and comes with short payback times.

Attic insulation works in a single-family house in Belgium © Agata Smok

Retrofitting works . © Smart Cities Marketplace

Attic insulation

There are two types of attic: cold and warm.

In the cold attic, insulation is **placed on the attic floor** rather than in the roof structure, keeping the loft cold. This may be a viable solution where the attic is not used, or only as a storage space for materials that can resist heat and cold shocks. When storing materials in an attic, attention must be paid in order not to damage the insulation layer in the use phase.

In the warm attic, **thermal insulation is placed in the roof structure**. In this way, the attic can be used as a living space rather than as a storage space solely.

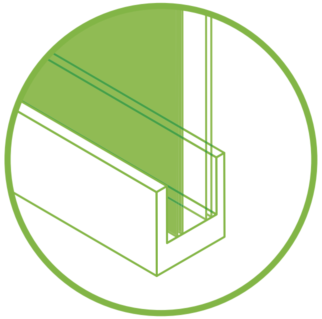
Retrofitting works . © Smart Cities Marketplace

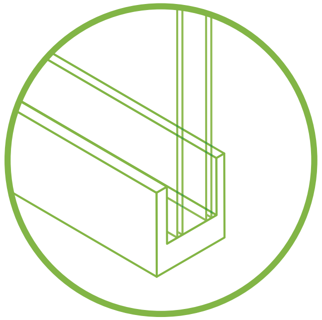
Windows/Doors

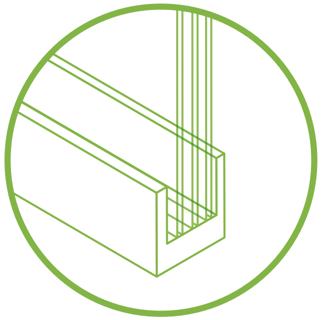
Replacing old single – or double-glazing windows with **energy-efficient glazing and profiles** (e.g., low-E glazing, up-to-date double/triple glazing, window frames with double or triple thermal chambers) can significantly increase the energy performance of the building. Indoor comfort will increase as well, as the cold radiation from windows in winter will substantially decrease.

There may however be a limit to set on the thermal performance of the windows, depending on the thermal characteristics of the other parts of the building envelope. **Installing triple – or even double-glazing windows in poorly insulated walls may provoke condensation problems on the walls.** The latter now becomes the cold spot in a space where before the condensation would happen on the (single) window surfaces.

Retrofitting works . © Smart Cities Marketplace







Low-emissivity windows (Low-E windows)

Low-E glass windows have a special glass surface coating that **minimises the amount of infrared (IR) and ultraviolet (UV) radiation passing through** them, without preventing most of the visible light to come through. The long-wave infrared radiation, which is heat, emitted from the room to the outside is reflected by the coating.

Double-glazed windows

These windows feature **two panes separated by an air or noble gas-filled layer.** The fenestration system is airtight. A spacer is in place to separate the panes and seal the gas inside.

Triple-glazed windows

The concept is the same as with double glazing, however, with **three glass panes and two layers of gas (either air or noble gases)**. Triple glazing will result in better thermal properties compared to double glazing.

The thermal transmittance of windows includes both the glass and the frame. **Correct installation of the glass is crucial in order not to create leaks and draughts near the frame.**

Commercially available glazing often combines the above characteristics, e.g., coatings and air/gas chambers.

Door replacement

Replacing an old exterior door with an energy-efficient door with a lower u-value will both **reduce energy consumption and increase the airtightness** of the building.

Retrofitting works . © Smart Cities Marketplace

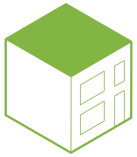
Other measures

External/Internal shading

Shading devices can limit the amount of undesired solar radiation entering the building. They can be either external or internal, either fixed or dynamic.

External shading is **more efficient** than internal shading as solar radiation is prevented from entering the interior space where it will be absorbed and turned **from light into heat**.

Fixed shading can be smartly designed so that **with low solar altitudes in winter, the sunlight enters the building and provides free heat gains while with high solar altitudes in summer,** the radiation is blocked off.



Green roof

A green roof is a layer of vegetation on top of the roof.

It can improve the thermal and acoustic properties of the roof both in terms of thermal capacity and **insulation of heat and noise**, but also **retain, collect, and use stormwater, improve the local air quality, reduce the urban heat island effect and provide for more local biodiversity.**

And of course, a green roof is nicer to look upon than a black polymerous surface.

External shading integrated into the architecture of the building: overhangs, mobile louvres (Tietgencollegiet, Copenhagen). © Smart Cities Marketplace

Green roof in Oud-Heverlee, Belgium STORY Horizon 2020 Demo Site. © Th!nk E

Prefabrication

Full façade or even full building envelope retrofit is being offered as a prefabricated solution.

