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Urban Retrofit Design
Codes and Labels for Building Energy Efficiency

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Federica Bonavero

Turin, July 11, 2018

Summary

Buildings are a major contributor to energy consumption and associated greenhouse gas emissions, and their energy-efficient renovation has been widely accepted as a cornerstone in the low-carbon transition of Europe's cities. Due to the slow turnover of the stock, any policy option which does not take existing buildings into account would fall a long way short of meeting the 2050 EU carbon reduction targets.

Through an investigation into the policies and practices for the retrofitting of residential buildings, the research draws on the experience gained by leading member states and exemplary retrofit projects to highlight their most innovative aspects and practical implications from a design perspective.

Building retrofitting is often regarded as a technical matter, something that concerns building systems experts and engineers. However, the ongoing shift from (purely) prescriptive to (primarily) performance-based energy requirements is unleashing new opportunities for architecture and urban design professionals to engage with many aspects related to energy use in buildings and the built environment.

An expanded way of understanding retrofitting is thus possible, which goes beyond the energy performance of a building to encompass its spatial and functional performance.

The thesis is structured in three main parts. It starts by presenting facts and figures about the current state of the building stock across Europe, and discussing the most relevant European directives and policy instruments for national implementation (i.e. Building Energy Codes, Building Energy Labels and related incentives). Then, it proceeds by describing the regulatory framework for building retrofitting in three reference countries (i.e. Denmark, France and Germany) and analysing a number of retrofit projects involving post-war multi-family buildings.

Finally, it summarizes and systemizes findings from the case studies, identifying a set of retrofit measures that have proven to be effective in meeting, and in some cases exceeding, codes and/or labels requirements for building energy efficiency while at the same time improving urban quality of life.

It concludes by putting the spotlight on some challenges and issues that may arise when implementing retrofitting at scale with regards to local building and planning regulations, building tenure status and financing.

Acknowledgments

No case study review can be accomplished without the support of those who have designed and built the projects. Therefore, many thanks go to all the architecture studios, engineering firms and clients whose buildings are presented in the research for providing the necessary material and information.

In particular, thanks to: Peter Sikker Rasmussen and Line Dea Langkjær from C.F. Møller Architects, Jeppe Nørgaard from KAAI, Maria Ellegaard Zneider from Kullegaard A/S and Jonas Bjørn Whitehorn from Boligselskabet Sjaelland, Marion Leclercq from LAN Architecture, Cécile Azoulay from Atelier Du Pont and Guillaume Boudry from PLAN02, Jullien Callot from Lacaton & Vassal Architectes, Frank Lattke from lattkearchitekten, Frank Heinlein and Marc Gabriel from Werner Sobek, Jochen Freivogel from Freivogel Mayer Architekten and Matthias Rammig from Transsolar KlimaEngineering.

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Chapter 1

Introduction

1.1 Background

Buildings are a major contributor to energy consumption and associated greenhouse gas emissions, and their energy-efficient renovation has been widely accepted as a cornerstone in the low-carbon transition of Europe's cities.

On the one hand, new construction represents only a very small proportion of the already existing buildings. At the current construction rate, it would take a long time before new builds have any significant effect on the building stock as a whole. On the other hand, demolition and replacement produces high environmental (and societal) impacts. When embodied carbon is accounted for, it takes many decades for an efficient new building to catch up with an old building that has been energy renovated.

Due to the slow turnover of the building stock, any policy option which does not take existing buildings into account would fall a long way short of meeting the EU carbon reduction targets. With more than three-quarters of present buildings expected to be still in use in 2050, millions of square meters of floor area will have to be renovated yearly.

The good news is that being part of the problem means that existing buildings are also part of the solution. Given that the most of them were built with no or minimal energy requirements, a huge potential for savings lies unexploited and, best of all, it could largely be untapped through measures that come at low or even negative cost.

In the last two decades, the European Union passed several directives and initiatives to grasp the buildings' cost-effective energy efficiency potential: the 2010 Energy Performance of Building Directive, the 2012 Energy Efficiency Directive and the 2050 Roadmap for a Competitive Low-Carbon Economy, just to mention a few.

In response to this, all member states have been called upon to transpose and implement EU legislation into national law, either amending existing policy instruments or introducing new ones. Indeed, energy requirements for new buildings have been in place since the first oil crisis, but it is only in recent times that building codes and labels have evolved to adopt a whole-building approach, and to cover energy use also in existing buildings.

1.2 Aim of the research

The aim of this PhD research is to develop an investigation into the most innovative aspects of Building Energy Codes and Building Energy Labels for the retrofitting of existing residential buildings. Within this broad field of research, it aims to investigate retrofits from an architecture and urban design perspective.

Building retrofitting is often regarded as a technical matter, something that concerns building systems experts and engineers. Even today, the conventional view is that retrofitting a building means implementing all the interventions necessary to ensure a state of thermal comfort to the occupants, at the lowest possible energy consumption and cost. In short: insulation of the building envelope, more energy-efficient services and appliances, higher use of renewable energy sources.

This is a narrow perspective which fails to acknowledge the full range of social and economic co-benefits that retrofits can deliver.

Indeed, retrofitting is not only about participating in the reduction of buildings' environmental impacts by burning less fossil fuels. It is also about avoiding building stock dilapidation, raising people living standards, future proofing cities against climate change, increasing property values, alleviating energy poverty, improving aesthetics, etc.

And this is where architects and urban designers enter the picture.

The ongoing shift from (purely) prescriptive- to (primarily) performance-based energy requirements is unleashing new opportunities for design practice to engage with building energy issues. Individual components are no more the focus, and systems thinking is fostered by considering the interactions among the different components.

An expanded way of understanding retrofitting is thus possible, which goes beyond the energy performance of a building to encompass its spatial and functional quality.

Drawing on some exemplary retrofit projects, an intended outcome of the research is to identify a set of technologies and design measures that can serve as a source of inspiration for professionals and building owners who want to undertake a retrofit project.

1.3 Methodology

The methodology adopted consists in a qualitative and comparative study of the retrofitting policy context and building practice in three European member states.

It entailed a combination of primary and secondary sources, including the following: buildings energy efficiency policies databases (e.g. the BEEP database, the ODYSEE-MURE database), research projects (e.g. the ABRACADABRA project, the E2ReBuild project, the ENTRANZE project, the REHA programme, the SuRE-FIT project, the TABULA/EPISCOPE project), statistical databases (e.g. Eurostat database, the EU Building Stock Observatory, the European Construction Sector Observatory), publications referring to building energy codes and labels by international agencies (e.g. reports and factsheets by the BPIE - Building Performance Institute Europe, the IEA - International Energy Agency, the IPEEC - International Partnership for Energy Efficiency Cooperation) and national energy agencies (e.g. by the ADEME - Agence de l'Environnement et de la Maitrise de l'Energie, the DENA - Deutsche Energie Agentur, the danske Energistyrelsen), legal texts, architectural project documents, and scholarly publications (in the areas of building engineering physics, architecture and urban design, urban policies, technologies of architecture, etc.).

As far as reference countries and case studies are concerned, some clarifications are needed about the criteria that led to their selection and to the method used for analysis.

Reference countries have been identified based on literature review [Atanasiu & Kouloumpi, 2013; BPIE, 2015; ENTRANZE, 2014a] and some informal interviews with renowned experts[1] in the field of building energy

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[1] Dr. Charles Pele, team leader of the Near Zero Energy Building division at the Centre Scientifique et Technique du Bâtiment.

Dr. Yamina Saheb, senior energy policy analyst at OpenEXP, prior policy and scientific officer at the Joint Research Centre of the European Commission and senior energy efficiency policy analyst at the International Energy Agency.

efficiency policies. As a whole, European policies are some of the world's most progressive, but substantial differences can be found among member states.

Denmark, France and Germany are considered by many to be among the most advanced countries in the development and enforcement of building energy codes and labels, with a particular focus on existing buildings renovation. The three of them have a long tradition of strong nationwide legislation, as well as a tendency to innovation. Their codes are performance-based and up-to-date, and their labels/certificates are well-established. Incentive schemes are available, even if to different extents.

Case studies have been identified mainly by looking at architecture publications, screening online project repositories and performing targeted web searches. After a first exploratory phase, an initial list of potential cases was defined and then progressively refined on the basis of selection criteria related both to the retrofitted building (i.e. building age, type and use) and to the retrofit project (i.e. timing, complexity of the retrofit measures). The application of these criteria led to the final selection of nine case studies, three for each reference country (Figure 1).

As the European building stock is very diverse, and in many respects not comparable, it was decided to limit the range of case studies to a specific time frame and building type. Because of their number and relatively poor energy performance, and also for their role in the image of our cities, post-war, multi-family buildings have been chosen for investigation[2].

Post-war buildings have traditionally been a major source for experimentation: nearly 50 years after construction, these buildings have come at the end of their expected life cycle and share a long list of common problems [van Kempen et al., 2005]. Despite undeniable signs of physical deterioration, low insulation, outdated installations, etc. many studies and projects [Castro & Denissof, 2005; Druot et al., 2007; Boeri et al., 2013; Angi, 2016; Ferrante, 2016] have demonstrated the opportunity for their retrofitting.

To maintain consistency across the case studies, these have been compiled according to a common four-page layout, based on some literature examples [Baeli, 2013; Penoyre & Prasad, 2014; Clemens et al., 2007].

Dr. Stefan Thomas, director of the research group on Energy, Transport and Climate Policy at the Wuppertal Institut fuer Klima, Umwelt, Energie.

[2] Only one case partially deviates from this. The project by Werner Sobek at Pfuhler Straße 4-8 is about a row house built in the late 1940s, but that was renovated in the 1970s.

The first page summarizes project’s key information about location and timing, client, design team, etc. The second and third pages feature a description of the retrofit measures taken on the building fabric and services, and/or other technologies installed (e.g. renewables, smart meters). The fourth page contains a number of tables with statistics related to the building envelope U-values, primary energy demand, project costs and financing sources.

In the following pages, drawings and photos complement the text allowing for a comparison between the pre- and post-retrofit building, highlighting those aspects of the case study which were found to be particularly interesting for the aim of the research. In principle, all the case studies contain: building elevations (1:500), typical floor plans and sections (1:250), and construction details (1:50).

Section diagrams of typical apartment units can be found in Appendix B.

Appendix A contains some graphs showing the difference in U-values of building envelope components before and after retrofit.

Notes: The information presented in the case studies comes from a variety of published and unpublished sources which include, but are not limited to: journal articles, books, housing association websites, project press kits, project documentation and reports, etc.

Project descriptions are the sole responsibility of the author. For each case study, main sources of information are listed in the ‘References’ section at the end of the thesis. The design teams collaborated by providing additional material such as architectural drawings and diagrams, professional photos and performance data, and all have been given the opportunity to comment on the final draft of their project’s template.

Third-party copyright holders are noted by citation in figure captions.

For a number of reasons, above all for the continuous evolution of building energy regulations, it was not possible to guarantee the correspondence between codes and projects. This implies that, in some cases, there is a mismatch between the version of the code applied to the project and the version of the code analysed in the thesis, which is the most current one.

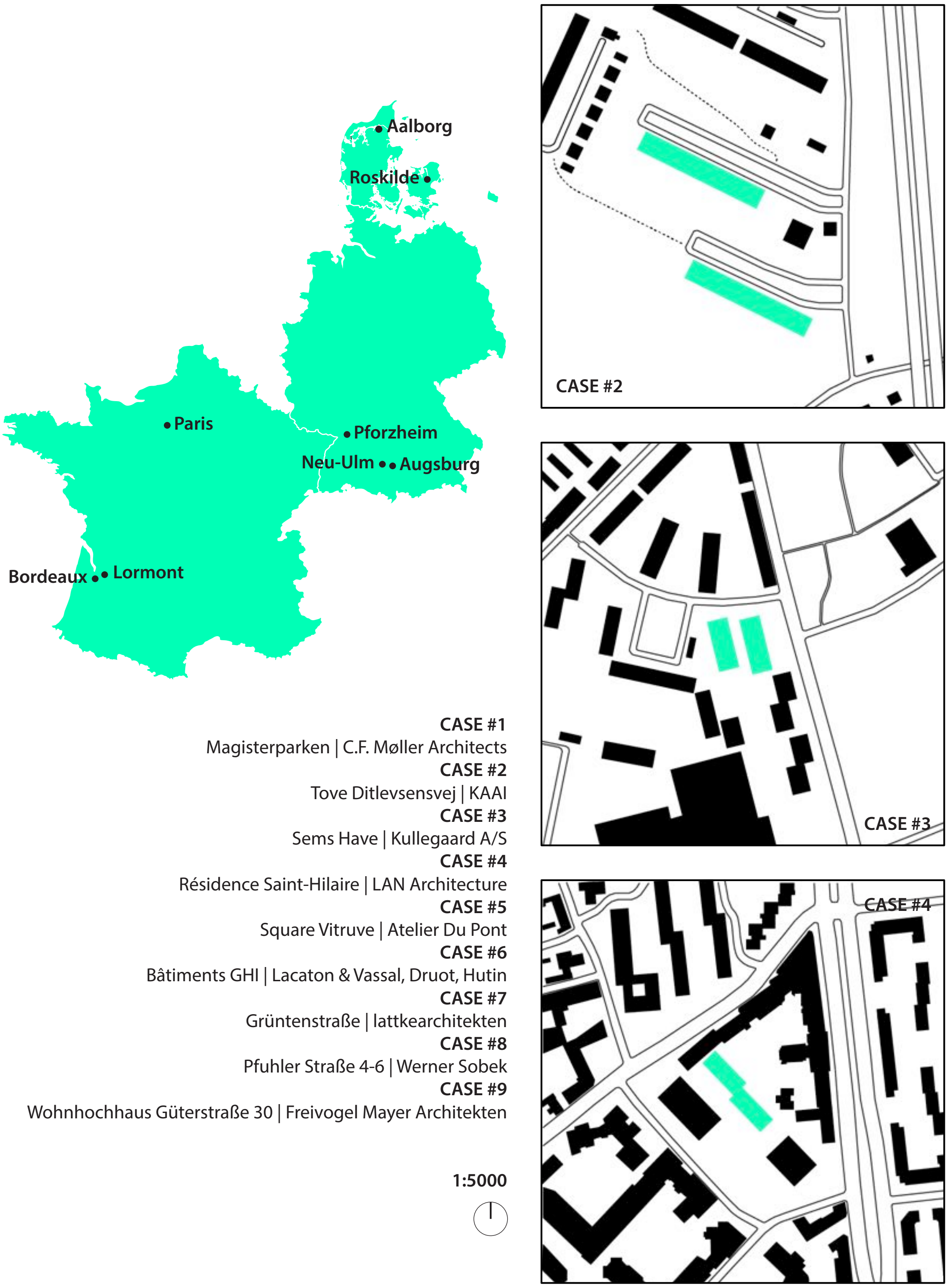
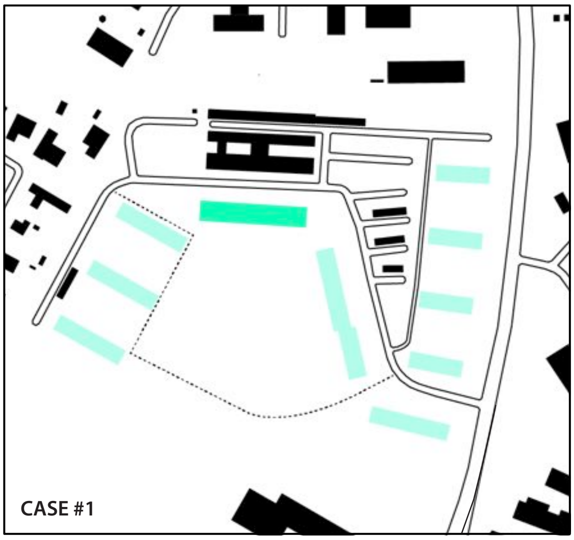


Figure 1: Case studies. Project locations and figure ground diagrams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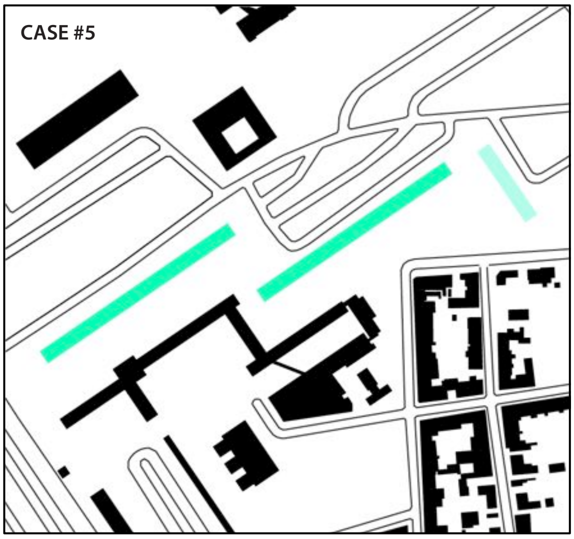
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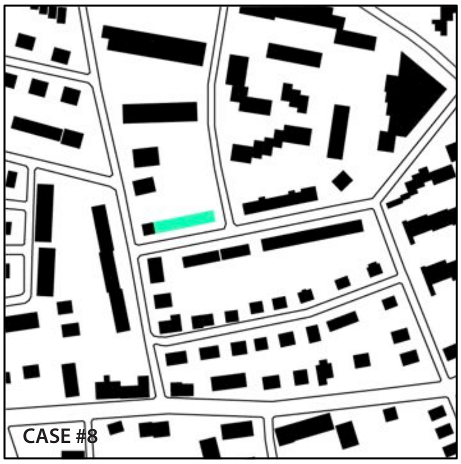
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CASE #9

1.4 Outline

The thesis is structured as follows.

Chapter 2 sets the stage for the research by introducing building energy efficiency policies. It presents facts and figures about the current state of the building stock across Europe, and discusses relevant European directives. Then, it moves on to consider the policy instruments for national implementation. It reviews the basic categories of such instruments before to focus on Building Energy Codes and Building Energy Labels.

Chapter 3, **Chapter 4** and **Chapter 5** offer an in-depth look at building retrofit policies and practices in three member states, namely Denmark, France and Germany.

Each of these chapters is structured in two parts. The first part investigates the codes and labels put in place by the reference country and describes the related incentive schemes. The second part features extensive sections on a number of building retrofit case studies.

The case studies form the basis for **Chapter 6** which summarizes the most important findings, puts the spotlight on existing challenges and issues, and identifies prospects for future research.

Chapter 2

Building Energy Efficiency Policies in the EU

2.1 Facts and figures on the EU building stock

There are approximately 210 million buildings in Europe, and a significant share of them were built before energy efficiency became a common issue.

With almost half of the stock dating back before the 70s, buildings alone account for about 40% of the EU primary energy consumption and 36% of total greenhouse gases emissions [Economidou et al., 2011]. Through construction and operation, the sector is one of the biggest contributors to global climate change, even bigger than transport and industry (Figure 2 and Figure 3).

Then, it is not surprising that buildings have come at the forefront of the policy debate, becoming one of the crucial sector in the transition towards post-carbon cities.

While in emerging economies more than half of the buildings that will be standing in 2050 have yet to be built [Saheb, 2013], in European countries almost all of them already exist. Given the low building construction rates - around 1% of the total stock - and long building life spans - generally between 50 and 100 years -, buildings change slowly both in number and quality.

Because today's buildings comprise the largest segment of tomorrow's buildings, the most critical challenge that policy-makers face is to significantly accelerate the rate and depth of building renovations.