This solution typically starts with a 3D scan of the current building and develops a full envelope that is added as a new outer layer to the existing building. As the engineering cost is generally higher, it is mainly used for projects with a large number of similar buildings or high-rise buildings such as apartments. Though, innovations in scanning and processing are making it more competitive for single-building projects.

While insulation, new windows, and a new finish are typically included, prefabricated systems can additionally include technical elements such as new ventilation tubes or integrated PV panels.

Alternative approaches to renew the technical installations further include a complete technical box that is positioned next to the building.

Energy-efficient façade renovation works for CRAC office building in Namur, Belgium
© Machiels Building Solutions 2019

Energy module for multi-family house Renovates (D7.1 Façade solutions and Energy Modules). © Renovates

Completed energy-efficient façade renovation works for CRAC office building in Namur, Belgium
© Machiels Building Solutions 2019

Insulating the right way: the importance of respecting the principles of good building physics

From the above, it has already emerged that thermal retrofit must happen while strictly respecting the principles of good building physics. This implies that the following problems will be avoided:

Thermal leaks, mostly in the form of thermal bridges at particular building nodes but also as badly placed insulation materials all over the building envelope's surface;

Internal and surface condensation may not only lead to problems with indoor air quality but also materials degradation, mould, rot and even structural collapse;

Uneven performance of (adjacent) parts of the building envelope, leading to suboptimal investments and potential problems from both a thermal and a moisture point of view;

Air leaks lead to problems of heat and moisture transfer as well as outdoor noise penetration.

Doing a bad job: when the insulation panels do not connect tightly to each other, much of the insulation capacity is lost and moisture problems may occur with time. Capacity building in the workforce and strict control of the building works are essential to avoid such deficiencies.

Condensation on surfaces and in the building structure; problems of heat and moisture leaks

It is mandatory to apply the insulation measures according to the standard details as provided by the manufacturers or as instructed by a building expert (architect, building engineer,...).

Thermal bridges must be avoided or reduced to an unharmful degree. The latter means that there are still some higher thermal losses at the specific building node, but these losses are not problematic as to provoke condensation, for example.

Air, vapour and moisture barriers must be placed in the right sequences, with the greatest care and precision, to avoid any of the above-mentioned problems. Avoiding (internal) condensation is a main priority for any type of insulation work.

See also the box about the role of vapour barriers: "The importance of vapour barriers" on page 18.

Doing a bad job: when the insulation panels do not connect well and tightly to each other, much of the insulation capacity is lost. Capacity building in the work force and strict control of the building works are essential to avoid such situations. © Smart Cities Marketplace

Airtightness and leakage (infiltration/exfiltration) versus ventilation and indoor air quality

Apart from good thermal insulation, it is also important to focus on the airtightness of the building. Building airtightness is defined as the resistance to inward or outward air leakage through unintentional leakage points or areas in the building envelope. Increasing the airtightness of the building should receive enough attention while retrofitting, as air leakage can reduce the effectiveness of thermal insulation, allowing conditioned air to escape to the outdoors or unconditioned outdoor air to infiltrate into the interior, meanwhile causing extra workload to the heating or cooling systems. Air leakage further leads to serious issues of moisture, condensation, and indoor comfort.

Infiltration and exfiltration are difficult to measure, and the associated losses are hard to control. It requires professional execution to avoid such leaks to the minimum; a blowerdoor test can be performed after the works to prove that the required level of airtightness has been achieved.

Making a building airtight reduces thermal losses and thermal discomfort, but strongly increases the need for a good ventilation system as consumed indoor air must be sufficiently refreshed by the controlled import of clean outside air. Hereby it is important to make sure that the right volumes of air are being extracted and supplied – this stands in contrast with the uncontrolled air changes that occur with a poorly performing building envelope. In fully 'balanced' ventilation systems, there will also be an opportunity to recycle the heat (or cold) from the extracted air to pre-heat (or pre-cool) the incoming air. This minimises the thermal losses resulting from the (necessary) ventilation flows.

Controlled ventilation may further be supported by CO_2 – or moisture detection, giving the right impulses to the ventilation system so that with higher indoor air contamination the ventilation flow is accordingly increased, and vice versa. Such control further reduces energy consumption related to ventilation flows.

Blowerdoor test. © Th!nk E

Technical versus non-technical barriers

In a principle, good technical solutions exist for any insulation problem. These may however come at considerable cost and careful execution is of paramount importance to arrive at the desired performance levels.

The latter aspect may be challenging to realise. The construction sector is known to have a high failure rate and struggles with capacity problems both in terms of the size of the labour force and professional skills. Therefore, it is recommended that the building client is supported by impartial professionals like architects and engineers or building consultants, but also through new set-ups like a 'retrofit one-stop shop' facilitated by local authorities so that sufficient quality guarantees are built into the design and the realisation of the retrofit operation.

One-stop shops are strongly on the rise and may at the same time provide the building owner with financing strategies and other types of support and de-burdening. In this way, technical, logistic, and financial barriers are addressed in one single, concerted action.

Insulation materials

Depending on the building envelope retrofit method, a variety of materials can be used in different components of the building envelope. The most used thermal insulation materials can be classified based on their properties:

Inorganic materials:

Glass wool, mineral wool.

Organic materials:

Natural: cork, cellulose, cotton, hemp, straw

Synthetic: expanded polystyrene (EPS), extruded polystyrene (XPS), polyurethane (PUR), polyisocyanurate (PIR), etc...

Many parameters should be taken into account when selecting thermal insulation materials, **including thermal properties, cost, ease of placement, building code requirements, durability, acoustical performance, air tightness and environmental impact**.

However, the thermal resistance of insulation materials remains the most important property when considering thermal performance and energy conservation.

BUSINESS MODELS AND FINANCE

BUSINESS MODELS AND FINANCE

Possible business models

The appropriate business model for building retrofit is project and client dependent. The possible retrofit business models and incentives can be summarised into six main types/ groups:

- → Single building client market model
- → Market intermediation model
- → One-stop-shop
- → ESCO model and energy performance contracting
- → Additional revenue models including financial support incentives
- → Innovative financing schemes

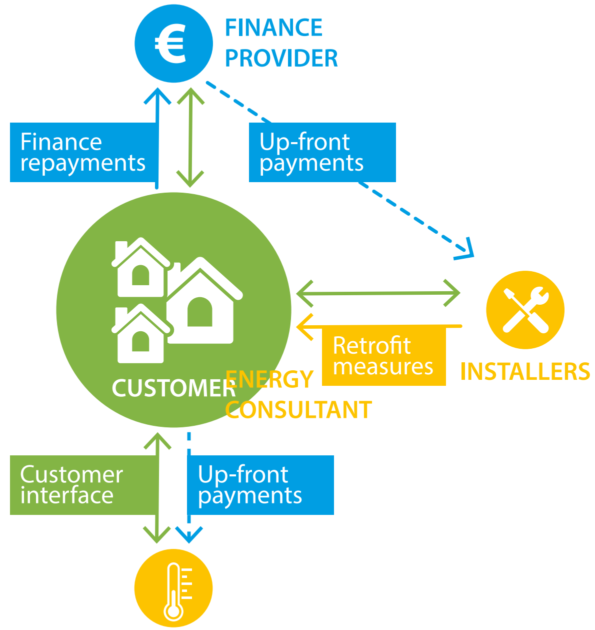
Combinations of the different models are common (e.g., single building client supported by financial incentives).

In general, these business models are not only intended at financing the building envelope measures but at supporting the **entire retrofit** operation.

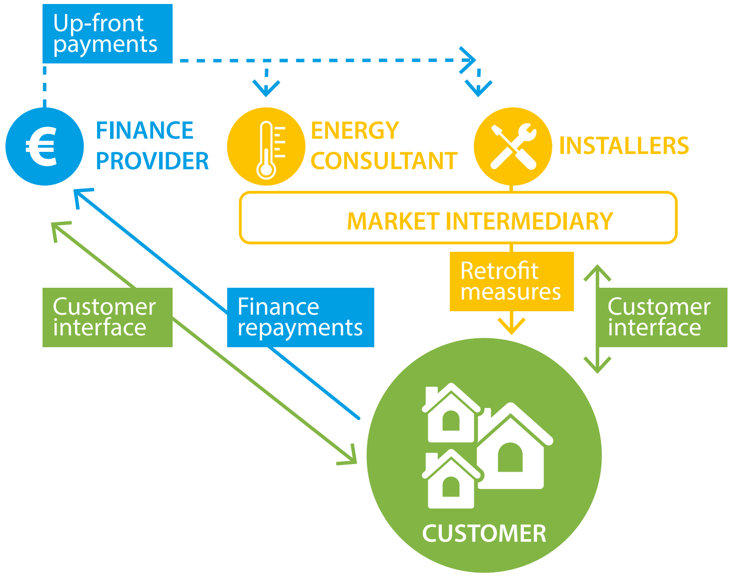
The traditional **single-building client market model** is the most common business model delivering residential retrofit in Europe, especially in **small-size projects** (e.g., single-family house rehabilitation).