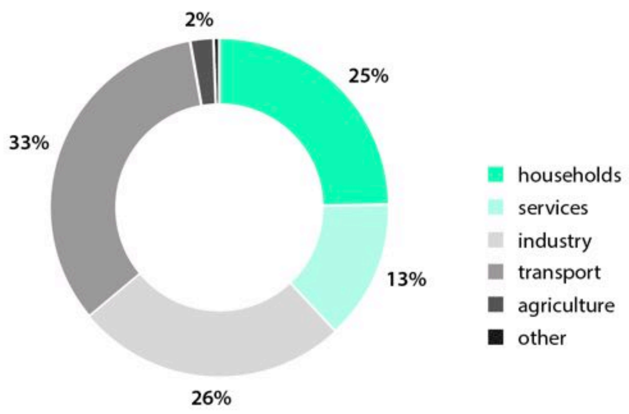

Figure 2: Final energy consumption by sector (EU-28, 2014)
Source: Eurostat database

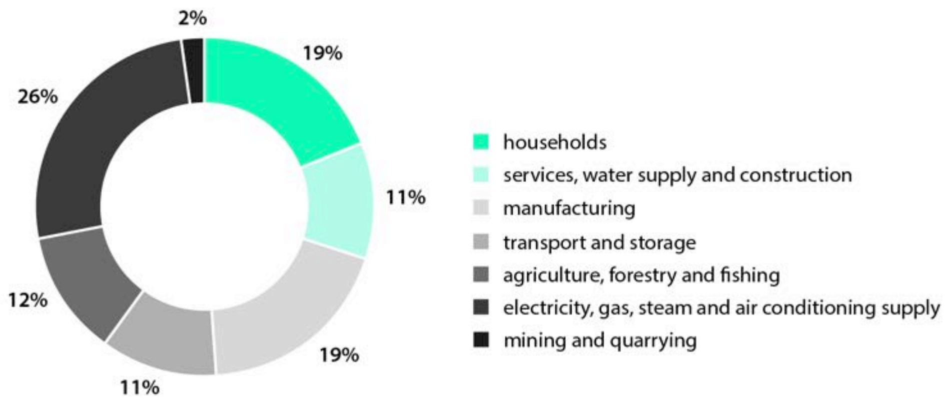

Figure 3: Greenhouse gas emissions by sector (EU-28, 2014)
Source: Eurostat database

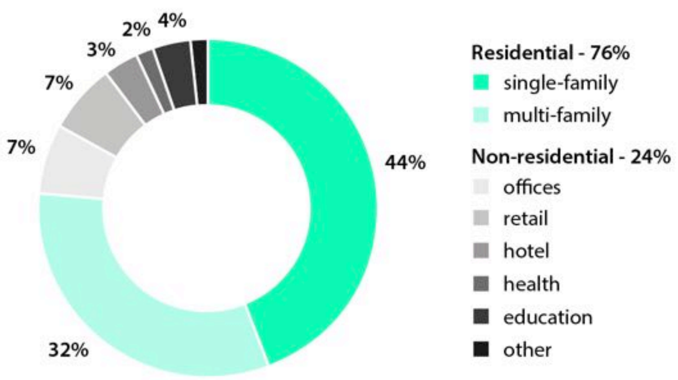

Figure 4: Building floor area by sector and type (EU-28, 2013)
Source: Eurostat database

According to available EPC data, over 97% of the existing building stock is not energy efficient [BPIE, 2017], or at least not as much as it would be necessary for Europe to achieve its 2050 carbon reduction targets. Despite steady improvements in buildings' energy performance [Odyssee-Mure, 2015], only a small share of European buildings can be considered as highly efficient (i.e. energy class A), while the large majority of them are old and in dire need of upgrade.

The good news is that there is plenty of cost-effective energy efficiency potential locked in our buildings, and strong evidence that the realization of this potential will have positive impacts across many different spheres.

Making European buildings more energy efficient would not only reduce the total EU energy consumption by 5-6% and lower carbon emissions by 5% over the period 2012 to 2020 [EC, 2017], but also bring a range of co-benefits that go beyond environmental issues, to encompass economic and social ones. Among others, building energy efficiency is expected to have positive effects on energy security, employment and productivity, energy poverty alleviation, health and well-being, local air pollution, household disposable incomes, asset values and public budgets [IEA, 2014] and, most of all, it is expected to help contain the slowdown that hit the construction industry as a consequence of the global financial crisis of 2008 [Saheb et al., 2015].

Trends in the residential sector

Since around two-thirds of the existing buildings are dwellings (Figure 4), the residential sub-sector is in a privileged position to deliver these multiple benefits at scale.

Most of the dwellings we live in were built between the mid 1950s and the 1980s (Figures 5), in order to deal with the post-war housing shortage. The consequences in terms of final energy consumption and envelope thermal performance are apparent (Figure 6 and Figure 7), with a stock performing well under today's standards, especially with regard to space heating.

Despite the huge energy efficiency potential, renovation rates across the member states are low, with just 0.4-1.2% of the stock being renovated each year, and energy savings are modest, around 20-30% of the final energy consumption. If the EU is to meet its targets, both renovation rates and savings should increase significantly, at least to 2.5-3% and 60% respectively [BPIE, 2013].

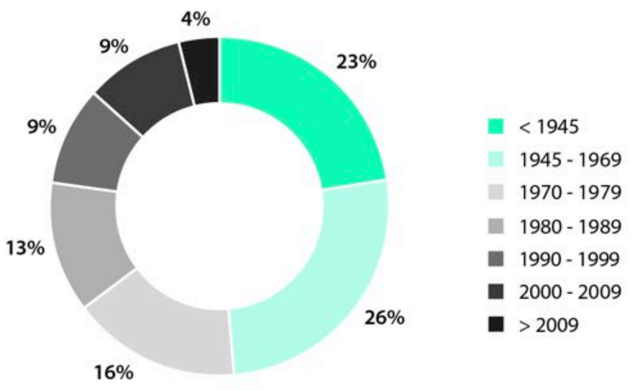

Figure 5: Residential building units by construction year (EU-28, 2014)
Source: Eurostat database

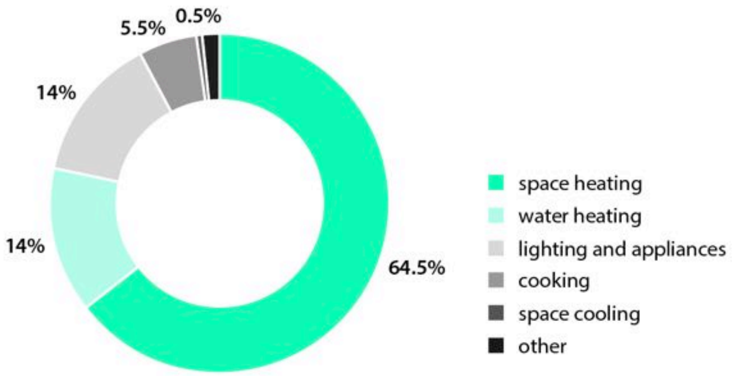

Figure 6: Final energy consumption in the residential sector by type of end-use (EU-28, 2015)
Source: Eurostat database

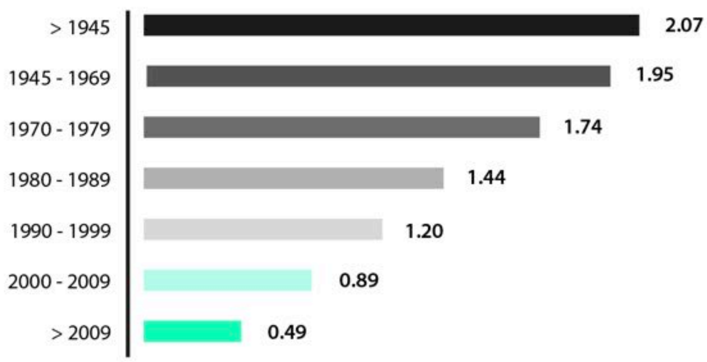

Figure 7: Average envelope U-value of residential buildings by construction year (EU-28, 2014)
Source: EU Building Stock Observatory

2.2 EU energy legislation related to existing buildings

Several waves of EU legislation, enacted over a period of around 20 years, have sought to address the various aspects of energy use in buildings (Figure 8). From the early directives about hot-water boilers and household appliances, until the most recent EPBD - Energy Performance of Buildings Directive [Directive 2002/91/EC], EPBD recast [Directive 2010/31/EU] and EED - Energy Efficiency Directive [Directive 2012/27/EU], the regulatory framework has evolved in the direction of more and more comprehensive provisions.

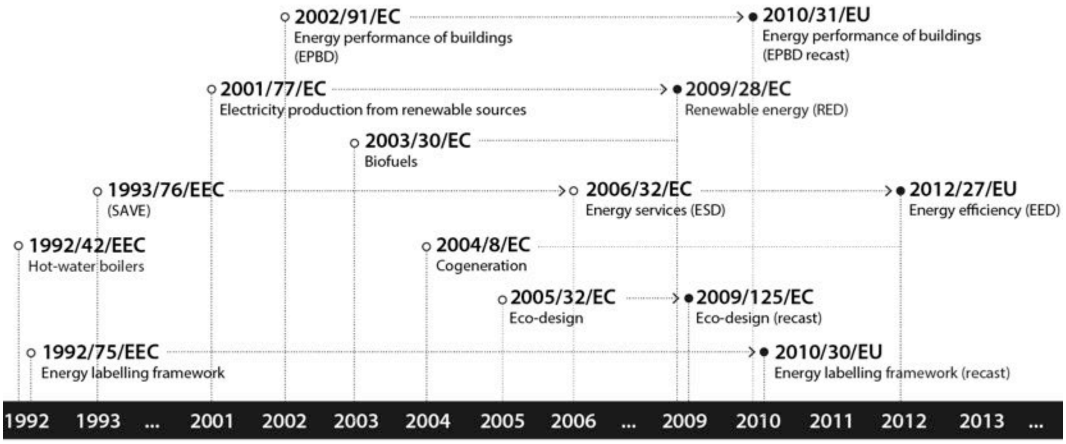

Figure 8: Timeline of EU directives dealing with energy aspects in buildings

In line with Europe's long-term climate strategies and targets set out in the 2020 Climate and Energy Package [COM(2010) 639], 2030 Framework for Climate and Energy [COM(2014) 15; COM(2014) 520], and 2050 Low-carbon Economy Roadmap [COM(2011) 112], the member states have been gradually pushed to implement the 'efficiency first' principle by using a combination of fabric and system level measures.

Some underlying concepts and implications

As far as existing buildings are concerned, the main underlying concept upon which the EU directives are based is that of major renovation. According to Article 7 of the EPBD recast, a **'major renovation'** is defined as one where:

- the total cost of the renovation relating to the building envelope or the technical building systems is higher than 25 % of the value of the building, excluding the value of the land upon which the building is situated;

- or more than 25 % of the surface of the building envelope undergoes renovation.

This definition replaced the 1,000 m^2 threshold that was in the original EPBD, in part expanding its scope, and in part still limiting it to a small portion of the Europe's building stock [Atanasiu & Kouloumpi, 2013]. Indeed, not all existing buildings are covered by current EU legislation, but rather only those undertaking the most comprehensive upgrades.

Nevertheless, major renovation is not the only concept mentioned and different terminologies are used to refer to similar, but not identical, concepts.

Articles 4 and 5 of the EED, for example, introduced the concepts of **'cost-effective deep renovations'** and **'staged deep renovations'** as a type of renovation that reduces both the delivered and the final energy consumption of a building by a significant percentage compared with the pre-renovation levels, and that leads to a very high energy performance. In the specific, 'staged' refers to a deep renovation that is implemented in a number of stages, in accordance to a long-term renovation plan tailored on the individual building and the specific situation [Fabbri et al., 2016].

Article 2, instead, defines **'substantial refurbishments'** as a building renovation whose cost exceeds 50% of the investment cost for a new comparable unit.

When it comes to implementation, this multiplicity of concepts, along with the absence of a target rate or depth for the renovation of the existing building stock, may lead to confusion and further undermine a policy that, in several respects, can be considered a low ambition one [Economidou et al., 2011; Saheb, 2016]. As discussed in the next section, despite the fact that significant developments have happened (the previous 1,000 m^2 threshold excluded around 72% of the European building stock's total area from the EPBD directive's remit), more targeted measures are necessary for fostering building renovations.

A further concept that is not solely related to existing buildings but that is likely to have a significant impact in the direction of higher and deeper renovation rates is that of **'cost-optimality'**.

According to this concept, while setting national requirements, all the EU member states should act with a view to achieving a balance between the investment involved in implementing a specific energy efficiency measure and the energy costs saved throughout its expected useful life. As defined by Article 5 of the EPBD recast, the cost-optimal level of a building, or building element, corresponds to the energy performance level which leads to the lowest cost over its estimated economic lifecycle (from installation, through maintenance and operation, to disposal or replacement).

This cost should be determined by applying a comparative methodology framework that differentiates between new and existing buildings, and between different categories of buildings, and that takes into account parameters such as the climatic conditions and practical accessibility of energy infrastructure.

Since the EPBD requires the implementation of energy efficiency measures in case of major renovations but does not ask for a certain amount of savings, the application of cost-optimal levels to building renovations could represent an important step forward in establishing requirements in terms of renovation depths [BPIE, 2011; Concerted Action EPBD, 2015].

Provisions on building energy renovation in the EPBD, EED and RED

Having said that, the provisions of the **Energy Performance of Buildings Directive (recast)** relating to existing buildings pertain to five main areas.

Article 7 states that - in so far it is technically, functionally and economically feasible - major renovations must meet **minimum energy performance requirements** set in accordance with Article 4 of the same directive. These requirements should be applied to the renovated building or building units as a whole, and/or to the retrofitted or replaced elements that form part of the building envelope with a view to achieving cost-optimal levels. Different requirements can be defined for new and existing buildings, and for different categories of buildings. The cost-optimal levels must be calculated following a comparative methodology framework established in accordance with Article 5.

In addition, Article 8 demands **system requirements** to be established for technical building systems whenever they are installed, replaced or upgraded. These requirements should cover at least heating, hot water, air-conditioning and ventilation systems, and consider the systems' overall energy performance, proper installation, appropriate dimensioning, adjustment and control. The deployment of intelligent metering systems and high-efficiency alternative systems (e.g. renewable sources, cogeneration, district heating, heat pumps) should be encouraged.

Article 9 requires the member states to draw up national plans for increasing the number of **nZEBs - Nearly Zero-Energy Buildings,** that is buildings with a very high energy performance and where the low amount of energy required is to a significant extent covered by renewable sources. Unlike what happens with new buildings, no target dates are set for existing buildings to become nZEBs but, in drafting these plans, the member states should develop policies and take measures in order to stimulate the uptake of nearly zero-energy renovations.

Article 10 specifies the importance of providing appropriate financial incentives to overcome market barriers and support buildings' energy performance improvements. For this purpose, all member states should draw up a **list of existing and, if appropriate, proposed measures and instruments** that promote the objectives of the EPBD. These lists should be communicated to the Commission and updated every three years.

It is the duty of the Commission to examine the effectiveness of the listed measures, provide advice and recommendations and, if appropriate, assist upon request member states in setting up financial support programmes for increasing the energy efficiency of buildings, especially of existing buildings.

Finally, Articles 11, 12 and 13 requires to establish a scheme for **certification of the energy performance of buildings**. Every time a building is sold or rented out, an Energy Performance Certificate must be made available to the prospective buyer or tenant. Such a certificate should be issued by an independent expert, and include at least information about the building energy performance and recommendations for cost-effective improvements. For further details, see the dedicated section in the next chapter.

Existing buildings are dealt with by the **Energy Efficiency Directive** in two specific areas.

First, Article 4 requires the EU member states to establish **long-term building renovation national strategies** for mobilizing investment in the energy-efficient renovation of the overall building stock beyond 2020. By 30 April 2014 a first version of the strategy should be submitted to the Commission as part of their NEEAPs - National Energy Efficiency Action Plans, and then updated every three years. These strategies should:

- provide a status report of the national building stock;
- identify cost-effective approaches to renovations, relevant to the building type and climatic zone;
- identify policies and measures to stimulate deep renovations, including staged deep renovations;
- adopt a forward-looking perspective to guide investment decisions of individuals, the construction industry and financial institutions;
- provide an evidence-based estimate of the expected energy savings and wider benefits.

Second, Article 19 states that member states should evaluate and if necessary take appropriate **measures to remove regulatory and non-regulatory barriers** (e.g. landlord/tenant split incentives) to energy efficiency. Such measures may include providing incentives, repealing or amending legal and regulatory provisions, adopting guidelines and interpretative communications, simplifying administrative procedures, and possibly be combined with education, training and technical assistance activities. Furthermore, Article 20 highlights the need to facilitate the establishment of **financing facilities**, or use existing ones, and **technical support schemes** for energy efficiency improvements.

Besides the EPBD and EED, some provisions relating to existing buildings are also contained in the **RED - Renewable Energy Directive** [Directive 2009/28/EC].

In particular, Article 13 mandates the introduction of appropriate measures in order to increase the share of all kinds of renewable energy in the building sector, thus making an earlier step toward nZEBs. By means of their building regulations and codes, or by other instruments with equivalent effect, all member states should require the use of **minimum levels of energy from renewable sources** in new buildings as well as in existing buildings that are subject to major renovation.

Recent achievements and perspectives

Despite some positive results, international agencies and institutions warn that the European Union is at risk of not achieving the climate and energy targets defined under the Paris Agreement.

To combat this risk, in November 2016 the European Commission released the 'Clean Energy for all Europeans' package [COM(2016) 860]. Also known as 'Winter Package', it aims at enabling the EU to deliver on its Paris Agreement commitments by providing member states with the framework required to facilitate the clean energy transition and the creation of the Energy Union.

With regards to buildings, the package confirms the pivotal role of the building stock in meeting the 2030 targets [Saheb, 2017]. By proposing changes to the EPBD, EED and RED, and launching the 'Smart Finance for Smart Buildings' initiative, it aims at enhancing the energy performance of existing buildings and increasing the uptake of renewable energies by means of both legislative and non-legislative measures.

In particular, the main proposed changes to the **EPBD** [COM(2016) 765] relate to the shift of the provisions on long-term building renovation strategies at EED Article 4 to EPBD Article 2a, and the addition of two new subparagraphs with a view to decarbonizing the building stock by 2050 and supporting the mobilization of investments. Furthermore, a stronger link between the financial incentives provided by public funds for the energy-efficient renovation of buildings and the achieved energy savings is envisioned at Article 10.

The revised **EED** [COM(2016) 761] proposes: to set a 30% binding EU energy efficiency target for 2030, to be achieved through indicative national energy efficiency contributions; to extend beyond 2020 the energy savings obligation, which requires energy suppliers to save 1.5% of energy sold to end-users every year; to update the rules about metering and billing information.

Besides legislative proposals, Annex 1 to COM(2016) 860 launches the **SFSB - Smart Finance for Smart Buildings** initiative.

Building upon the Investment Plan for Europe, the SFSB is a non-legislative proposal that aims at increasing trust in the market and unlocking additional, public and private, funds for energy efficiency and renewables in buildings. According to the three pillars around which the initiative revolves, this should be done through:

- the effective use of public funding (e.g. the European Structural and Investment Funds and the European Fund for Strategic Investment), by developing sustainable financing models based on national/regional investment platforms;
- the aggregation and assistance for project development, by reinforcing existing facilities (e.g. the ELENA facility) and encouraging the creation of dedicated local/regional one-stop-shops;
- the de-risking of investments in sustainable energy renovation of buildings, by fostering a deeper understanding of the real risks and benefits connected to projects.

Although it is too early to draw any conclusion on its effectiveness, some doubts have been raised about whether or not the ‘Winter Package’ is likely to deliver on energy efficiency. Low-ambition targets, opportunities for slippage in attainment, possibilities of exclusions and exemptions, partial revisions, missing definitions [Rosenow et al., 2017], non-consideration of important sources of revenues and inadequate incentives [Saheb, 2017] are the main criticisms to a set of proposals that anyway represents a valuable step forward.

2.3 Policy instruments for national implementation

Under the framework of EU legislation, an increasing number of widely different policy instruments have been adopted by the member states to transpose directives into national law. Regardless of the terminology being used, these are generally split into three main categories: regulatory instruments, information instruments and financing instruments, their objective being to overcome the many barriers and gaps to building energy efficiency.

Regulatory instruments (i.e. Building Energy Codes) and information instruments (i.e. Building Energy Labels) will be the focus of the next two sections. Financing instruments, instead, can be divided into two main categories [BPIE, 2012]:

- **conventional instruments**, in turn divided into financial and fiscal instruments, e.g. grants and subsidies, loans, and tax incentives;
- **innovative instruments**, e.g. Energy Performance Contracting (or Third-Party Financing) and Energy Efficiency Obligations (or White Certificates).

Acknowledging the additional costs that an energy-efficient building renovation may involve, the goal of financing instruments is to improve the economics of retrofitting for those who undertake such a project. As a matter of fact, even though retrofit measures are known to be cost-effective, they still necessitate the availability of initial investment and the willingness to act. Long payback periods due to high up-front costs, lack of awareness about saving and funding opportunities, competing interests among a range of stakeholders (i.e. property owners, tenants, contractors), etc. often undermine the conditions for building energy efficiency to happen.

On the one hand, thanks to their relatively easy and well-established working mechanisms, conventional instruments are by far the most common in the private sector.

Grants award clients a non-repayable sum of money to pay for part or all of the cost related to the implementation of energy efficiency upgrades. **Soft loans** (often backed up by guarantee funds) cover the up-front cost of investments in energy efficiency, charging a low- or zero-rate of interest, and/or providing credit risk support. **Tax incentives** reduce the taxes a consumer pays either reducing the taxable income, or lowering the value added tax on eligible products and energy efficiency measures. With regards to renewable energy sources, **feed-in tariffs**

offer a guaranteed price for each unit of renewable heat or electricity produced and supplied to the grid.

On the other hand, innovative instruments offer the advantage of being independent from public budgets, with ESCOs - Energy Service Companies and utilities playing a major role in supporting private investments.

Under an **Energy Performance Contracting** arrangement, the ESCO finances and implements all necessary energy efficiency measures at no charge for the client and uses energy savings to repay the costs. Under an **Energy Efficiency Obligations** scheme, end-users are given the possibility to get certificates for implementing energy efficiency measures and utilities can purchase them for meeting related saving obligations.