In this business model, retrofit measures are implemented by one or more contractors on behalf of a single building client/owner. Building owners source the individual refurbishment measures (including follow-up quality control and commissioning), energy audits, and finance separately, further resulting in separate customer interfaces for a comprehensive residential retrofit package. Financing in this formula typically involves own liquidity, a loan, or a mortgage. **Energy savings are generally not guaranteed.** The major drawback of this business model is that projects become fragmented due to many interfaces, which further results in problems in communication, planning, coordination, and execution.

Opportunities for economies of scale are missed.



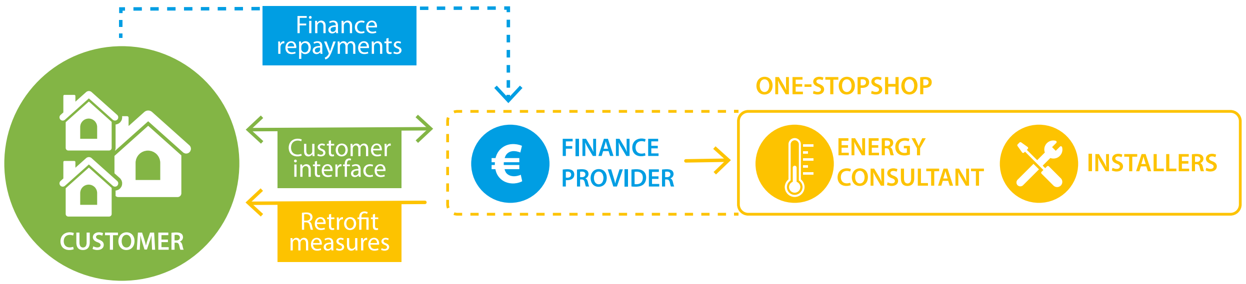
The **market intermediation model** is another relatively common business model for residential retrofit. The main difference between this model and the single building client model is an extra player in the market: an intermediary organisation that **coordinates the supply chain** (e.g., energy audit, pooling contractors, coordinating installation, quality control) and provides one aggregated customer interface, which therefore largely **simplifies the customer journey** and unburdens the building owner.



However, in this model, there is still a customer interface between the finance provider and the building owner. This model usually involves the implementation of government subsidy schemes focused on single measures and uses estimates of the associated energy cost and carbon savings from a basic energy audit. Typically, in this model, local municipalities or NGOs can play a crucial intermediary role in **providing trustworthy information and guidance** to the building owners.

As part of the actions developed in [mySMARTLife] project, Nantes Métropole developed and offers a free-public renovation service called "[Mon Projet Renov]". This online platform allows residents to access relevant information to help them develop their rehabilitation project, by sharing contacts with local companies listed on the stock exchange and can even play an intermediary role by offering quotes from the company and financial support available.

The **one-stop-shop (OSS) model** builds on the previous scheme and includes services from information provision, over audits, to completely unburdening the customer by integrating the whole supply chain, including the financing solution, into a **single service for the customer.** Thus, a single contractor can offer either parts or the full-service package related to the energy retrofitting, including consulting, energy audit, renovation works, follow-up and financing. The holistic approach can hence bundle different resources and services into one comprehensive package and delivers it to the end customer via one interface.



This model is deployed more and more: Denmark launched the [“Better Home” programme](), one-stop-shop counselling through the building process to remove barriers and make retrofitting simpler, easier and manageable for building owners; In France, the region of Picardie launched a [pilot project “Picardie Pass Rénovation”](), offering an integrated service (technical, financial and informational assistance) for the energy retrofit of residential buildings; [Bolig Enøk](), a Norwegian pilot project, developed a “project manager”-approach: building owners employ a “project manager”, who provides technical analysis, recommendations and project management of the full renovation process. More examples can be found in a dedicated [EC report]().

Local and national governments play a key role in enabling one-stop-shop services, through the provision of financial support or establishing the one-stop shop within the governmental services. They can consequently manage quality (e.g., in [Ireland]()), as well as develop support for dedicated groups such as vulnerable households.

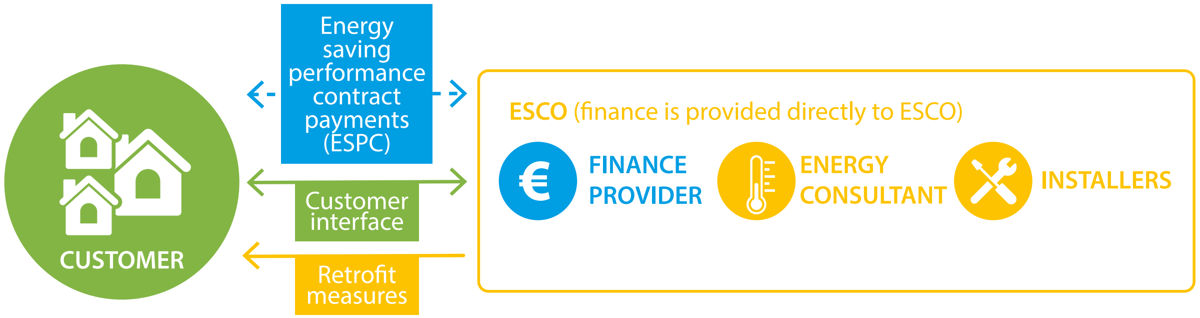
A model close to the one-stop shop is based on Energy Service Company (ESCO), and the most common variants of services delivered are Energy Performance Contracting (EPC) and Energy Supply Contracting (ESC). As with the OSS, the whole supply chain is integrated.

The **EPC model** offers its customers guaranteed performance or savings, usually within a certain period. Customers are guaranteed certain performance levels of specific services, for instance, a constant indoor room temperature or hot water temperature throughout the year.

Under the **ESC model**, an ESCO supplies energy, such as electricity and heat to a building owner or user through a long-term contract.

EPC thus goes beyond ESC: ESC guarantees energy supply, while EPC is a business model for energy savings. The goal is to avoid wasting energy and invest savings in energy efficiency.

The ESCO typically offers customised energy contracting packages that contain planning, execution, operation, and maintenance elements. In addition, it also manages energy purchasing and financing of various projects. A status review of current ESCOs and EPC in various European countries has been published by the EC.



ESCOs and EPC can play an important role in improving energy efficiency and driving energy efficiency investments at the market level.

The main differences between the ESCO and the one-stop-shop models are:

→ ESCOs tend to approach individual building owners whereas a one-stop-shop typically addresses collective/upscaled retrofit in each geographical area;

→ ESCOs are mostly private market players whereas an OSS will typically be initiated and managed by one or more local or regional authorities, utilities or other institutions with a public interest mission;

→ ESCOs will mostly rely on private financing whereas an OSS may tap into publicly supported schemes with specific investment banks, soft loans or similar;

→ Resultantly ESCOs target interventions with shorter payback times (commonly up to 10-15 years) whereas an OSS can, through public or institutional financing schemes, allow for longer payback times.

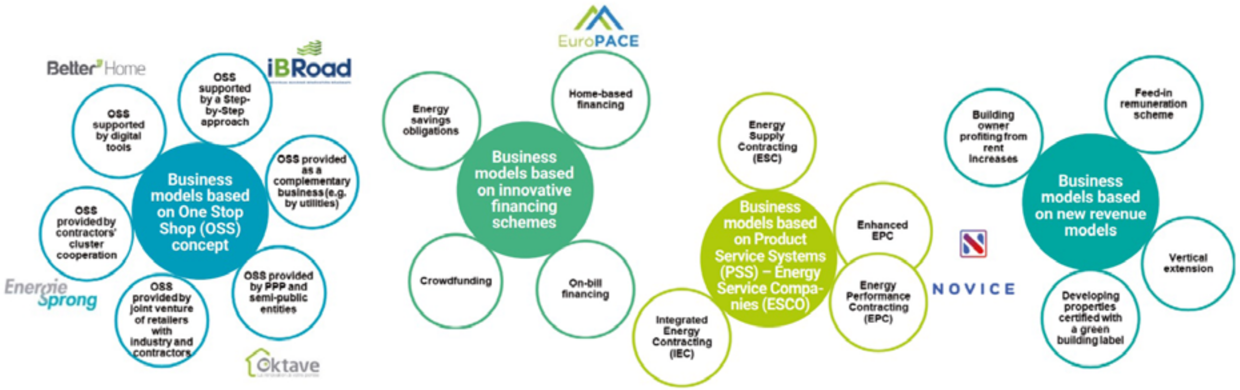
This implies that for deep retrofit, with payback times that may amount to several decades, the OSS comes with an advantage compared to the ESCOs as they operate in the market today.

Business models based on **financial incentivisation** can derive from the use of available government support. For example, building owners can obtain a **tax reduction** or **receive subsidies** when conducting certain energy retrofitting measures. Soft loans may be considered another form of financial incentive. They come at advantageous conditions and may be issued by a bank or fund with a public interest character. They are, by definition, destined for specific investments – in this case, the retrofit measures.

Business models based on **innovative financing schemes** are built upon programs that help to break down the high upfront cost barriers.