Generally speaking, since no single policy category can address all the market barriers that affect the existing building stock alone, analyses of national renovation strategies show that member states increasingly go in the direction of **policy packages** [Saheb, 2013; IPEEC, 2017].

Combining a variety of policy instruments and implementing them in a balanced and coordinated manner, policy packages (also known as policy mixes) are considered to be more relevant, have greater impact, and be more sustainable [IEA, 2008] compared to individual instruments. Most of all, they seem to be the most effective way to target the various market actors and respective barriers [ENTRANZE, 2014b], and respond to the need of policy synergy and complementarity. For instance, energy efficiency incentives need information campaigns to raise citizens' awareness; building energy codes and standards need incentives to achieve high compliance rates.

2.4 Building Energy Codes

Building Energy Codes (BECs) represent the key policy instrument adopted by governments to regulate energy use in buildings [Economidou et al., 2011; Saheb, 2013; Allohui et al., 2015]. Sometimes referred to as Building Energy Standards[3], they consist of a set of (mandatory) requirements aimed at reducing the energy consumption of buildings, without compromising the comfort of the building's occupants.

[3] Although some authors have shown semantic differences between the two terms, for the purpose of this research they can be considered synonyms. The term 'codes' is nevertheless preferred to 'standards' in order to avoid confusion with 'appliance standards'.

Due to literal translations, it is not unusual to find further terms such as 'energy conservation building codes', 'building thermal regulations' or 'thermal building regulations'.

History of BECs

Early in their history, BECs have been introduced in most of the European member states to set prescriptive requirements about new buildings' thermal properties.

The first attempts in the field of building energy codes date back to the mid-1940s, when some Scandinavian countries started to promote the adoption of traditional architecture features that could help in ensuring adequate heating conditions and raise people's living standards [Laustsen, 2008; Papadopoulos, 2016]. It is in this perspective that, for example, features like air layers in cavity brick walls or double layer wooden floors became mandatory for newly constructed multifamily residential buildings in Denmark, or that the use of triple-pane windows and extra insulation was incentivized in Sweden and became widespread in single-family housing.

Apart from these early beginnings, there is not much evidence of further measures during the 1950s and 1960s. In 1952, a DIN-standard (DIN 4108:1952-07) was adopted by Germany to avoid moisture damage and summer overheating. In 1960, requirements about component specific U-values and double-pane windows were implemented in Sweden through the national building code (Byggnadsstadgan 1960). In 1965, the UK Building Regulations introduced thermal transmittance coefficients for walls and roofs in order to prevent water condensation.

As far as western Europe is concerned, it was necessary to wait until the second-half of the 1970s to see member states systematically regulate building energy efficiency.

After the 1973 oil crisis, the objective of reducing energy dependence gained importance on improving housing comfort and BECs, as commonly understood, began to emerge on a wider scale [Economidou et al., 2011; Pérez-Lombard et al., 2011; Allohui et al., 2015]. Those countries where regulations had been previously enforced tightened their requirements, and those where no actions had been taken quickly followed.

In 1974, a thermal regulation (RT 1974) dealing with insulation and ventilation of residential buildings was adopted by France. In 1976, Italy enacted its first energy saving law (L. 373/76) focusing on building material and installation requirements. In the same year, an updated version of the UK Building Regulations came into force. In 1977 and 1978, two ordinances were published by Germany in order to regulate heating transmission and supply (WärmeschutzV, 1977; HeizAnIV, 1978). In 1979, both Denmark (BR 1977) and Sweden (SBN 1975) strengthened preceding regulations.

From 1980s on, all over Europe BECs began to be revised and upgraded at an accelerated pace until the 1990s, when new background conditions led to the rise of codes characterised by a stronger commitment towards the reduction of greenhouse gas emissions and limitation of global warming [Pérez-Lombard et al., 2011; Copiello, 2017]. In view of the European Directive 93/76/CEE and the Kyoto Protocol, energy-related regulations broadened their scope to include energy certification schemes, regular inspections of boilers and diffusion of renewable energy sources; calculation methods were also developed.

At the turn of the 2000s, a major change in the EU building energy code trends occurred. Following the EPBD Directive, the shift from prescriptive- to performance-based requirements became imperative and all member states had to adapt their BECs accordingly [Laustsen, 2008; Allohui et al., 2015].

BECs (alternative) approaches

In order to achieve compliance and enforcement of BECs, two principal approaches exist [IEA, 2013; IPEEC, 2015], and sometimes coexist [BPIE, 2011; IPEEC, 2015]: prescriptive and performance-based.

In **'prescriptive' codes**, minimum energy performance requirements for newly placed or replaced building elements and systems must be met. Setting standards for individual components, prescriptive requirements vary a lot from code to code. Besides the ever-present thermal insulation requirements for the elements that form part of the building envelope (e.g. walls, roof, windows and doors), further requirements such as ventilation rate, airtightness level, indoor temperature, mechanical systems efficiency, daylight factor, cold bridges, etc. are sometimes established.

Compliance assessment is conducted component by component, checking whether it meets or exceeds the specific requirement/s. Trade-offs between the efficiency of different components, usually between envelope and equipment components, might or might not be allowed.

In **'performance-based' codes**, a single target must be met for the overall energy performance of the building (i.e. envelope insulation, space heating, air-conditioning, hot-water, ventilation and lighting). Depending on the code, this performance target can either be expressed in terms of absolute consumption of energy per unit of floor area (i.e. kWh/m^2.y) or as percentage improvement in comparison to a certain baseline.

In order to assess compliance, a specific calculation methodology has to be used. Usually embedded into a computer software and predicated upon a typical building configuration for the relevant building class (the so-called 'reference building'), it checks if the efficiency of the proposed design is equivalent to, or better than, the efficiency of the reference design, that is one built to the prescriptive code.

Each of these two broad approaches has its own benefits and drawbacks.

Prescriptive codes are simple but inflexible. On the one hand, they clearly lay out minimum and/or maximum values for distinct components; on the other hand, they do not reward the synergies that may arise from component interactions [Saheb, 2013]. Under a prescriptive code, compliance is easy to verify by code officials because designers are limited in their choices. As such, they foster the use of the most established technologies and those that ensure the least initial investment, rather than those that might ensure higher paybacks.

Performance codes, instead, are flexible but complex: in order to consider the interactions among different components and optimise the building's savings potential, they require knowledge in energy modelling. Under a performance code, compliance is difficult to check: because code officials do not necessarily have the expertise to verify the accuracy of the model inputs, certification of model outputs is typically deemed sufficient. However, once a project has been modelled, architects and engineers can evaluate countless alternative options until they arrive at the solution that provides the highest energy savings for the lowest cost.

These pros and cons have led to a situation where it is not unusual to find prescriptive and performance requirements used either: a) in parallel, with the component approach mainly used for (minor) renovation projects, and the whole-building approach for major renovations and new constructions, or b) in combination, with performance-based codes including also some prescriptive requirements so that basic features (e.g. building envelope insulation) are not completely left out of projects even though the modelling demonstrates that these are not necessary to achieve the target [BPIE, 2011].

Prescriptive and performance-based codes are currently the approaches used by most of the European countries. However, both of them fail in predicting how well the building will actually perform.

Requirements are based on ideal situation assumptions, not actual practice. Building components are assumed to be installed correctly and function as specified by manufacturers, as well as the data entered in energy models are assumed to be accurate and not influenced by occupant behaviours. Also, current codes do not cover all energy use in a building. For example, plug-loads, which represent an increasing part of a building's energy use, are frequently out of the scope.

On top of that, it is not unusual to detect differences between predicted and measured savings (also known as the 'energy performance gap'), with real buildings operating below expectations [IPEEC, 2015; IPEEC, 2017].

Recognizing the difficulties of prescriptive- and performance-based codes in achieving the expected levels of energy use, **'outcome-based' codes** [Denniston et al., 2011; Colker, 2012] have been gaining interest and momentum in very recent years.

According to this approach, compliance is based on the actual performance of the occupied building and verified against a target energy-use level set by the code. It follows that the compliance process entails both a pre-occupancy inspection and post-occupancy measurements.

Because of the significant challenges in managing the reporting mechanisms (i.e. the need for individual utility meters) and ensuring enforcement (i.e. the extended involvement of building officials), a widespread adoption of outcome-based codes is not foreseeable in the immediate future. To date, Sweden is the only European member state having implemented such a kind of code [IPEEC, 2017].

2.5 Building Energy Labels

In the literature, there is no standard definition of what a Building Energy Label (BEL) is[4]. According to the common understanding, BELs can be defined as any kind of official document, issued by a private company, a government body or a legal person designated by it, that provides a standardized way to (quantitatively) evaluate, rate and compare energy use in buildings.

By following this definition, BELs emerged in the early 1990s as an essential tool for enabling greater transparency with regards to the use of energy in the building sector [Perez-Lombard et al., 2009]. On the basis of the SAVE Directive [93/76/EEC], which introduced the concept of 'energy certification of buildings', the Netherlands and Denmark were the first European countries to set up mandatory energy labelling schemes for new buildings in 1995 and 1997

[4] As for BECs, also for BELs a variety of terms have emerged with sometimes overlapping meanings. In particular, the terms 'benchmarking' and 'rating' are frequently used as synonyms for 'labelling'.

respectively [Annunziata et al., 2013], but the overall implementation remained low until 2002, when the EPBD entered into force.

In some ways similar to energy rating labels on household appliances, energy labels for buildings can be considered as a sub-category of environmental building labels. While environmental labels (e.g. the well-known LEED and BREEAM schemes) assess the overall impact of the building and include energy as one of many issues of assessment, energy labels keep the focus on energy aspects.

BELs usually take one of two forms: positive or comparative labels [Laustsen, 2010; IPEEC, 2014].

Voluntary certification is often considered a type of **'positive' labelling**, used by builders and building owners that want to advertise the energy performance of their buildings. As such, positive labels tend to identify the most efficient buildings in the stock, those that go beyond current building codes and standards.

In contrast, mandatory certification is a type of **'comparative' labelling**, adopted by governments that want to rate buildings in relation to other similar buildings. Applied to a large share of the building stock, comparative labels help investors and policy makers to identify the most inefficient buildings and to take decisions on how to improve them.

Basically, there are two main approaches for the evaluation of building energy performance [Perez-Lombard et al., 2009; Laustsen, 2010; Leipziger, 2013]:

- **asset (or calculated) ratings**, based on the theoretical energy use in a building, as estimated through modelling software under a set of standardized conditions (e.g. for indoor and outdoor temperatures, weather, occupancy patterns);
- **operational (or measured) ratings**, based on the actual energy use in a building, as metered from utility bills, generally normalized.

It follows that asset ratings are seen to be the most appropriate approach for residential buildings, and the only possible in case of new buildings, as the rating is independent of the occupants' behaviour and can be assessed even before occupation. Operational ratings, instead, are more appropriate for large and complex non-residential buildings, or for the regular rating of public buildings [BPIE, 2010].

Energy Performance Certificates

Among the many types of building energy labels that have been developed, the EPC - Energy Performance Certificate constitute a type in itself. Introduced by the

EPBD [2002/91/EC] and further reinforced by the EPBD recast [2010/31/EU], it represents the most visible aspect of the EU's action in the building sector.

General requirements regarding the EPC implementation are described in Articles 11, 12, 13, 17 and 18 of the EPBD recast.

According to these articles, by January 2006 (with a possible extension period until January 2009) all member states must ensure that an EPC, not more than 10 years old, is made available by the owner to the prospective new buyer or tenant whenever a building or building unit[5] is (constructed or) deeply renovated, sold or rented out.

Such a certificate must state the energy performance of the building, calculated on the basis of a methodology specified in the directive, and include reference values that make possible for consumers and/or users to compare and assess the energy performance of different properties in the market. To this end, the **energy performance indicator** of the EPC must be stated in sale/rent advertisements, and displayed in a prominent place when public buildings, or other buildings frequently visited by the public, with a total useful floor area over 500 m^2 are concerned.

Unless there is no reasonable potential, the EPC must be accompanied by **recommendations** for cost-optimal or cost-effective improvements of the building energy performance. The recommendations included in the EPC must cover both measures to be carried out either in connection with a major renovation of the building envelope or technical building systems, and other measures for individual building elements, be technically feasible for the specific building and indicate where to find more detailed information. Estimates of payback periods or cost-benefits over the measures' lifetime, as well as advice on incentive and financing opportunities, may be provided.

In order to ensure the objectivity of the assessment, all EPCs must be carried out in an independent manner, by qualified and/or accredited experts/companies with specialist knowledge and expertise in the field. Updated lists of certifiers must be made available to the public. An **independent control system** for EPC must be established and penalties applied for non-compliance or poor execution.

Different backgrounds have led to varying implementation solutions, particularly with respect to the chosen calculation methods, the registration procedures, promotional activities, quality control mechanisms and enforcement systems [BPIE, 2010; BPIE, 2014].

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[5] Exemptions apply to buildings and monuments officially protected, buildings used as places of worship and for religious activities, temporary buildings, industrial sites, workshops and non-residential agricultural buildings, holiday homes, stand-alone buildings with a total useful floor area of less than 50 m^2.

Building Renovation Passports

With specific regard to the role that energy labels and certificates can play for existing buildings, some criticisms have been raised in more recent times about their apparent inability to stimulate renovation practice. In most cases, the current EPC schemes provide scarce and generic recommendations, overlook indicators related to air quality, thermal and visual comfort, and are therefore considered a waste of money by many homeowners [Sesana & Salvalai, 2018].

This has led a number of member states to explore the opportunity for EPCs to evolve towards more comprehensive, dynamic tools that are usually referred to as **Building Renovation Passports** (BRPs).

According to the BPIE, a BRP is a document, either in electronic or paper format, which outlines a long-term, step-by-step renovation roadmap for a specific building [Fabbri et al., 2016; Fabbri et al., 2018]. Resulting from an on-site energy audit and being developed in close dialogue with building owners, it is a tool intentionally designed to provide tailor-made and user-friendly information about costs and savings of staged deep renovation plans.

By foreseeing the step-wise implementation of selected retrofit measures over a period of up to 10 or 20 years, BRPs offer the advantage of supporting investment decision making and avoiding lock-in effects. When combined with a **building logbook**, that is a repository of up-to-date building-related information on aspects such as operations and maintenance (e.g. energy bills, executed works), they can also be used to collect and keep track of the building' features.

To date, examples of BRP ongoing experiences across the EU are the 'Passeport Efficacité Énergétique' in France, the 'Woningpas' in Flanders region (Belgium), and the 'Individuelle Sanierungsfahrplan' in Germany (cfr. Section 5.3).

Chapter 3

Denmark

In Denmark, the transposition of the EPBD into national law is the responsibility of the Danish Energy Agency (ENS - Energistyrelsen), an agency within the Ministry of Energy, Utilities and Climate (Energi-, Forsynings- og Klimaministeriet), and the Danish Transport, Construction and Housing Authority (TBST - Trafik-, Bigge- og Boligstyrelsen), a similar agency within the Ministry of Transport, Building and Housing (Transport-, Bygnings- og Boligministeriet).

Danish Building Regulations (BR - Bygningsreglement) are the reference legislation. Since the introduction of the first energy requirements for new buildings in BR61 - Bygningsreglement 1961, these have been regularly tightened (in year 1967, 1972, 1977, 1982, 1995, and 1998) and significantly revised in year 2006, to include provisions also on the renovation of existing buildings.

3.1 BR15

Current requirements on the energy performance of buildings are defined in the Danish Building Regulations 2015 (**BR15 - Bygningsreglement 2015**)[6]. BR15 have been in effect since 1 January 2016 with a transitional period until 30 June 2016 during which BR10 could still be applied [BEK nr. 1028 af 30/06/2016]. They apply to residential and non-residential buildings, regardless of the

[6] In the course of writing this thesis, an updated version of the Danish building regulations (BR18 - Bygningsreglement 2018) was published [BEK nr. 1615 af 13/12/2017], but no major changes have been made about energy performance requirements for new and existing buildings.

construction year, at the time of construction/renovation works subject to the application for a building permit or notice.

From a general point of view, the BR15 document is laid out in two columns. The ‘provision’ column contains the legal requirements, while the ‘guidance’ column contains guidelines, sketches and comments on the legal requirements.

As for BR10 [Thomsen et al., 2015], also BR15 disclose some of the minimum energy requirements that will become legally binding with the entry into force of BR20. Indeed, with the aim of preparing the market for the future tightening of requirements, many of the provisions come with a voluntary low-energy class, the so-called Building Class 2020 (**Bygningsklasse 2020**), which complies with the EPBD provisions on nearly-zero energy buildings.

The parts of the regulations with requirements relevant to the retrofitting of existing buildings are primarily Chapter 6, ‘Indoor climate’, Chapter 7, ‘Energy consumption’, and Chapter 8, ‘Services’. Further requirements are in Chapter 4.5, ‘Moisture and durability’. Appendix 6, ‘Building energy consumption’, contains design assumptions to be used in the calculations.

According to Chapter 7, BR15 distinguish between six categories of projects [SBi-Anvisning 258; VEB, 2016], from minor to major renovations. These categories are:

- new construction (nybyggeri);
- change of use (tilbygninger), i.e. conversion to a new use that involves higher energy consumption;
- extension (ændret anvendelse), i.e. addition of floor area to an existing building;
- conversion and other alterations (ombygning eller renovering), i.e. modifications that do not belong to either of the two preceding categories;
- replacement of building elements and installations (udskiftning af bygningsdele), without other alterations to the existing building;
- reparations and upkeep (reparationer), i.e. minor renovation measures such as paint treatment, façade plastering, roof recovering, etc.

For each of these categories the regulations set different requirements (Figure 9). Only ‘reparations and upkeep’ cases are exempted.

For ‘change of use’ cases, two alternative compliance options are possible.

The first option consists in the application of the EPF - Energy Performance Frame (**Energiramme**) as for new construction, in combination with further requirements for design transmission loss, minimum thermal insulation, and energy gain through windows, doors and roof lights.

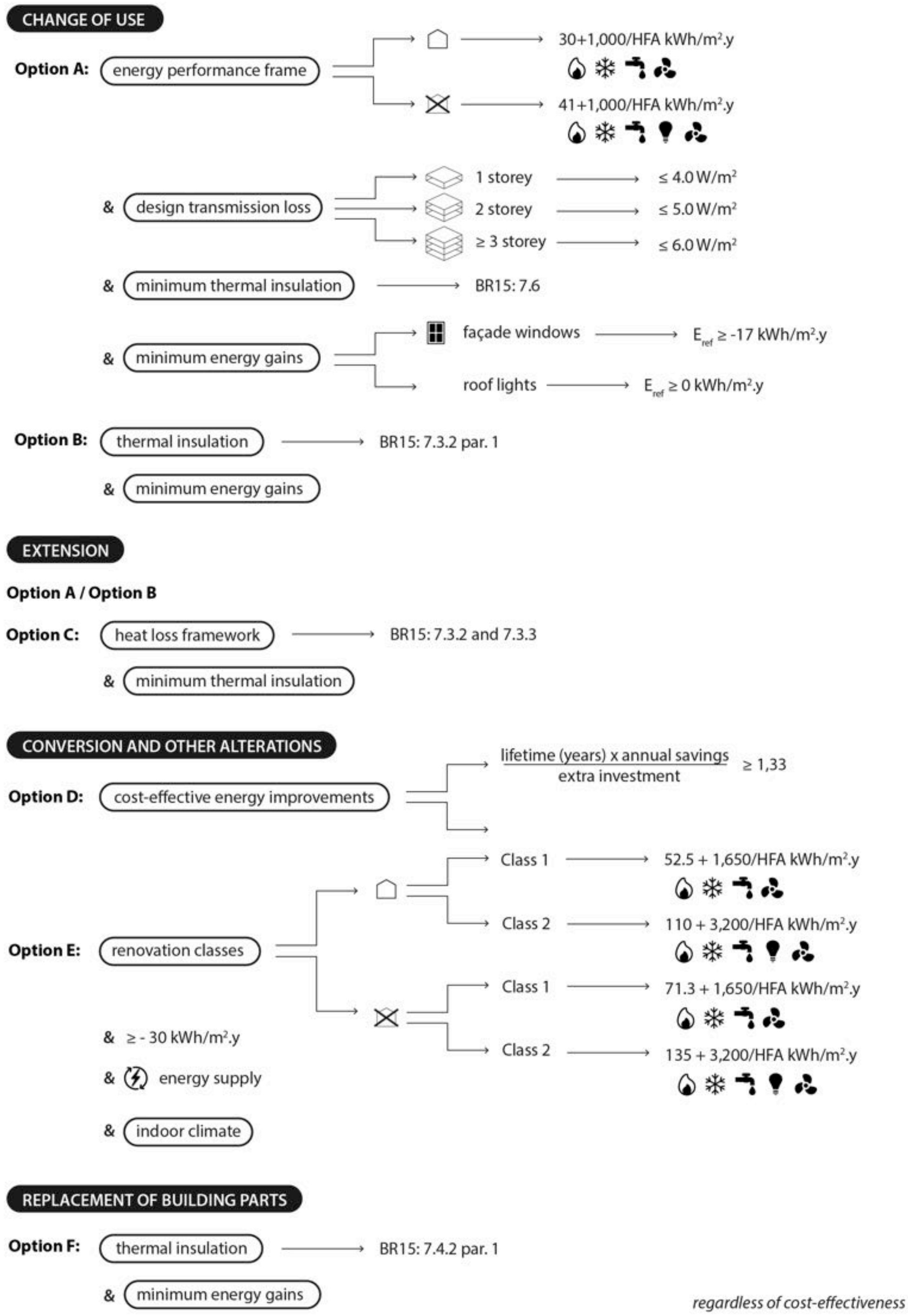


Figure 9: BR15. Compliance options

The EPF indicates the building's total demand for supplied energy to heating, ventilation, domestic hot water, cooling and, where appropriate, lighting per square meter of HFA - Heated Floor Area[7] (Table 1). For residential buildings (e.g. dwellings, student accommodations, hotels), it must not exceed 30 + 1000/HFA kWh/m^2.y, while for non-residential buildings (e.g. offices, schools, institutions), it must not exceed 41 + 1000/HFA kWh/m^2.y.