Financial institutions (and utility companies) can play an essential role in providing financial products for boosting energy improvements in buildings. Various innovative financing schemes are emerging in the market. For instance, with on-bill financing, a utility provides capital to a homeowner for insulation, whereas homeowners repay the on-bill loan (issued by the utility) through an extra fee on the utility bill (e.g., demonstrated in Renonbill).

The main families of business models as identified in the STUNNING project. Note that business models based on new revenue go beyond building envelope retrofit and include, for example, installing RE installations or extending the building while retrofitting it.



Sustainable business models for the deep renovation of buildings – Final Publication. © Stunning project

Financial barriers

The following financial barriers remain to be addressed in any of the retrofit business models:

- **The upfront cost of building envelope retrofit stays high**, especially compared to the more affordable renewable energy production solutions (like PV, solar boilers, heat pumps,...). Hereby the building envelope retrofit must be deep enough to render the building sufficiently future-proofed. If the (financial) burden is too high for realising this at once, a stepped approach following a building roadmap may be followed.

- **Long payback time and negative net present value:** the payback time could be up to the range of 30-50 years or even longer. Current low energy costs (gas and electricity) add to the challenge. There is, in general, still a lack of comprehensive financing systems that are aligned with the specific needs of the homeowners. In addition, classical financing schemes are usually risk-averse and do not, or very conservatively, consider energy savings and related financial returns.

SOCIETAL & USER ASPECTS

SOCIETAL AND USER ASPECTS

Gaining stakeholder support & engagement

Leveraging on primary and secondary benefits

Homeowners and – occupants can substantially benefit from building envelope retrofit, in multiple dimensions. These can be primary (related to energy use) or secondary (co-benefits for the building owner, the occupant and the wider society and the environment):

Economic benefits

Envelope retrofit reduces the heating/cooling demand, which brings a lower operational cost, and potentially reduces initial investment costs due to the reduced equipment size being required (e.g., a less powerful heating installation). Energy-efficient buildings reduce energy dependency and risks of energy poverty. They realise higher values in the real estate market.

Use benefits

→ **Thermal comfort:** envelope retrofit increases thermal comfort without excessively relying on thermal and electrical systems operation;

→ **Acoustical comfort:** suitable insulation materials can potentially reduce noise levels and improve indoor acoustical comfort;

→ **Indoor air quality:** proper design and installation of thermal insulation (in combination with the necessary ventilation strategies) can help prevent indoor air quality problems, for example resulting from condensation, humidity and mould or draughts throughout the building;

→ **Fire protection:** non-combustible insulation materials can slow the spread of the flames in case of fire.

Retrofitting project in Kortrijk, Belgium © Agata Smok

© Getty images

Environmental benefits

Envelope retrofit further results in environmental benefits as reliance on energy usage with the associated sourcing impacts and emitted pollutants are reduced.

The latter holds in particular for greenhouse gas emissions, but also for other pollutants resulting from combustion processes (e.g., fine particles).

Nevertheless, the environmental impact of the insulation and construction materials used for the retrofit should also be considered in order to arrive at a complete environmental impact assessment.

Societal benefits

Envelope retrofit helps to improve indoor quality and health, the productivity of occupants, comfort, and well-being in more general terms. This leads to noticeable reductions in the cost of labour (for enterprises) and of social and health expenditures (for public authorities).

The reduced environmental impacts mentioned higher also lead to societal benefits, through climate change mitigation and preventing the related damage costs.

In addition, broad societal benefits (e.g., local job creation and business stimulus, supporting the local green economy) are tangible for the various stakeholders involved in retrofitting projects.

Homeowner engagement

Even though the many benefits are clear, it is still rather challenging to convince homeowners and get them on board. The main **societal barriers** are:

- There is a lack of information and awareness of energy issues;
- Homeowners fear risks and uncertainties;
- Homeowners would rather avoid the hassle of reallocation and/or renovation works;
- There is a lack of clear financing and funding schemes, and it is not easy for homeowners to get access to them.

Homeowners can be easily discouraged by these known or even unknown obstacles. Thus, from a societal perspective, one key element for upscaling building retrofit is to engage and involve homeowners. De-burdening the homeowner is crucial in this perspective.

Analysis has clearly shown the importance of the customer interface in this engagement process, such as promoting and marketing building retrofit packages, assisting in the design, execution and control of the retrofit works, and facilitating funding and financing schemes. On the one hand, it is essential to **motivate and support the building owners towards well-informed retrofit**; on the other hand, however, it is also important to **deliver advice and messages in a neutral manner**, especially in the case of the single customer interface. Only with **transparent information** and **non-biased advice**, homeowners can make rational decisions toward building retrofitting strategies and interventions.