Table 1: BR15. Energy Performance Frames

	Residential buildings (kWh/m^2)	**Non-residential buildings (kWh/m^2)**
BR10	52.5 + 1650/A	71.3 + 1650/A
BR15	30 + 1000/A	41 + 1000/A
BR20	20	25

Compliance calculations are to be performed using the **Be15 - Bygningers energibehov** tool, or equivalent calculation method. Developed by the Danish Building Research Institute (SBi - Statens Byggeforskningsinstitut), the Be15 is a building performance simulation tool based on monthly steady-state calculations [SBi-Anvisning 213]. Comprising of a graphic user interface and a calculation engine, it estimates the building energy performance by applying standard conditions of use and temperature, and by adopting typical weather data [Wang et al., 2013].

Be15 calculates the Energiramme as the difference, in primary energy, between the building's energy consumption and on-site renewable energy production, plus a possible overheating penalty.

According to Danish standards [DS 474:1993], indoor temperatures should not exceed 26°C for more than 100 hours a year, and 27°C for more than 25 hours a year. The penalty for overheating is then calculated as a fictive energy demand, equal to the energy used by an imaginary mechanical cooling system in order to keep the indoor temperature at 26°C.

In order to ensure that you cannot comply with the EPF primarily by renewable energy, energy production from renewable sources can be deducted up to 25 kWh/m^2 per year.

Besides the EPF, Be15 automatically calculates also the Design Transmission Loss (**Dimensionerende Transmissionstab**), that is the sum of the total heat

[7] 'Heated Floor Area' means the total floor area of the storeys, or parts thereof, that are heated to at least 15°C.

transmission loss through one square meter of building envelope (excluding windows, glazed doors and skylights, but including thermal bridges), with a temperature differential between the indoor and outdoor air of 32°C.

Depending on the building's number of storeys, BR15 require it must not exceed 4.0 W/m^2 of the building envelope in the case of single-storey buildings, 5.0 W/m^2 in two-storey buildings, and 6.0 W/m^2 in buildings with three storeys or more (Table 2).

Table 2: BR15. Design Transmission Loss

No of storeys in the building	**BR10**	**BR15**	**BR20**
1	5.0	4.0	3.7
2	6.0	5.0	4.7
3 or more	7.0	6.0	5.7

To avoid condensation and moisture issues, Minimum Thermal Insulation requirements (**Mindste Varmeisolering**) also apply to individual opaque elements of the building envelope (Table 5). These should be insulated in such a way as the heat loss through them do not exceed the listed U-values and linear losses [DS 418:2011].

Transparent elements, instead, must ensure a net Energy Gain (**Energitilskud**). Calculated as the solar heat transmitted in, minus the heat loss transmitted out through one square meter of glazing over a typical heating season ($E_{ref} = I \cdot g_w - G \cdot U_w$), it represents the ability of a reference window to provide passive solar heat.

Table 3: BR15. Net Energy Gains

	BR10	**BR15**	**BR20**
Windows and glazed doors	$E_{ref} \geq -33$ kWh/m^2.y	$E_{ref} \geq -17$ kWh/m^2.y	$E_{ref} \geq 0$ kWh/m^2.y
	Energy Label C U = 1.4 W/m^{2}K	Energy Label B U = 1.1 W/m^{2}K	Energy Label A U = 0.8 W/m^{2}K
Roof lights	$E_{ref} \geq -10$ kWh/m^2.y	$E_{ref} \geq 0$ kWh/m^2.y	$E_{ref} \geq 10$ kWh/m^2.y

For windows and glazed doors, E_{ref} must not be less than -17 kWh/m^2.y, or Energy Label B according to the Danish window energy rating system; for roof lights it must not be less than 0 kWh/m^2.y (Table 3).

The second option is to comply with the requirements for Thermal Insulation (**Varmeisolering**), in combination with the above-mentioned requirements for windows, doors and roof lights. As an alternative to the provisions for new buildings, building elements must satisfy stated U-values and linear losses that vary depending on the temperature of the rooms/spaces around them (i.e. T > 15°C or 5°C < T < 15°C).

For ‘building extension’ cases, a third compliance option is possible. This consists in the application of the HLF - Heat Loss Frame (**Varmetabsramme**), in combination with the requirements for Minimum Thermal Insulation.

The HLF indicates the maximum heat transmission loss (in W) allowed for the extension at issue. To fulfil the regulations, the extension’s actual heat loss must not exceed the HLF, calculated as if the Thermal Insulation requirements were satisfied (Table 4).

In case of ‘conversions and other alterations’ to building elements, BR15 provides for two compliance options.

The first option requires to carry out energy saving works to the point that the investment is cost-effective, i.e. to the point measures can be repaid within a payback time of less than 75% of their expected lifetime (Table 4).

Table 4: BR15. Insulation requirements and linear losses

	Change of use	**Extension**	**Conversion & other alterations**
U-values (W/m^{2}K)			
External/Basement walls	0.30	0.15	0.18
Slabs on ground	0.20	0.10	0.10
Ceiling/Roof structures	0.20	0.12	0.12
Doors	1.40/1.50	1.80	1.80
Windows	1.80	-	1.40/1.65
Roof lights	1.40	1.40	1.40
Linear losses (W/mK)			
Foundations	0.40-0.20	0.12	0.12
Joints - Walls	0.06	0.03	0.03
Joints - Roof	0.20	0.10	0.10

If the Cost-effectiveness (**Rentabilitet**), calculated as the ratio between the energy cost savings over the expected lifetime of the measure and the extra investment required for the measure itself, is greater or equal to 1.33, then the works must be implemented and relevant thermal insulation requirements achieved. Should cost-effectiveness be lower than 1.33, or impossible to reach without detriment of moisture resistance, less extensive improvements still need to be carried out.

As an alternative to fulfilling component requirements, a second compliance option allows to apply the Energy Performance Frames for existing buildings (**Energirammen for eksisterende byggeri**), also known as Renovation Classes (**Renoveringsklasser**) [Kragh, 2016; Bjørneboe et al., 2018].

Table 5: BR15. Renovation Classes

Residential buildings		**Non-residential buildings**	
Renovation Class 1	**Renovation Class 2**	**Renovation Class 1**	**Renovation Class 2**
52.5 + 1650/HFA kWh/m^2.y	110 + 3200/HFA kWh/m^2.y	71.3 + 1650/HFA kWh/m^2.y	135 + 3200/HFA kWh/m^2.y
EPC class A2010	EPC class C	EPC class A2010	EPC class C

BR15 sets two levels of renovation: ‘Renovation Class 1’, corresponding to a Class A of the Danish energy performance certificate scheme, and ‘Renovation Class 2’, corresponding to a Class C (Table 5). In order for a building to achieve one of these levels, the following requirements must be met:

- the total demand for supplied energy to heating, ventilation, domestic hot water, cooling and, where appropriate, lighting per square meter of heated floor area must not exceed the relevant EPF;
- the energy demand for supplied energy must be reduced by at least 30 kWh/m^2.y;
- a share of renewable energy (or district heating) in the total energy supply must be guaranteed.

To reach ‘Renovation Class 1’, the building must also meet the requirements for indoor climate set in Chapter 6 of the BR15 and further specified in non-binding guidelines [SBi-Anvisning 196]. These mainly relate to: thermal conditions, air quality (ventilation, emissions from building materials), acoustic indoor climate, and lighting conditions (daylight, electric lighting).

As regards indoor thermal conditions, the provision is fulfilled when it can be proven by calculation that the temperature of the critical room exceeds 27°C for no more than 100 hours per year, and 28°C for no more than 25 hours per year.

About indoor air quality, all habitable rooms, as well as the building as a whole, must have a fresh air supply of at least 0.3 $l/s.m^2$ of heated floor area. Moreover, in kitchens and bathrooms it must be possible to increase the extraction of exhaust air to at least 20 l/s and 15 l/s respectively.

In principle, ventilation must be provided by mechanical systems with heat recovery. Natural ventilation can be used in single-family houses with adequate openings. The use of air extractors may be allowed for construction reasons or due to space constraints.

Minimum requirements about acoustic indoor climate are deemed to be met if the building falls within Class C/D of the national sound classification scheme [DS 490:2007].

Lighting conditions are considered satisfactory if the room is fitted with windows providing views of the surroundings and, assuming the pane transmittance is higher than 0.75, the glazed area of side lights and roof lights respectively corresponds to no less than 10% and 7% of the internal net floor area. Instead of the glass to floor ratio, a calculation or measurement can be performed to demonstrate that a daylight factor of no less than 2% is reached in half of the room. In the case of lower transmittance or outdoor obstructions (e.g. solar glazing, nearby buildings), the glass area must be increased correspondingly.

For ‘full replacement’ of building elements, both opaque and glazed, or installations, the new component must always meet the requirements set in BR15, regardless of cost-effectiveness (Table 4).

This means that, when being replaced, building elements must satisfy the requirements for minimum heat insulation and energy gain as described above. Installations (i.e. heating, cooling and DHW distribution, ventilation, water and drainage, plumbing, lifts) must satisfy the eco-design requirements (**Ecodesignkrav**) specified in Chapter 8 of the building regulations and other relevant standards [DS 447:2013; DS 452:2013; DS 469:2013].

3.2 Energimærkning

Denmark first introduced mandatory energy labelling of new and existing buildings in 1997, when two different types of certificates were established [Lov nr. 485 af 12 juni 1996]: the ELO-scheme (Energi Ledelses Ordningen), for buildings over 1,500 m^2, based on measured values and to be renewed every year; and the EMO-scheme (Energi Mærkning Odningen), for buildings under 1,500 m^2, based on calculated values and to be issued, in the case of sale, every 3 years.

In 2006, the previous version of the scheme had to be revised in order to make it compatible with the EPBD [Lov nr. 585 af 24 juni 2005]. Since then, classifications and corresponding thresholds have been changed five more times [Brøgger & Wittchen, 2016], with another substantial revision in 2010.

From 1 February 2011, the issue of an Energimærkning is mandatory for all properties that are for sale or rent.

In principle, it is valid for 10 years[8]. However, apartment buildings, or other large buildings not being owned by the public, with a total floor area of more than 1,000 m^2 must always have a valid EPC (**Regelmæssig Energimærkning**) [Energistyrelsen, 2016a]. Furthermore, if the certificate identifies savings with a repayment period of less than 10 years and accounting for more than 5% of the building energy consumption, then its validity is reduced to 7 years.

As far as existing buildings are concerned, the energy label report (**Energimærkningsrapport**) comprises of two main parts: the energy label (**Energimærke**), assessing the building's energy consumption, and the energy plan (**Energiplan**), providing recommendations for energy-saving measures [Energistyrelsen, 2015a; Energistyrelsen, 2015b].

The Energimærke scale ranges from A to G, where A indicates the highest energy standard and G the lowest. Class A is further divided into three sub-classes (A2020, A2015 and A2010), respectively indicating whether the building meets the BR10, the BR15 or the future BR20 requirements.

Depending on the building use (residential or non-residential) and size (heated floor area), label thresholds are as in Table 6. When certifying mixed-use buildings, that is buildings where the main use constitutes less than 80% of the total heated floor area, or where the secondary use area exceeds 1,000 m^2, the primary energy demand must be determined as a weighted average of residential and non-residential zones [Energistyrelsen, 2016b].

The building's primary energy demand is given on the basis of:

- calculated consumption (**beregnet forbrug**), based on the building's estimated consumption under standard conditions of use (using the same calculation tool of the relevant building regulations);
- measured consumption (**målt forbrug**), based on the building's actual consumption over a period of at least 12 months.

[8] Certificates issued before 1 September 2006 were valid for 5 years, while those issued from 1 September 2006 until 31 January 2011 were valid for 7 years.

Table 6: Energimærkning classes (kWh/m^2.y)

Label	Residential buildings	Non-residential buildings
A2020	20.0	25.0
A2015	≤ 30.0 + 1000/A	≤ 41.0 + 1000/A
A2010	≤ 52.5 + 1650/A	≤ 71.3 + 1650/A
B	≤ 70.0 + 2200/A	≤ 95.0 + 2200/A
C	≤110 + 3200/A	≤135 + 3200/A
D	≤ 150 + 4200/A	≤ 175 + 4200/A
E	≤ 190 + 5200/A	≤ 215 + 5200/A
F	≤ 240 + 6500/A	≤ 265 + 6500/A
G	> 240 + 6500/A	> 265 + 6500/A

In general, all buildings should be certified by calculated consumption (Figure 10). Buildings that can be certified by measured consumption include multi-family buildings and parts of non-residential buildings (representing less than 25% of the total floor area) to rent.

The calculation methodology is the same as that used for demonstrating that a building meets the EPF in BR15.

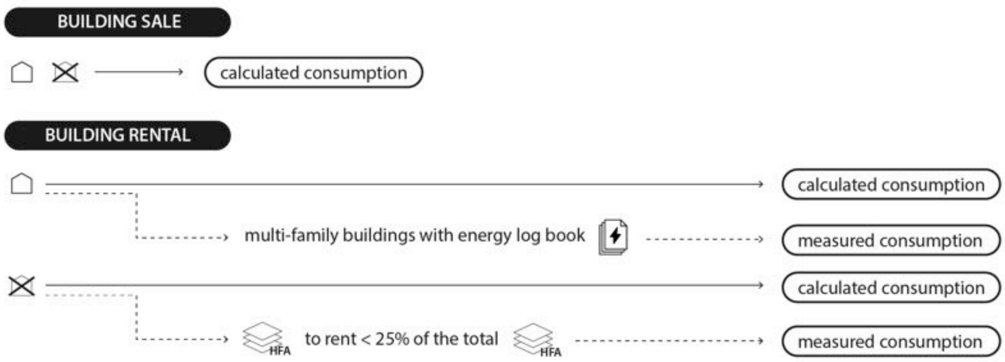


Figure 10: Energimærkning. Methods used to issue the certificate

The cost-effective measures include a short description, estimates of necessary investments, annual savings (in DKK and CO_2 emissions/energy units) and payback times.

Recommendations must refer to the specific building. Indeed, the labelling system entails that an energy consultant inspects the property. Buildings that can be labelled without inspection (**Energimærkning uden bygningsgennemgang**) and refer to standardized recommendations are detached, semi-detached and row houses less than 25 years old and previously certified.

All registered certificates are publicly available at SparEnergi.dk.

3.3 Energiselskabers Energispareindsats, BoligJobordningen and BedreBolig

Despite a long tradition in building energy efficiency, financial incentives are very limited in Denmark, with no options for soft loans or grants [Bjørneboe et al., 2018]. When undertaking a building energy renovation, households can take advantage of two national schemes: the Energy Saving Obligations for Energy Distributors (**Energiselskabers Energispareindsats**) and the Housing-Job Scheme (**BoligJobordningen**).

The first is a subsidy scheme based on the obligation for Danish energy companies to achieve annual energy savings. As an alternative to the direct implementation of energy-saving projects, companies can buy the right to report the savings achieved by final customers through their building renovations, in exchange for an amount of money [SparEnergi, 2018a].

Depending on the energy saved and the energy company involved, the amount of the subsidy is determined on a case-by-case basis and established in an agreement between the company and the customer before the works start. It is up to the customer to find out the company that offers the best deal. In general, the subsidy covers only a very small part of the renovation costs, usually about 0.30 DKK per kWh of energy saved.

The second is a permanent tax deduction scheme that allows the taxpayer to recover some of the expenses associated with craftsmanship services for energy improvements and/or climate adaptation works of existing dwellings [SKAT, 2018]. Eligible measures include both interventions on the building envelope and technical building systems, as well as the installation of renewable energy sources. From 2018, energy advice is no more eligible.

The total maximum deduction is 12,000 DKK a year per person (i.e. about 1,600 €), calculated as a percentage approximately amounting to 27% of the expenses incurred for labour costs, not materials[9]. The claim for deduction is subject to the following conditions: the taxpayer must be resident in the property while the work is being done, regardless of whether a tenant or owner-occupant;

[9] Further 6,000 DKK per person can be deducted for services such as ordinary cleaning, childcare, gardening, etc.

the payment must be done by electronic methods only; and the taxpayer must report all information in an electronic module to SKAT (the Danish tax authority).

These two schemes can be combined to support the same project.

A third (market-based) national scheme is the **BedreBolig** (Better Homes) consulting service by the Danish Energy Agency [SparEnergi, 2018b]. Through a ‘one-stop-shop’ concept, homeowners can get advice from qualified consultants for the energy-efficient renovation of their properties and, after a non-binding screening, request the development of a BedreBolig-Plan [SparEnergi, 2018c], that is a detailed plan of work to be done, including investments and savings.

Depending on the size of the building, a fee typically ranging between 3,000 and 8,000 DKK (i.e. 400 and 1,100 €) must be paid by the customer to the energy advisor (craftsmen, engineers, architects and other professionals) for developing the plan. In order to overcome this potential barrier, some municipalities and energy companies provide grants to cover up to 50% of the service cost.

Initially launched as a pilot involving nine municipalities, the BedreBolig scheme became nationwide in 2014 with DEA being responsible for the training of advisors, the running of marketing campaigns, and the organization of meetings and workshops with stakeholders. Despite being a well-designed policy initiative, evaluations carried out in 2016 show that, compared to number of advisors trained - over 400 -, the number of developed and reported plans - about 700 - is relatively low [ECSO, 2018].

CASE #1
Magisterparken | C.F. Møller Architects

Comprehensive renovation of a high-rise apartment block with cantilevered extension to the front elevation of the building.

LOCATION: Magisterparken 77-413, Aalborg - 57°01'38.5"N, 9°56'29.7"E

DATE: 1964, construction; Jan 2012 - Nov 2015, renovation

CLIENT: Himmerland Boligforening

DESIGN TEAM: C.F. Møller Architects (mandatory architecht and landscape architecht), MOE & Brødsgaard A/S (engineering), Fjelsøe Entreprise (general contractor)

BUDGET: 29.6 Mio EUR excl. VAT (whole housing estate)

AWARDS: 2016, RenoverPrisen (nomination); 2016, Aalborg Kommunes Arkitekturpris; 2017, Premio Europeo di Architettura Matilde Baffa e Ugo Rivolta (special mention)

PLOT SIZE: 5,730 m^2

BUILDING SIZE: 1) Total floor area: 12,565 m^2 > 12,770 m^2; 2) Heated floor area: 8,830 m^2 > 8,700 m^2

Magisterparken is a social housing estate located about one kilometre south of Aalborg city centre. Built at the beginning of the Sixties, it originally comprised of 319 housing units, which are divided into one 13-storey high-rise and nine 3-storey low-rise blocks, arranged around a shared green space and along a tree-lined street, providing access to garages and parking lots.

It was year 2009 when C.F. Møller Architects were commissioned to develop a comprehensive renovation project for the estate. While the low-rise buildings benefitted from refurbished bathrooms, repaired roofs and façades, and redesigned gardens, it was the high-rise building that received the most eye-catching makeover.

To protect the structure against wind and rain, both the (common) covered walkways and staircases to the north, and the (private) enclosed loggias to the south are provided with a new transparent skin. Original concrete parapets/walls were removed, and replaced by aluminium framed glass panels in different sizes and shapes. A series of bay windows and colourful aluminium frames protrude from the building, adding variation to the otherwise flat façades. Hopper and sliding windows ensure air circulation.

The east and west elevations, instead, are insulated with a 19.5 cm thick layer of mineral wool (U-value 0.18 W/m^2K) and cladded with dark grey metal plates. New double-glazed windows are placed on the previous blind walls. No additional insulation is applied to the roof. Major upgrades were carried out to mechanical ventilation, heating and plumbing systems.

Besides a thermally and architecturally improved building envelope, the project features modified apartment layouts. In order to meet today's housing needs, several units are merged into larger ones, either horizontally or vertically, by connecting rooms and/or adding internal stairs.

As a result of these changes, the total number of apartments was reduced from 169 to 120, but their types do not (Figure 11). On the contrary, new apartment typologies were established, now ranging from one- to four-bedroom (i.e. from 58 to 130 m^2, winter gardens included) and including some fully accessible units. To enable the renovation, tenants were temporarily to other apartments on site.

On the top two floors, penthouse apartments were created by extending the existing balconies beyond the building's profile and transforming them into wide winter gardens. About twenty steel beams placed on the roof, but anchored down to the walls of the 12^{th} floor, hold up a 1.5 m deep lightweight structure made of steel and aluminium. Behind the outer skin, floor-to-ceiling glass walls and swing doors replace the original façade allowing panoramic views to the south.

On the ground floor, all apartments were provided with terraces and small gardens that directly overlook the landscaped surroundings, for an additional 30 m^2 of semi-private open space. Two broad passages were carved through the building to allow for a connection between the street-side arrival area and the park-side wooden deck. Here, seating steps offer an informal meeting and gathering place for tenants and visitors.

In front of the staircase, the 2-ha lawn was landscaped with gentle mounds, groves and paths. Meadows and water meadows, instead, mark the southern border of the site. Park amenities include improved sports and recreational facilities (e.g. roller skating rink, skate ramps, multi-use games area, fitness circuit), upgraded children playgrounds and outdoor furniture (e.g. table and benches, picnic areas, bicycle racks, greenhouse). A shared kitchen and some guest rooms were made available in the neighbourhood house.

Thanks to a careful choice of renovation strategies, with preference for economical solutions for the interiors and more sophisticated ones for the façades, the overall cost of the project could be kept below the usual construction cost for Denmark.

Residents were involved throughout all the project stages: the actual design proposal was adopted at a public meeting, and a tenants' committee was set up and given the opportunity to influence layouts and materials, or ask for extra options. Furthermore, the support from Landsbyggefonden allowed for a minor increase in rents contributing to the success of the project. Today, the waiting time for a renovated apartment in Magisterparken is approximately 1-2 years.

before renovation

no.	type	fl. area
91	1-room apt.	52,4 m²
52	2-room apt.	76,6 m²
26	3-room apt.	85,4 m²
169		**10,970 m²**

after renovation

no.	type	fl. area	
5	1-room apt.	58,0 m²	
44	2-room apt.	83,0 m²	
22	3-room apt.	91,4 m²	
20	3-room apt.	99,7 m²	*hor. combined*
15	3-room apt.	99,7 m²	*ver. combined*
4	2-room apt.	76,5 m²	*11-12 floor*
4	4-room apt.	117,9 m²	*11-12 floor*
2	4-room apt.	127,6 m²	*11-12 floor*
4	4-room apt.	129,1 m²	*11-12 floor*
120		**10,990 m²**	

Figure 11: Magisterparken. Apartment types before and after retrofit
Source: Himmerland Boligforening

Climate: 3933 heating degree days / 16 cooling degree days

Building energy regulation: BR10
Calculation method: Be10

Table 7: Magisterparken. Building envelope U-values

	U-value before retrofit (W/m^2K)	**U-value after retrofit (W/m^2K)**
Roof		
External walls	1.04	0.18
Floor over basement		
Windows		

Air exchange rate: unknown // **Air tightness n_{50}**: unknown

Table 8: Magisterparken. Building energy demand

	Before retrofit ($kWh/m^2.y$)	**After retrofit ($kWh/m^2.y$)**
Space heating		
…		
Total PE demand	**unknown**	**unknown**
RES production	-	-
PE demand - RES	-	-

Table 9: Magisterparken. Building retrofit costs

	Mio €	**€/m^2**
Building costs		
Landscaping		
Total	**29.57**	**1,135**

Funding sources: Loan from Landsbyggefonden, a self-governing institution that assists public housing associations with soft loan and grant opportunities.

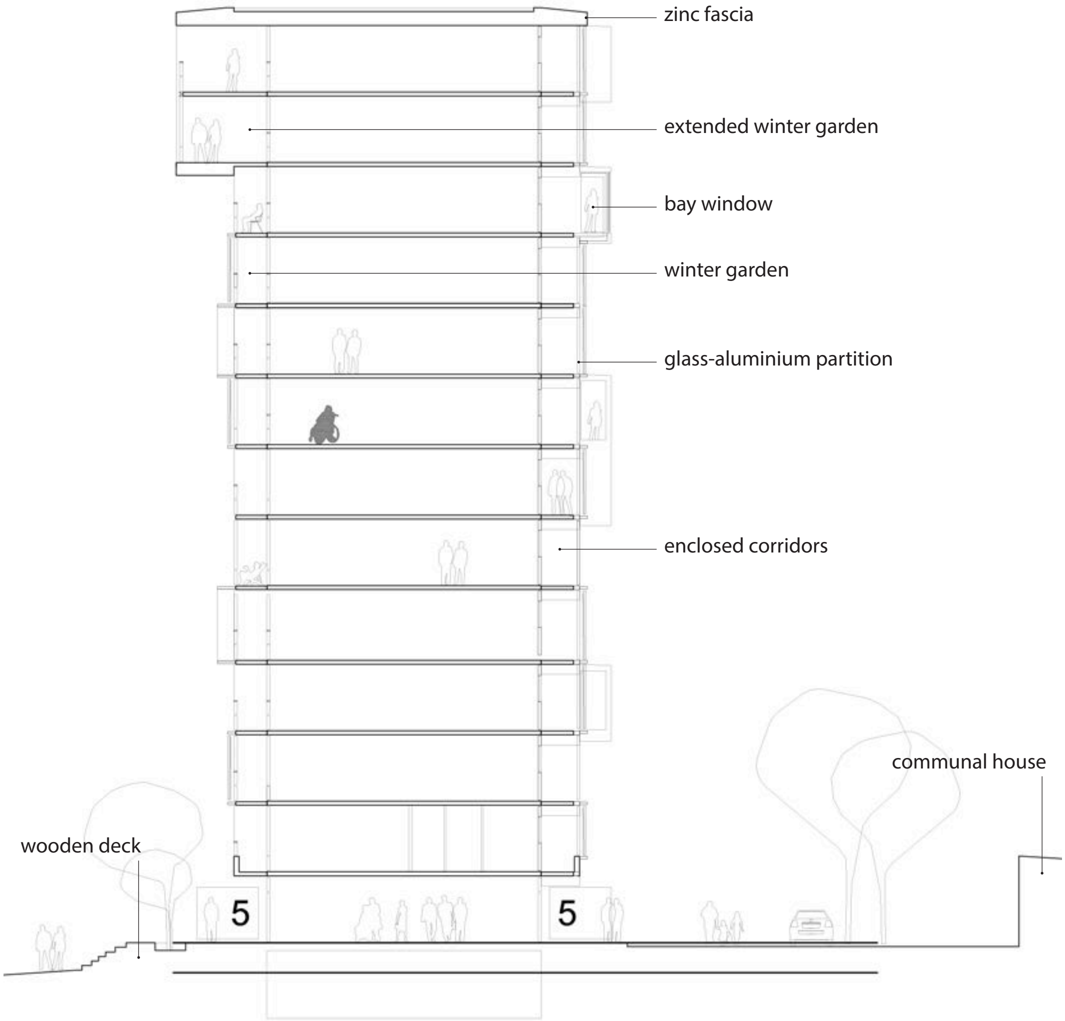


Figure 12: Magisterparken. Section (1:300)
© C.F. Møller

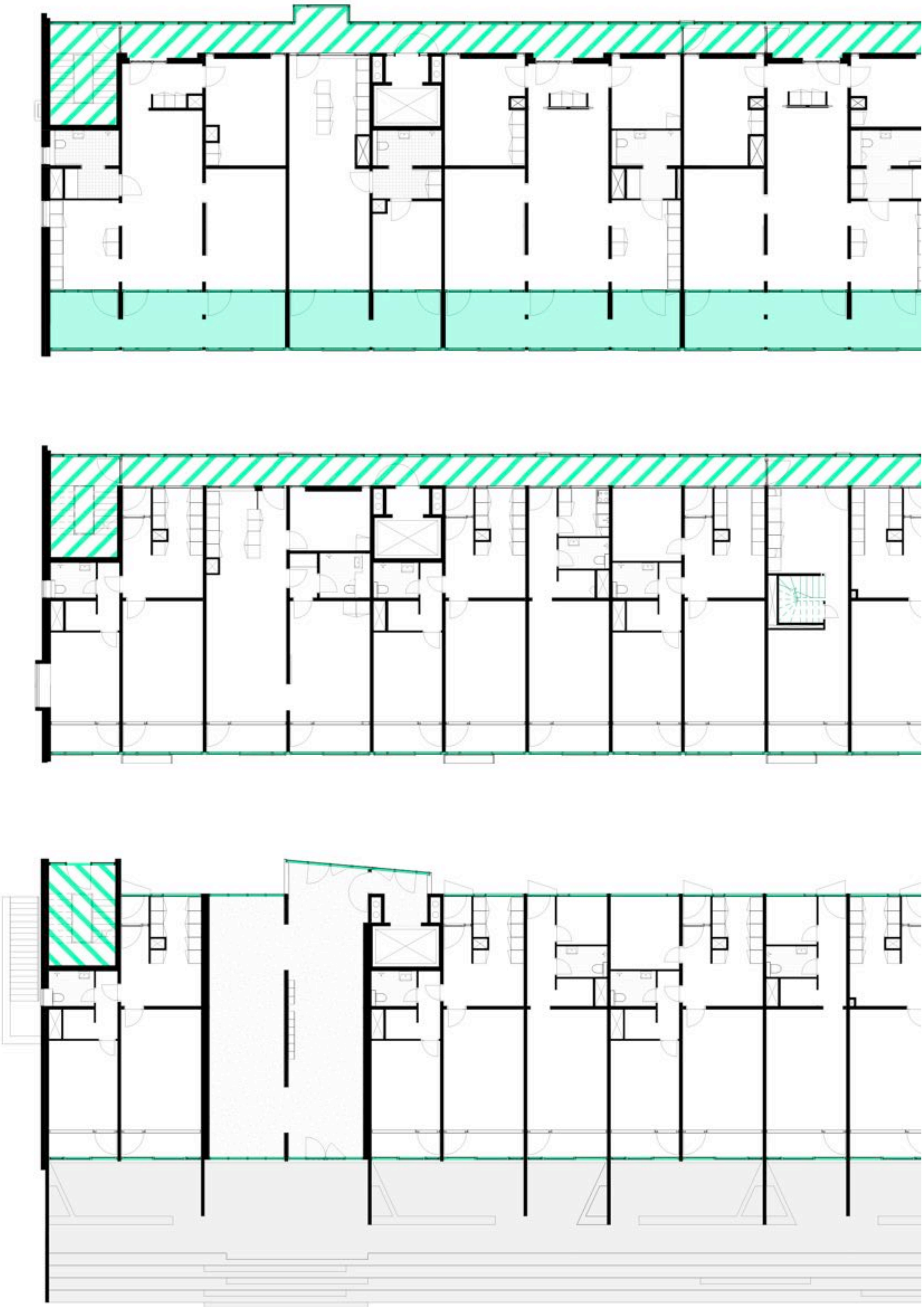
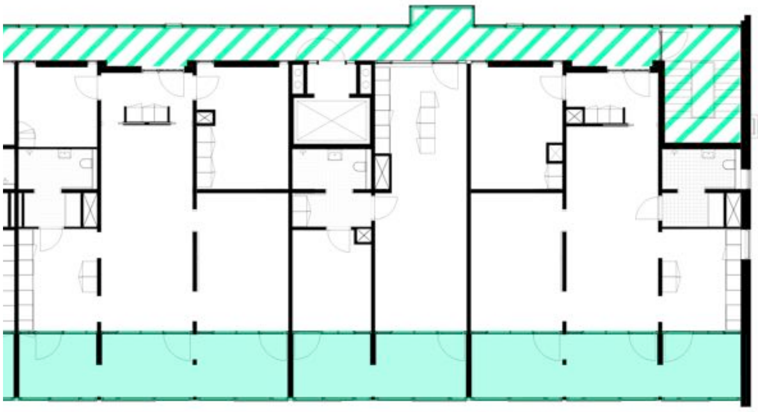


Figure 13: Magisterparken. Floor plans (1:300)
© C.F. Møller



Floor 12-13

Floor 2-11

Ground floor

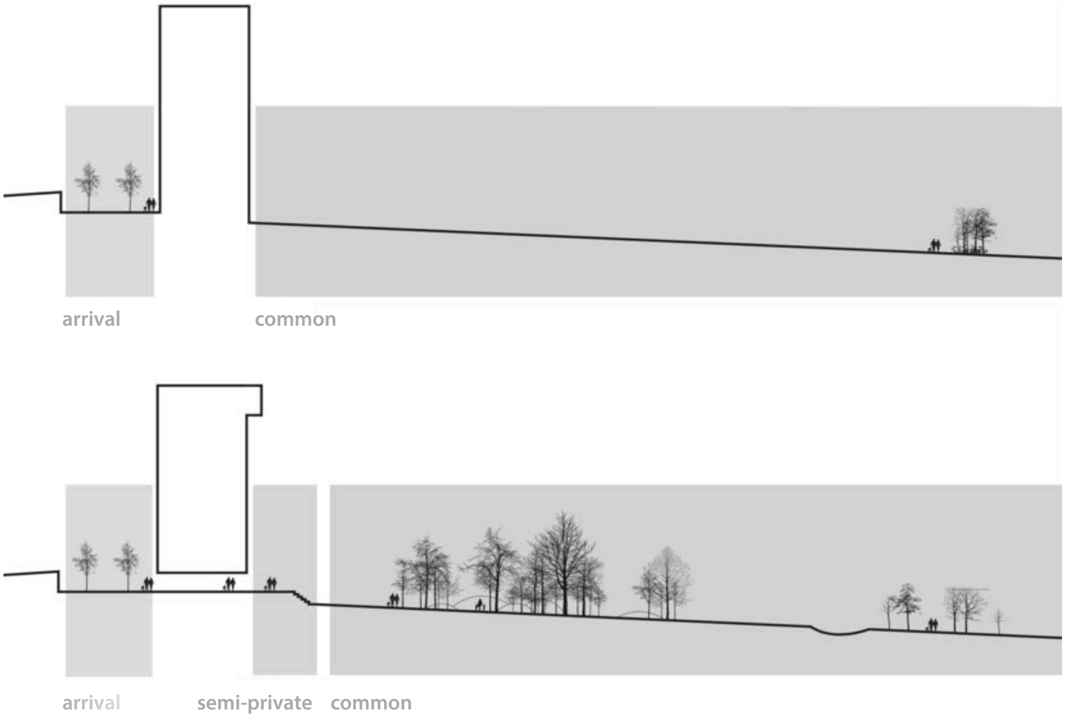


Figure 14: Magisterparken. Concept diagrams
© C.F. Møller

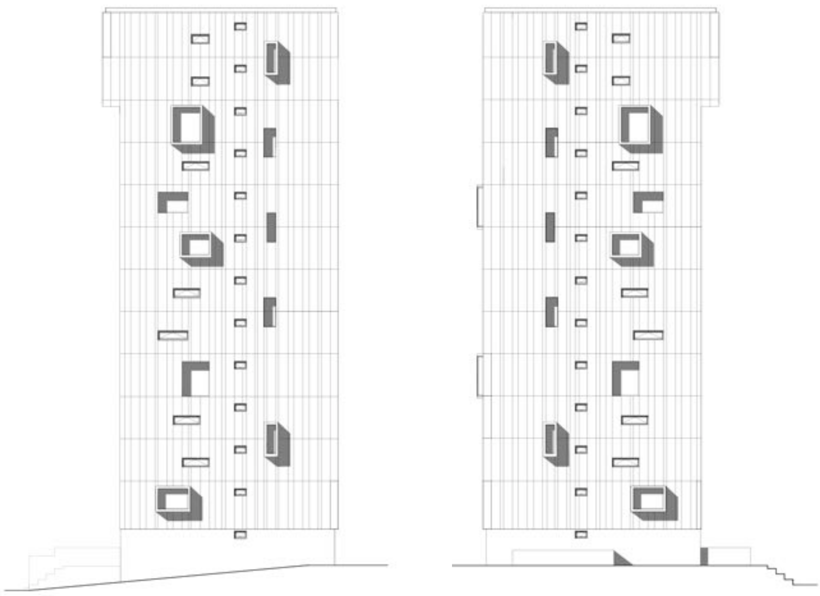


Figure 15: Magisterparken. East and west elevations (1:500)
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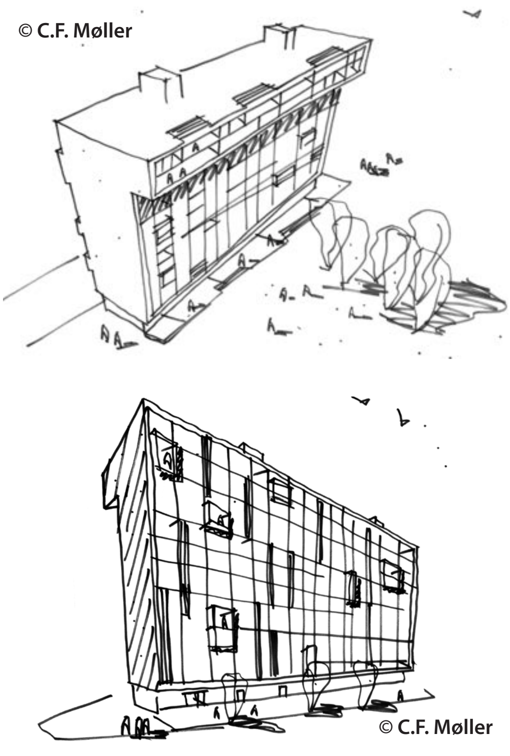
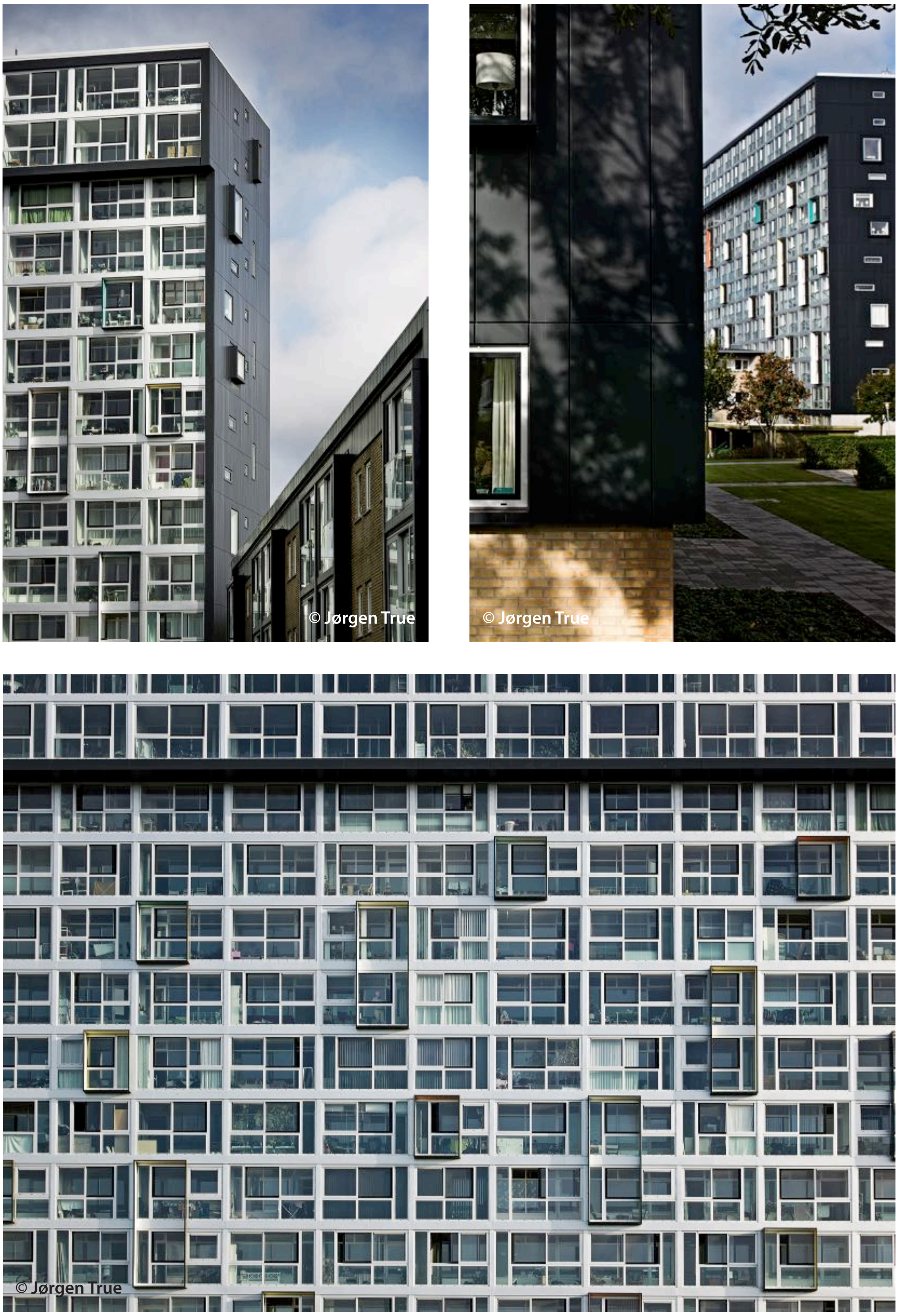
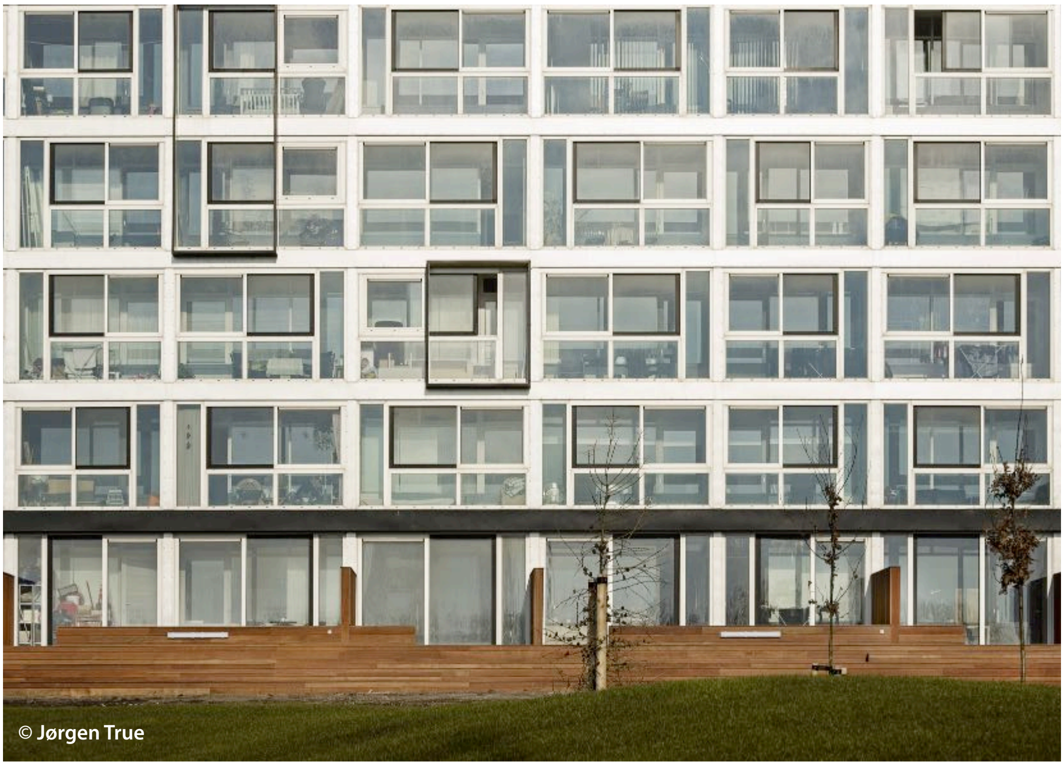
Figure 16: Magisterparken. Construction section through north elevation (1:50)
© C.F. Møller