Citizen engagement remains one essential aspect in promoting and upscaling many smart city solutions. One dedicated Solution Booklet is published specifically to focus on this topic.

GOVERNANCE & REGULATION

© Smart Cities Marketplace

GOVERNANCE AND REGULATION

Stakeholders in building retrofitting projects

The successful delivery of energy-efficient retrofitting generally involves a complex set of different stakeholders' interactions. The main stakeholders of building retrofit projects include:

- **Home/building owner:** owns the existing building or is the client of the retrofit project;
- **Facility manager:** manages the (energy and indoor climate) facilities in the existing building;
- **Designer:** architects and engineers involved in the retrofit design phase as well as in control of the executed works;
- **Contractor:** executor of the retrofit works;
- **Sub-contractor:** subcontracts mainly from a specific domain on behalf of the main contractor;
- **Municipality/Local or Regional Authority/Government:** manages policies, regulations, subsidies and roadmaps related to retrofit projects. May set up a One-Stop-Shop or other support mechanisms;
- **Financial institution/private or public bank/fund:** provides loans and financial support, directly to the building owner or via an intermediary vehicle (ESCO, OSS, energy utility,...);
- **Energy service providers:** energy producers, distributors, operators, flexibility providers, etc.

These stakeholders are involved in different stages of the retrofit project. Clear identification of **all involved actors and well-thought communication** between them from the early start of the project are key factors for success.

© Antenna on Unsplash

Regulatory barriers

Regulations and administrative procedures such as obtaining permits often remain a **challenge** and may even present **obstacles**.

In particular cases, the architectural and cultural value of buildings protected by law or local regulations may limit the choice of technical solutions and measures. For instance, where adding external wall insulation or replacing historic window frames and glazing is not permitted. Although there may be little discussion about such protection for real **monuments**, another patrimony may be well worth a trade-off between freezing the historic situation on the one hand and improving energy and comfort standards on the other hand. **Urban and spatial planning rules may lead to similar bottlenecks**. This illustrates the need for well-balanced policies that break through disciplinary silos.

Geographical differences in legislation might limit the replication potential of retrofitting measures.

Furthermore, the prohibition of accessing and gathering **home user energy data** (e.g., energy consumption, indoor temperature) adds to the **complexity of monitoring** and validating the actual building performance before and after envelope retrofit (to limit the rebound effect).

Rebound and prebound

Rebound effect: The increased energy efficiency might come with fewer energy savings than predicted, due to the changed behaviour of the building users after the retrofit. For example, the latter may now afford higher indoor temperatures as the building is energy-efficient in any case.

Prebound effect: this is the inverse phenomenon, where the predicted energy use of a badly insulated, not yet retrofitted building is higher than the monitored energy use. The reason here is that the building occupants, knowing that the building is energy-hungry, lower their comfort requirements and, for example, do not heat sleeping and circulation zones or limit the temperature level in the living spaces below the normal comfort standard.

© Andrada Riglea

GENERAL LESSONS LEARNT

LESSONS LEARNT – SUMMARY

Challenges

The EU building stock is currently facing challenges that prevent the upscaled implementation of energy efficiency measures in buildings. From an economic, technical, social and governance perspective, the barriers are identified and summarised as follows:

- **Building envelope retrofit requires large upfront investments and only pays back after a long to a very long time, up to the range of 30-50 years and even more.** Building owners often lack the investment means, as well as the investment horizon for undertaking such endeavours;
- **There is still a lack of comprehensive financing systems that are sufficiently aligned with the specific needs of the home – or building owners.** The atomised ownership structure remains another barrier for upscaled decision-making toward retrofit investments and their actual financing;
- **There is a shortage of (qualitative) labour force in the building sector.** The complexity of the retrofitting works brings technical and logistic challenges that need a highly skilled address.
- **Energy efficiency is one important aspect, however rarely considered as the top priority of home – or building owners in the decision-making towards retrofit.** In general, there is a **lack of awareness** of energy-related issues.

Drivers that may motivate or 'drag in' better and deeper energy retrofitting include:

- **Having to undergo renovation or some other kind of work (e.g. new kitchen/bathroom, periodic repair of roofs and façades,...);**
- **Change of building ownership;**
- **Planned building expansion;**
- **Wishing to improve indoor comfort;**
- **Desire to have an environmental-friendly house;**
- **Deep retrofit may be more cost-effective than demolition and rebuild;**
- **High and growing energy bills;**
- **Increasing real estate and aesthetic value of the property.**

Recommendations

Unburdening the home or building owner is a priority. This can be realised by integrating the whole supply chain into a single customer interface and by continuously engaging, motivating, and supporting home/building owners toward well-informed retrofit.