Top and bottom right: Building before retrofit
Bottom left: Project sketches



Top left and top right: Side view of the building after retrofit
Bottom: Front view of the south façade after retrofit



Top: Interior of the extended winter gardens and refurbished penthouse apartments
Bottom: Ground floor apartments and wooden deck

CASE #2
Tove Ditlevsensvej | KAAI

Renovation of two high-rise buildings with apartment extensions and addition of enclosed access walkways, stairwells and elevators.

LOCATION: Tove Ditlevsens Vej 36-234 & 236-434, Aalborg - 57°02'28.1"N, 9°58'13.8"E

DATE: 1973-74, construction; 1989, earlier renovation; Jul 2012 - Jul 2014, renovation

CLIENT: Plus Bolig

DESIGN TEAM: KAAI - Kærsgaard & Andersen Arkitekter og Ingeniører A/S (mandatory architect and engineering), ENG Arkitekter, in collaboration with BSAA URBANlab (landscape architects)

BUDGET: 29.6 Mio EUR excl. VAT

AWARDS: -

PLOT SIZE: 51,724 m^2

BUILDING SIZE: 1) Total floor area: 21,510 m^2 > 23,230 m^2; 2) Heated floor area: 18,360 m^2 > 23,230 m^2

ENERGY CONSUMPTION: 27,804 m^3.y (hot water)

CO_2 EMISSIONS: 159.17 ton/y

EPC class: C

Tove Ditlevsensvej is a social housing estate located on the eastern outskirt of Aalborg, in the Vejgaard district. Completed in 1974, it consists of two 8-storey high apartment blocks, surrounded by more than 5 ha of green and recreation areas.

Each block is 98 m long and contains 100 housing units, ranging from one-bedroom units of 50 m^2 to four-bedroom units of 108 m^2, for a total floor area of 9,180 m^2. All apartments, except the one-bedroom type, are duplex, with either a loggia or a small private garden. Access to the upper floors is gained through two stairs and lift towers, one at each end of the building, plus covered corridors running along the entire length of the façade.

In order to address the issue of thermal bridges, on the northern side, the exterior single loaded corridors were almost doubled in width (from 1.6 to 3.4 m wide) and transformed into enclosed, glazed walkways from where residents can enjoy views of the city.

Inside these corridors, painted white, ceilings and pillars contrast with the dark grey panelled walls (wood with asbestos infill). A new concrete paving was laid and parapets were replaced by perforated metal railings. Outside, white plastered bay windows protrude beyond the enamelled glass panels, revealing the apartment extensions.

Bedrooms on odd floors were extended above the walkway by cantilevered extensions of 4 up to 12 m^2.

Two additional stairs and lift towers were also added. Partly glazed and partly finished with dark bricks, these towers balance the long façade, breaking its monotony.

By the new entrances are the housing units which have been adapted into elderly and disabled apartments: here the existing duplex apartments were totally redesigned and transformed into one-level apartments to make them wheelchair accessible.

As a result, a total of 28 housing units per block were made barrier-free, while all the others were remodelled to varying degrees (i.e. refurbished bathrooms and kitchens, furnishing, flooring), with tenants being temporarily relocated during the works. The overall number of units increased from 200 to 208, and their types from 4 to 8 (Figure 17).

Due to the increase in the heated floor area (i.e. from 18,360 m^2 to 23,298 m^2, with the access walkway heated to above zero throughout the whole year), the building's energy consumption remains almost unchanged, around 27,804 m^3.y district heating water[10]. This corresponds to a reduction of about 30% per square meter of floor area, compared to the initial situation.

Flat roofs were insulated and all windows and glass doors replaced by double-glazed ones; a new central ventilation system with heat recovery was installed.

In the future, further savings may be achieved by implementing measures on the south façade, which is currently untouched due to lack of funding. Indeed, the loan from Landsbyggefonden (€ 28.1 Mio), could not cover the whole cost of the operation, and Plus Bolig had to defer some of the works to a later stage.

Apart from the retrofitted buildings, the project also features improved outdoor areas. A paved square was created between the blocks, with terraces and embankment steps bridging the existing difference in height. Immediate surroundings were landscaped and provided with trails, sport facilities and playgrounds. Additional street furniture (e.g. bicycle shelters, street lights, waste collection areas) was installed and the neighbourhood community house refurbished.

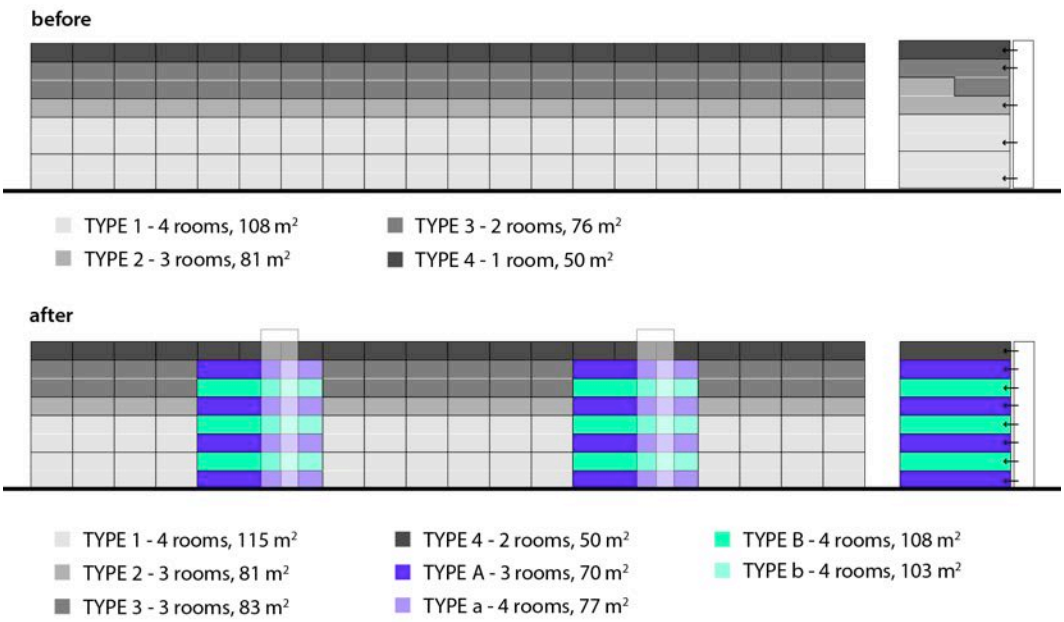


Figure 17: Tove Ditlevsensvej. Apartment types before and after retrofit

[10] KAAI could not provide the building energy consumption in $kWh/m^2.y$. Heating in the city of Aalborg is measured in $m^3.y$ of hot water.

Climate: 3933 heating degree days / 16 cooling degree days

Building energy regulation: BR10
Calculation method: Be10

Table 10: Tove Ditlevsensvej. Building envelope U-values

	U-value before retrofit (W/m^2K)	U-value after retrofit (W/m^2K)
Roof		0.1
External walls	0.35	0.14
Floor over basement		
Windows	2.7	1.4

Air exchange rate: unknown / **Air tightness n_{50}**: unknown

Table 11: Tove Ditlevsensvej. Building energy demand

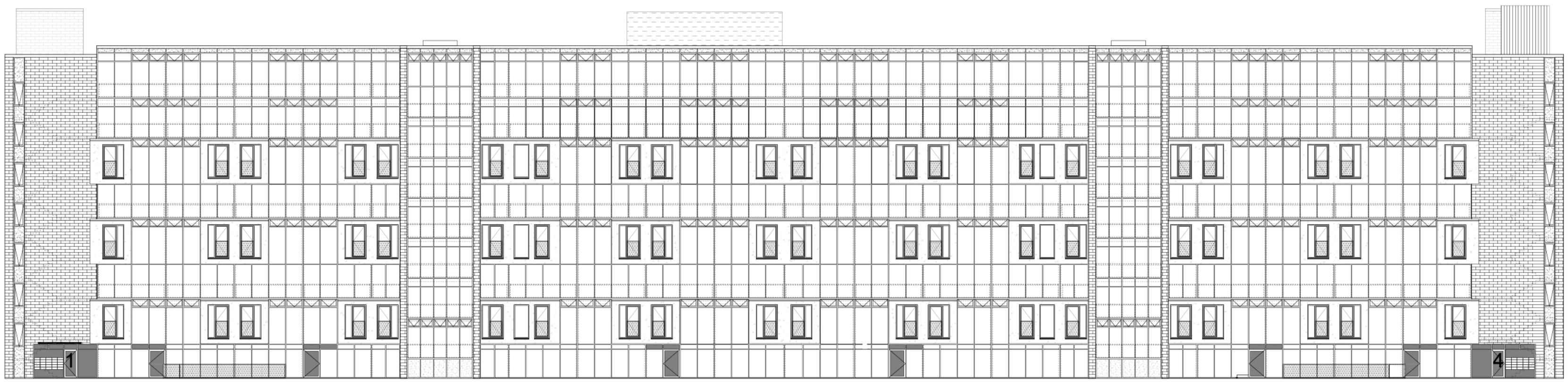
	Before retrofit ($kWh/m^2.y$)	After retrofit ($kWh/m^2.y$)
Space heating		27,804 m^3.y (hot water)
…		
Total PE demand	**unknown**	**unknown**
RES production	-	-
PE demand - RES	-	-

Table 12: Tove Ditlevsensvej. Building retrofit costs

	Mio €	€/m^2
Building costs		
Landscaping		
Total	**29.6**	**1,274**

Funding sources: €28.1 Mio loan from Landsbyggefonden.

north elevation



east elevation

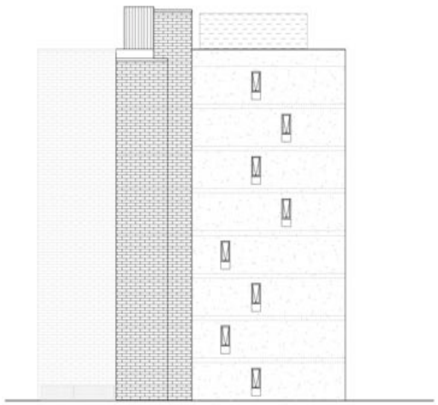
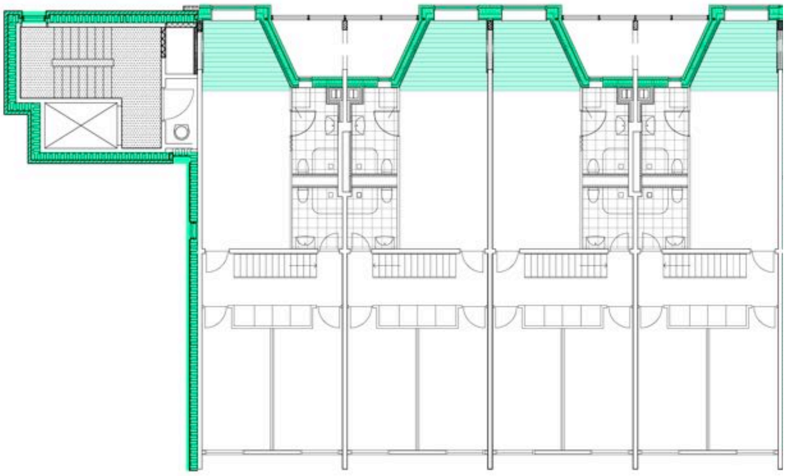
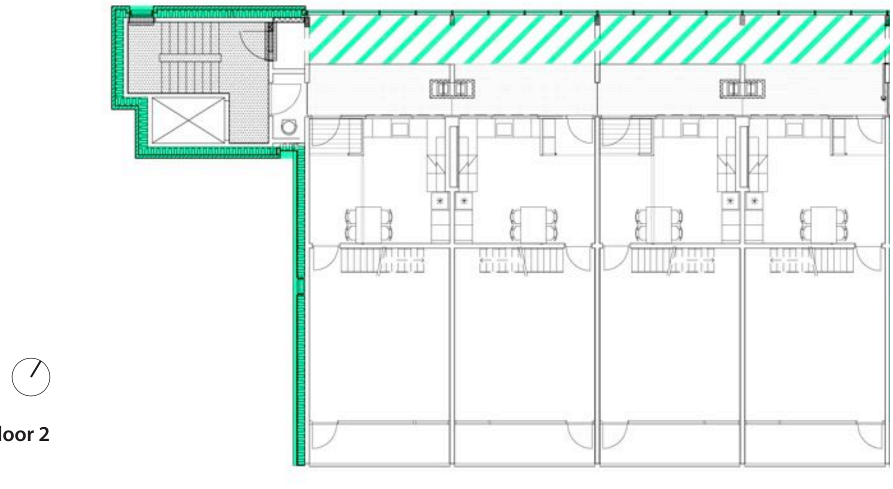


Figure 18: Tove Ditlevsensvej. North and east elevations (1:500)
© KAAI

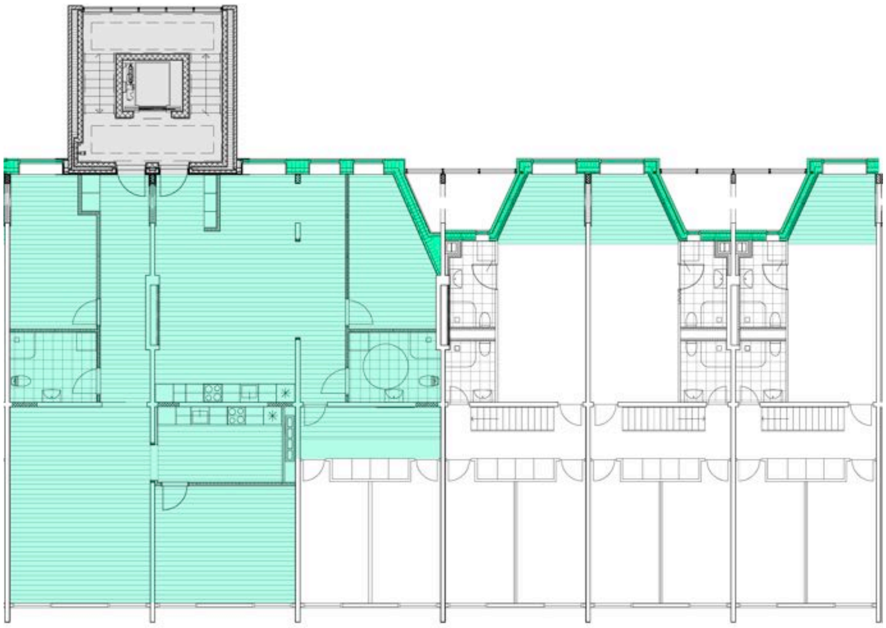


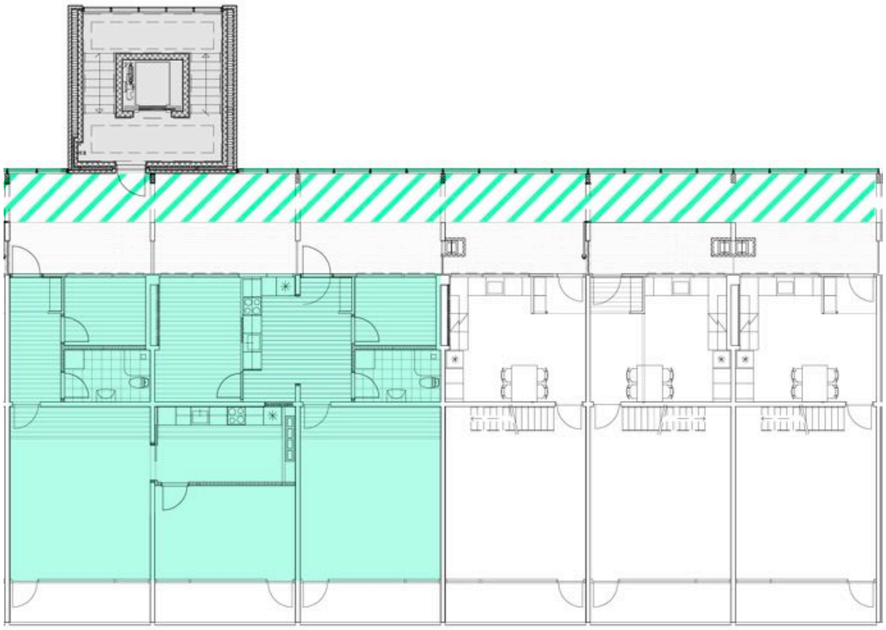
Floor 3



Floor 2

Figure 19: Tove Ditlevsensvej. Floor plans (1:250)