Municipalities and local governments can play an essential role as facilitators and regulators in promoting energy-efficient retrofitting and upscaling retrofit in the longer term. Well-balanced policies that break through the disciplinary silos will help to arrive at optimal, holistic solutions.

The optimal financing methods for retrofitting may be different from classical mortgages or loans. Innovative financing schemes from both public and private sources are needed to lower the financial threshold for building owners. The chosen business model in the retrofit project should be tailored to the targeted market segment.

There is an urgent need in improving the quality and quantity of the labour force in the EU building industry. Delivering qualitative work and good support to homeowners is essential to ensure their engagement.

Technically speaking, envelope insulation is a valid first step in achieving energy efficiency, but it is not enough. The combination of thermal insulation and other retrofit measures makes the overall retrofitting package. Such retrofit packages can either be done all in one go or incrementally in a step-by-step approach. Partial retrofit, however, without overall plans tailored to individual buildings, may clash with later necessary measures. Inadequate improvement of parts of a building may thus result at an end further improvements (lock-in effect), which shall be avoided.

Identifying relevant networks and communication channels, especially in the early stages, is necessary for homeowner engagement and awareness development during the decision-making process. Promoting and marketing retrofitting should not be only energy efficiency centred; the associated secondary benefits, such as health and wellbeing, should be highlighted as well.

Retrofitting in Amsterdam © City-zen

USEFUL DOCUMENTS

USEFUL DOCUMENTS

SCC project websites and deliverables on building (envelope) retrofit:

- InfiniteBuildingRenovation

Rennovates and similar (BAM)

- NOM in een smart grid (in Dutch)
- 39 woningen nul-op-de-meter in Woerden (in Dutch)
- Film: wat komt er kijken bij een NOM-renovatie (in Dutch)
- Renovatie (in Dutch)
- Film: Robot plakt steenstrips (in Dutch)
- Europe's Green-Building Retrofit Leader Is One of Its Smallest Countries (bloomberg.com)

mySMARTLife:

- Ile de Nantes – Retrofitting Actions
- Bergedorf-Süd – Retrofitting Project

Replicate:

- San Sebastian
- Florence

REMOURBAN:

- District retrofitting
- Retrofitting
- Valladolid (Spain)
- Nottingham (East Midlands)
- Tepebasi/ Eskişehir (Turkey)

Matchup:

- ICT urban platform
- Valencia Lighthouse Interventions Detailed Definition

IRIS:

- Nice France

SmartEnCity:

- District retrofitting monitoring program
- Sonderborg Building Retrofitting Complete
- Smart Solutions in Vitoria-Gasteiz
- Tartu retrofitting package
- Retrofitting (Sonderborg)

GrowSmarter:

- Energy efficient refurbishment of social housing
- Energy efficient refurbishment of public housing area
- Energy efficient refurbishment of a residential settlementCologne

Renonbill

PadovaFit Expanded

More on insulation materials

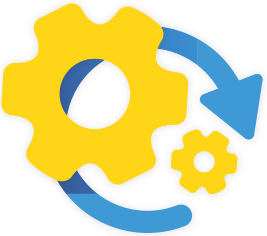
- Performance characteristics and practical applications of common building thermal insulation materials

More on business models

- Sustainable business models for deep energy retrofitting of buildings: state-of-the-art and methodological approach
- Key aspects of building retrofitting: Strategizing sustainable cities
- Business models for residential retrofit in the UK: a critical assessment of five key archetypes

Smart Cities Marketplace

The Smart Cities Marketplace is a major market-changing enterprise supported by the European Commission bringing together cities, industries, SMEs, investors, researchers and other smart city actors. The Marketplace offers insight into European smart city good practice, allowing you to explore which approach might fit your smart city project. Discover our digital brochure here.



Matchmaking

The Smart Cities Marketplace offers services and events for both cities and investors on creating and finding bankable smart city proposals by using our Investor Network and publishing calls for projects.

Investor network

Call for projects

Project finance masterclass

Focus and Discussion groups

Focus groups are collaborations actively working on a commonly identified challenge related to the transition to smart cities. Discussion groups are fora where the participants can exchange experience, cooperate, support, and discuss a specific theme.

Focus and Discussion groups

Community

EU initiatives

Apart from the smart cities marketplace, there are a number of adjacent EU initiatives focussing on making European cities better places to live and work.

Other EU initiatives

BUILDING ENVELOPE RETROFIT
SOLUTION BOOKLET

Smart Cities Marketplace 2023

The Smart Cities Marketplace is managed by the
European Commission Directorate-General for Energy