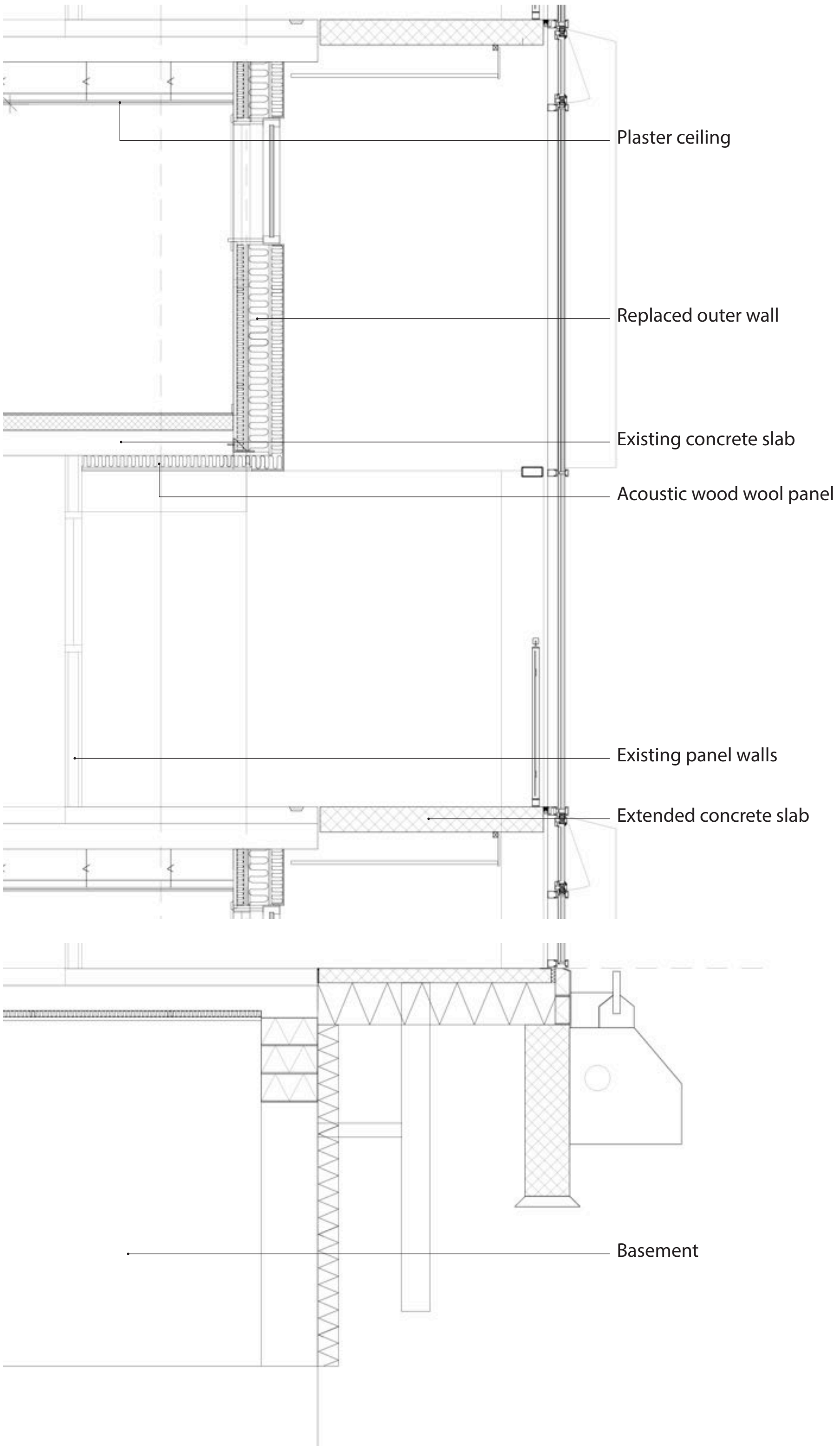


Figure 20: Tove Ditlevsensvej. Construction section through north elevation (1:50)
© KAAI

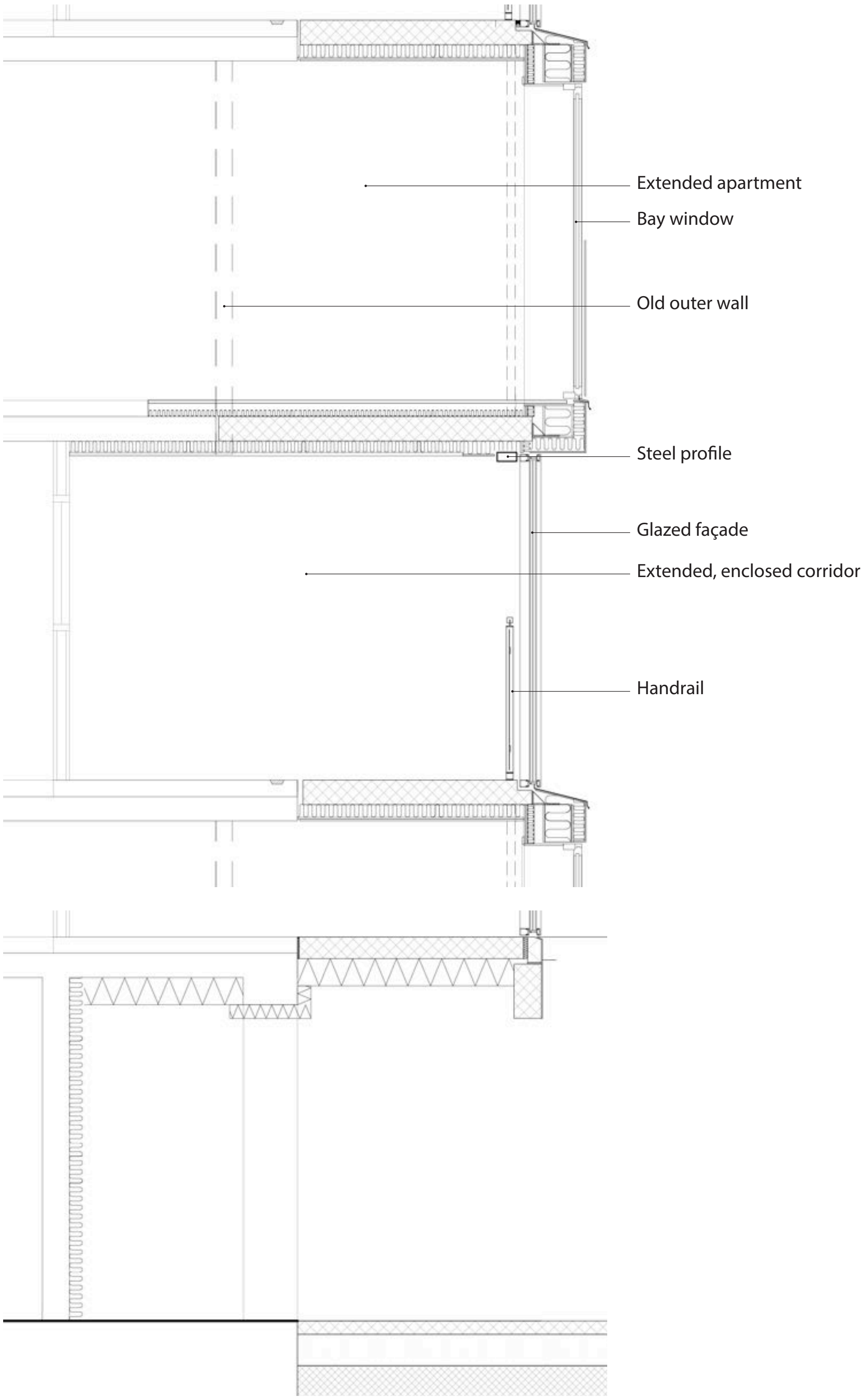


Figure 21: Tove Ditlevsensvej. Construction section through north elevation (1:50)
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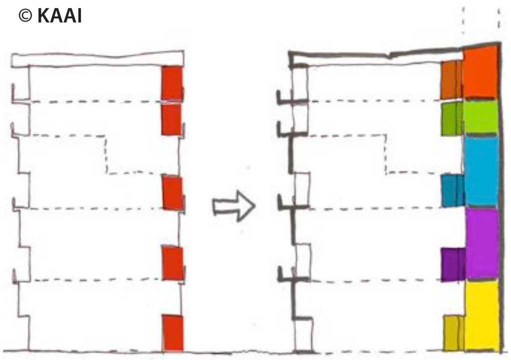

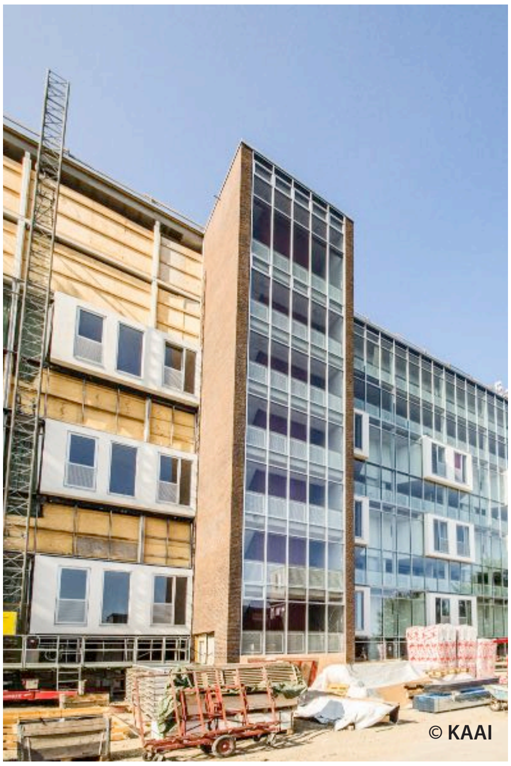

Top and bottom right: Building during retrofit
Bottom left: Project sketch

Building after retrofit
Exterior of the north façade with added stair and elevator towers

Interior of extended and enclosed access walkways

CASE #3
Sems Have | Kullegaard A/S

Deep energy renovation and transformation of a dormitory and day-care centre/multi-purpose hall into 30 nZEB apartments.

LOCATION: Parkvej 1-5, Roskilde - 55°38'13.9"N, 12°04'07.2"E

DATE: 1970-1972, construction; 1995, earlier renovation; Oct 2012 - Dec 2013, renovation

CLIENT: Boligselskabet Sjælland

DESIGN TEAM: Kullegaard Arkitekter A/S (mandatory architect), Terkel Pedersen Rådgivende Ingeniører ApS (engineering), Daurehøj Erhvervsbyg A/S (general contractor)

BUDGET: 9.7 Mio EUR excl. VAT

AWARDS: 2014, RenoverPrisen (nomination)

PLOT SIZE: 2,790 m^2

BUILDING SIZE: 1) <u>Total</u> floor area: 3,056 m^2 > 3,810 m^2; 2) <u>Heated</u> floor area: 3, 056 m^2 > 3,398 m^2

ENERGY CONSUMPTION: 86 - 136 > 16.17 kWh/m^2.y (primary energy)

EPC class: C > A2020

Sems Have is a social housing complex situated in Roskilde, just west of the city centre. Dating back to the early Seventies, it comprises of two buildings and some surrounding areas.

Block A, the structure to the east, is a 4-storey residential building with gabled roof, containing a day-care centre on the ground floor and a dormitory on the upper floors. Block B, the structure to the west, is a 2-storey service building with mansard roof, containing a day-care centre on the ground floor and a multi-purpose hall on the upper floor. Between the two main buildings there is a paved area, and a covered passageway. In the basements are further premises[11] (e.g. meeting rooms, fitness room), accessible from the street by a staircase and an entrenched walkway.

Property of the Boligselskabet Sjælland housing association, the site had been partially renovated in 1995 (double-glazed windows and extra insulation), but could not be rented out any more. In 2011, when the municipality terminated the lease, its conversion into two social housing apartment buildings was seen as the most viable solution.

As a first step in the project, both buildings were stripped down to their skeletons. A part from the load-bearing concrete structure, only the roof of Block A was preserved: the mansard roof of Block B was replaced by vertical walls and a new gabled roof (400 mm mineral wool insulation), while all front and partition walls were replaced by lightweight prefabricated components, with up to 480 mm mineral wool insulation. Basement floors were insulated from the underside with 100 mm expanded clay clinkers. Mezzanines were built to take advantage of the double-height ceilings on the first floor of Block B.

About one year later, 30 apartments of different sizes and layouts were delivered. Ranging from 67 to 145 m^2, they are divided as follows: 16 four-room apartments in Block A (1,980 m^2 gross floor area), and 2 two-room apartments, 7 three-room apartments, and 5 five-room apartments in Block B (1,418 m^2 gross floor area).

Access to the apartments is via external stairs (Block A) and a raised walkway (Block B); Block A is also equipped with elevators. Internal stairs lead to the Block B's mezzanine floors.

Thanks to the wise choice of materials, the complex was given a new contemporary appearance. Outside, slate tiles were preferred to the previous plastered façades, and openings were framed with white aluminium profiles to powerfully contrast with the dark polished cladding. Balconies, French balconies,

[11] Not covered by the original project, and thus not included in the construction costs and energy calculations.

sheltered staircases, and railings are in galvanized steel, with wooden boards used for step treads and flooring. Inside, all walls are covered with plasterboard, interrupted by triple-glazed windows of different dimensions.

Solar PV panels (117 m^2, 17.3 kWp capacity) were placed on the east-facing pitch of the roofs, a balanced mechanical ventilation system with a heat recovery rate of 84% was installed in the apartments, and the building (district) heating system was upgraded.

With an extra cost of about 31,000 Euro, a primary energy consumption of 16.17 kWh/m^2.y was thus reached and compliance with Bygningsklasse 2020 requirements guaranteed.

Outdoor spaces were also improved. In the central communal space, a new pavement surface was laid. A shared sunbathing area and a paved terrace, with small leisure corners for the ground floor apartments, were designed to the south of Block B and to the east of Block A respectively. Additional car parking spaces were made available along the access road.

Climate: 2906 heating degree days / 0 cooling degree days

Building energy regulation: BR10
Calculation method: Be10

Table 13: Sems Have. Building envelope U-values

	U-value before retrofit (W/m^2K)	U-value after retrofit (W/m^2K)
Roof	0.2 - 0.32	0.09
External walls	0.2/0.3	0.2/0.3
Floor over basement	2.3	1.1
Windows	2.8	1.0

Air exchange rate: unknown / **Air tightness n_{50}**: unknown

Table 14: Sems Have. Building energy demand

	Before retrofit ($kWh/m^2.y$)	After retrofit ($kWh/m^2.y$)
Space heating/DHW		11.1
Electricity		11.0
Overheating surcharge		1.0
Total PE demand	**86 - 136**	**23.1**
RES production	-	**6.93**
PE demand - RES	-	**16.17**

Table 15: Sems Have. Building retrofit costs

	Mio €	€/m²
Craftsmen	5.91	1,630
Consultants	0.69	190
Various building costs	3.05	840
Bygningsklasse 2020	0.03	10
Total	**9.68**	**2,670**

Funding sources: Financed as new social housing, i.e. not subsidized.

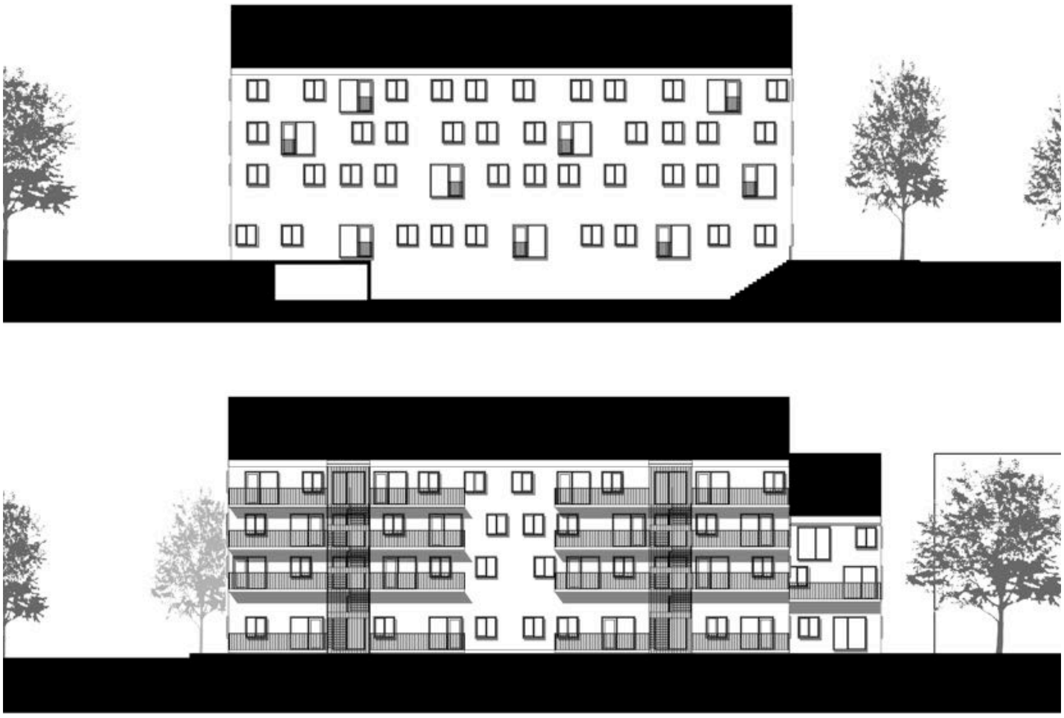

Figure 22: Sems Have, Block A. East and west elevations (1:500)
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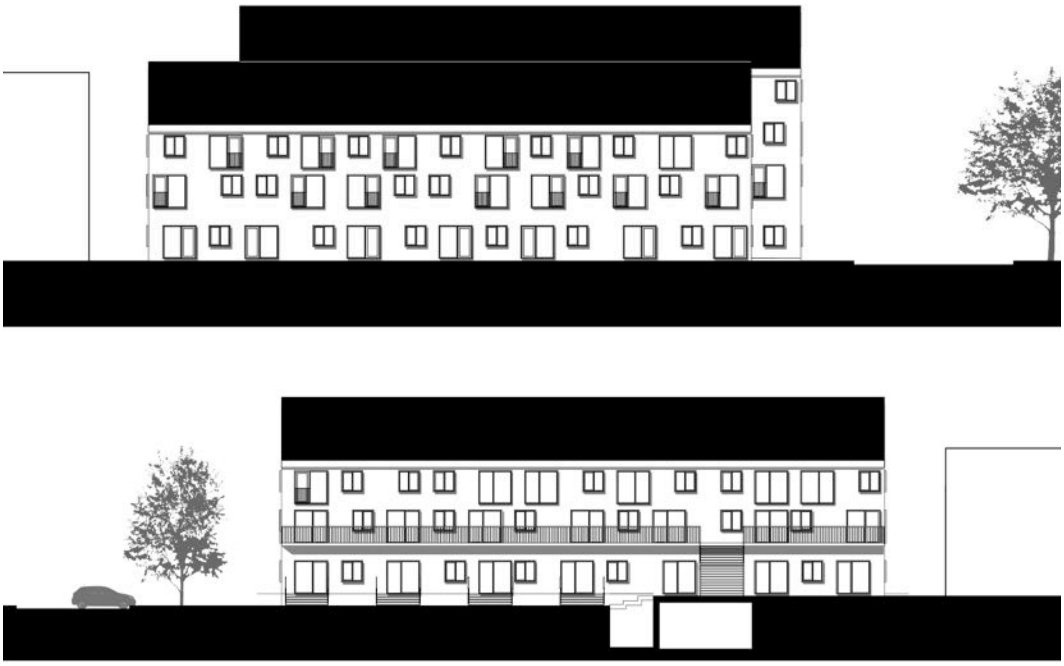

Figure 23: Sems Have, Block B. East and west elevations (1:500)
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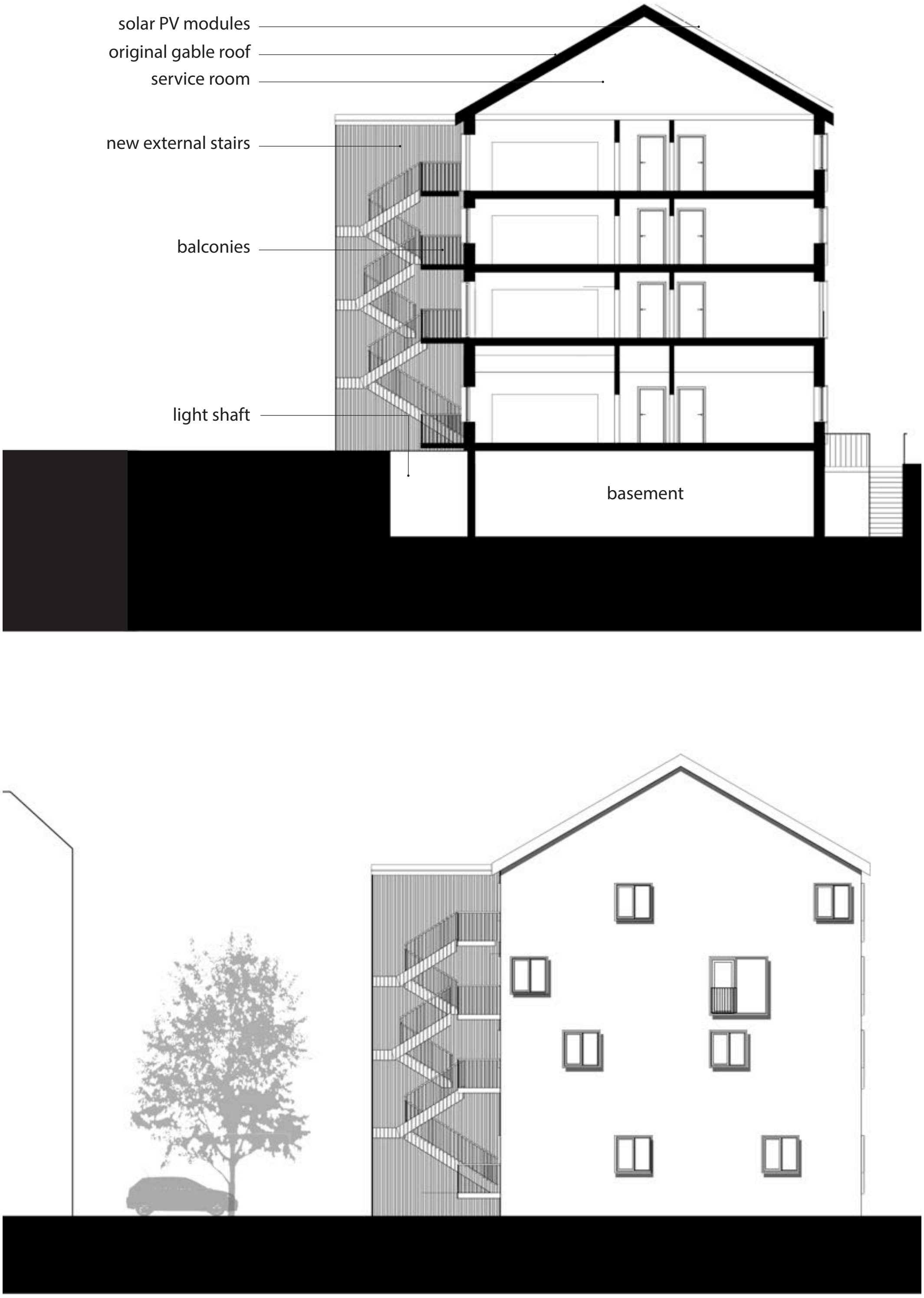

Figure 24: Sems Have, Block A. Section and south elevation (1:250)
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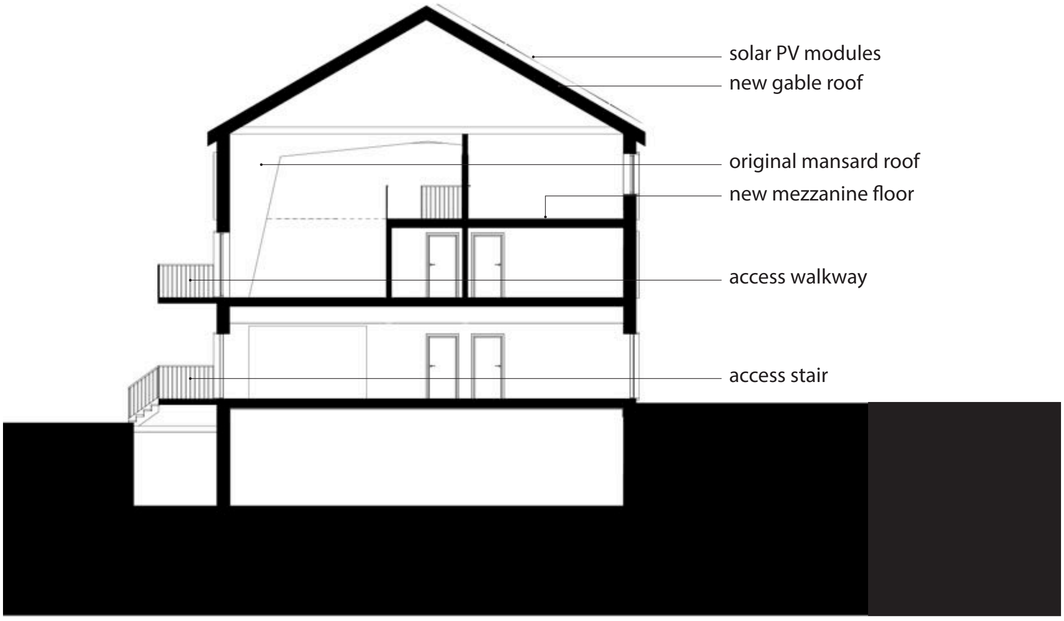

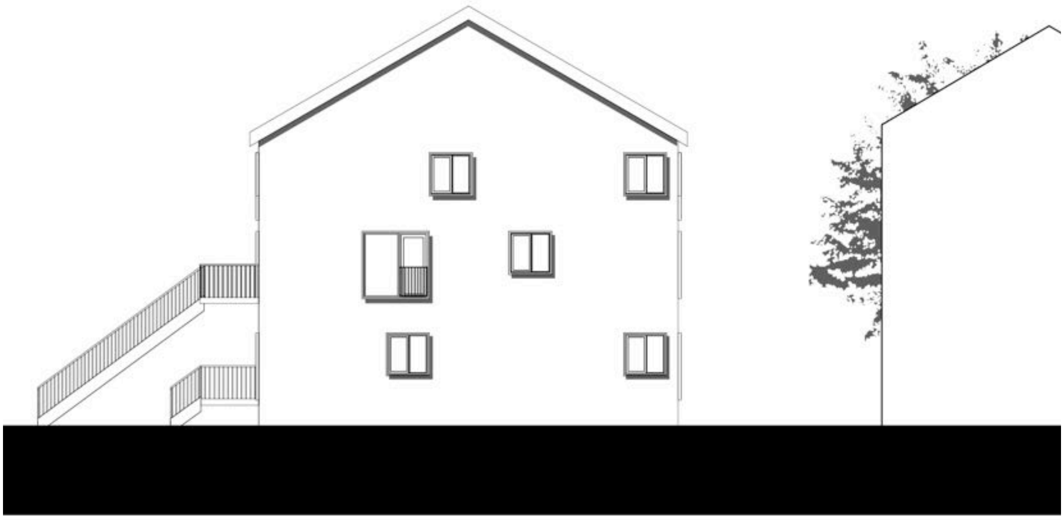

Figure 25: Sems Have, Block B. Section and south elevation (1:250)
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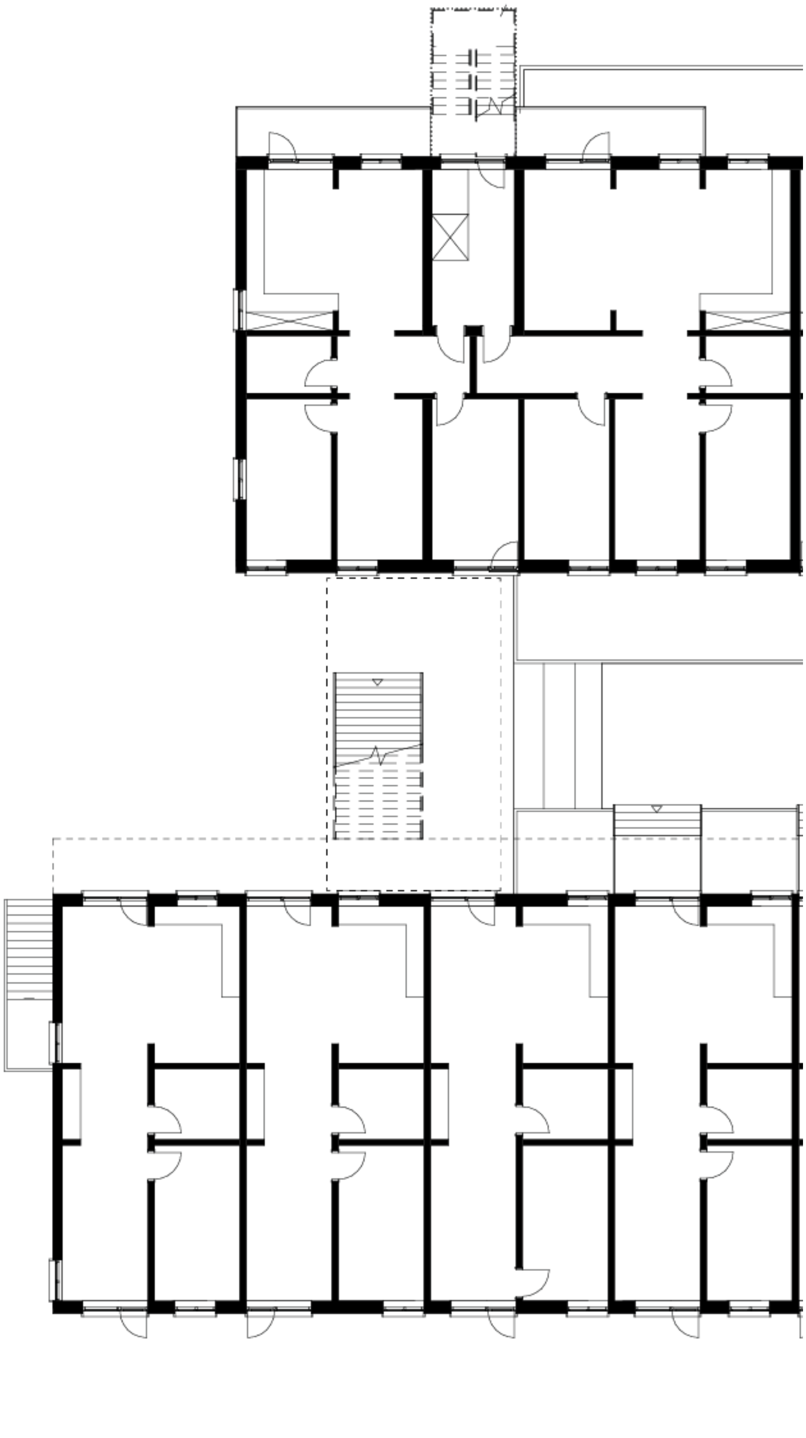
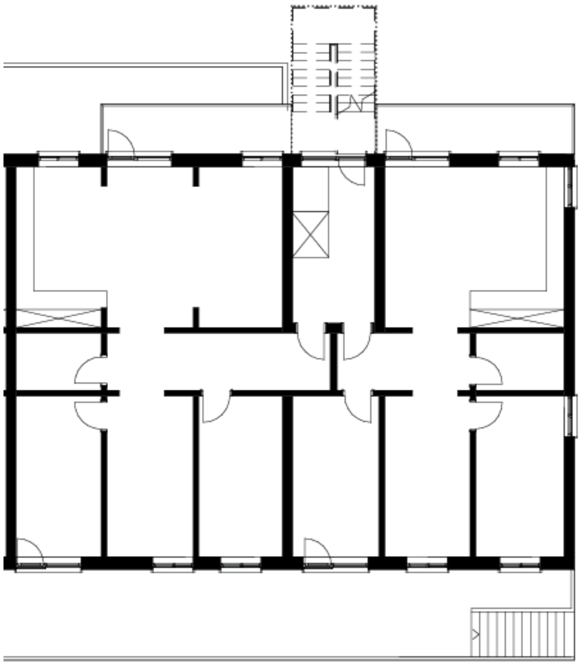
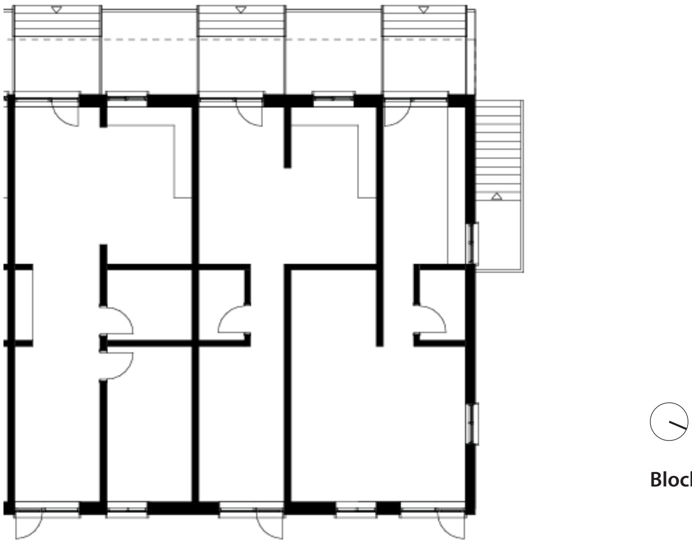


Figure 26: Sems Have. Ground floor plans (1:250)



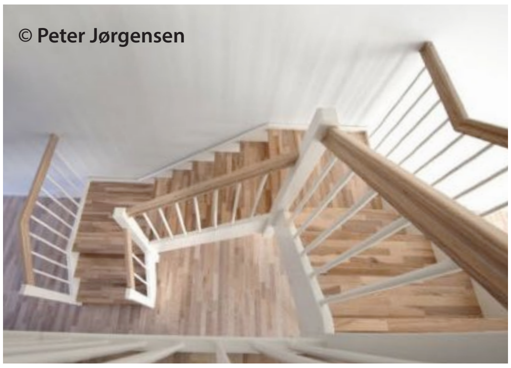
Block A



Block B

Top: Aerial view of Block A and Block B after retrofit
Bottom: Block A rear elevation with added external stairs and balconies

Top and bottom left: West façade of Block B with exterior stairs and walkways
Bottom right: West façade of Block A with exterior stairs



Block B after retrofit
Interior of the upper floor apartments with mezzanine

Chapter 4

France

In France, the implementation of the EPBD is the responsibility of the Ministry of Housing and Territorial Equality (Ministère du Logement et de la Cohésion des Territoires) and the Ministry of Ecology, Sustainable Development and Energy (Ministère de l'Ecologie, du Développement Durable et de l'Energie), which set up a regulatory system based on two distinct sets of regulations for new and existing buildings [Roger et al., 2015; IEA, 2016]. While new buildings are covered by the Thermal Regulation 2012 (RT 2012 - Réglementation Thermique 2012), existing buildings are subject to two different regulations: the so-called Element-by-Element Thermal Regulation (RT Ex par Élément - Réglementation Thermique Existant Élément par Élément) and Global Thermal Regulation (RT Ex Globale - Réglementation Thermique Existant Globale).

Pursuant to Articles L111-10 and R131-25 to R131-8-11 of the French building code (CCH - Code de la Construction et de l'Habitation) as well as their implementing decrees, both thermal regulations apply to existing residential and non-residential buildings in metropolitan France, as part of renovation works requiring the issue of a building permit. Depending on the building size (floor area larger or smaller than 1.000 m^2), the building age (construction year before or after 1948) and the renovation costs (more or less than 25% of the building value), the relevant regulation is determined as illustrated in Figure 27.

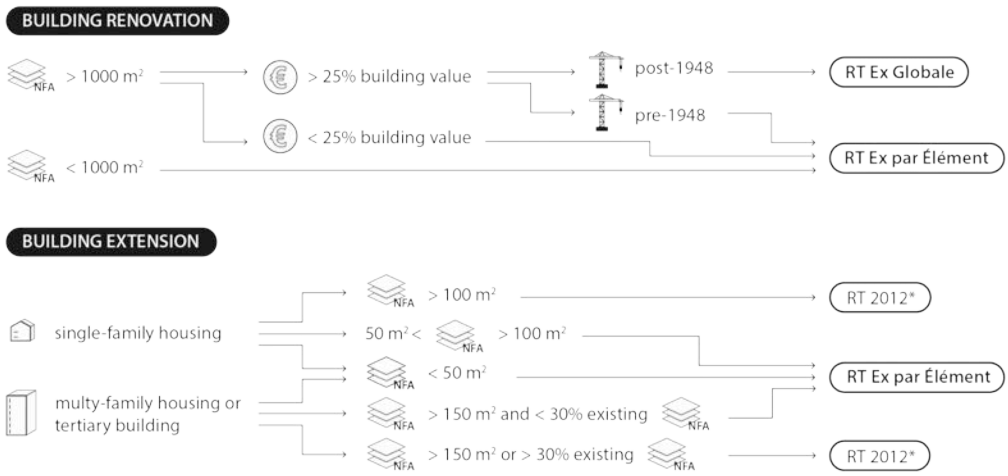


Figure 27: RT Existant. Compliance options

4.1 RT Existant Globale

The RT Ex Globale came into force on 1 April 2008. According to Articles R131-26 of the CCH and its implementing decree [Arrêté du 13 juin 2008], it applies to all renovations that respect the following concurrent conditions:

- the renovated building floor area is greater than 1,000 m^2;
- the building dates back to 1 January 1948 or later;
- the renovation costs - for exterior walls, heating, domestic hot water, cooling, auxiliary appliances for ventilation and heating, lighting and renewables - are higher than 25% of the building value (land value excluded).

Similar to the regulation for new buildings, the RT Ex Globale sets an overall performance target for renovated buildings, with only some minimum performance requirements for building elements (the so-called *garde-fous*). It does so by requiring the calculation and comparison of the energy consumption of the real building with the baseline consumption of the same building for imposed performance of structures and equipment that compose it.

The calculation method - the **TH-C-E Ex method** [Arrêté du 8 août 2008] - has been developed by the Building Scientific and Technical Centre (CSTB - Centre Scientifique et Technique du Bâtiment) and is based on two principal indicators: the Primary Energy Factor (**CEP - Coefficient d'Énergie Primaire**), and the Conventional Indoor Temperature (**TIC - Température Intérieure Conventionnelle**). The CEP is equal to the difference between the building's primary energy consumption for the five regulatory uses (i.e. heating, domestic hot water, cooling, auxiliary appliances for ventilation and heating, lighting) and the building's primary energy production from on-site renewables, expressed in kWh/m^2.y. The TIC is equal to the building's highest hourly operating temperature for the reference warm day, expressed in C°.

The TH-C-E Ex method requires both indicators to be calculated for the 'initial' building (before renovation) and the 'final' building (after renovation) by referring to the real building features, and for the 'reference' building by referring to conventional building features.

The principle of this regulation is that, to be considered satisfactory, any renovation works should lead to a renovated building that performs better than the not renovated one (Figure 28). This means that CEP_{FINAL} should be less than or equal to CEP_{REF}, and that:

- for residential buildings, the CEP_{FINAL} value for heating, domestic hot water and cooling of the renovated building should be less than a threshold value CEP_{MAX}, which depends on the type of heating fuel and on the climate zone (i.e. a value between 80-165 kWh/m^2.y, compared to an average of 240 kWh/m^2.y for the existing stock);
- for non-residential buildings, CEP_{FINAL} should be at least 30% lower than $CEP_{INITIAL}$.

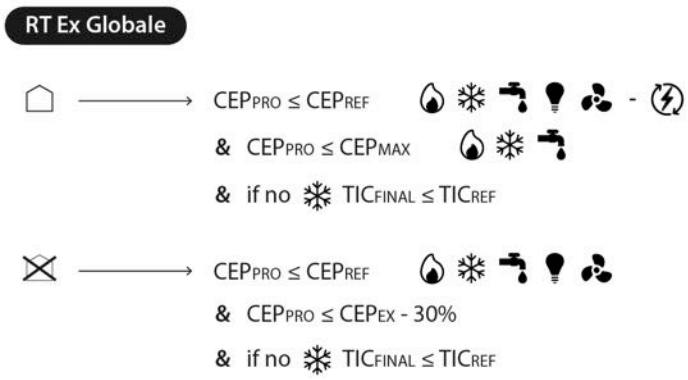


Figure 28: RT Existant Globale

Moreover, for buildings or parts thereof that are classified as CE1 (non-air-conditioned spaces), the maximum conventional indoor temperature reached in summer TIC_{FINAL} should be less than or equal to TIC_{REF}, calculated by employing reference solar shading devices. This requirement does not apply to CE2 (air-conditioned spaces, located in noisy areas) buildings or parts thereof.

According to Articles R111-22 to R111-22-2 and Article R131-27 of the CCH [Arrêté du 18 décembre 2007; Décret n° 2007-363], besides the application of the relevant thermal regulation, from 1 January 2008 all buildings with a net floor area of more than 1,000 m^2 undergoing major renovations (regardless of the construction year) must carry out a Technical and Economic Feasibility Study of Energy Supply Solutions, or **Étude de Faisabilité Technique et Économique des Approvisionnements en Énergie**. At least solar thermal systems, solar photovoltaic systems and wind systems ('foreseen systems') should be included in the study. Other energy supply systems ('variants') can be included, but with different specifications.

For the so-called 'foreseen systems', the study must show:

- the annual energy consumption in kWh of primary energy per square meter of net floor area;
- the annual emissions of greenhouse gases in $kgCO_2$ per square meter of net floor area;
- the annual operating cost.

For each of the possible 'variants', the study must show:

- the difference in capital cost between the variant and the foreseen system;
- the difference in energy consumption;
- the difference in GHGs emissions;
- the difference in annual operating costs;
- other advantages and disadvantages of the variant.

At the end of the feasibility study, the reasons behind the system choice are to be clearly stated and justified.

4.2 RT Existant Élément par Élément

The RT Ex Élément par Élément came into force on 1 November 2007. According to Article R131-28 of the CCH and its implementing decree [Arrêté du 3 mai 2007, as modified by Arrêté du 22 mars 2017], it applies to all types of renovations, except those covered by the RT Ex Globale, by setting minimum performance requirements for replaced or newly installed building elements.

In particular, requirements are established with regards to the following eight features (Figure 29):

- exterior walls (total thermal resistance of different types of wall);
- glazing (heat transmission coefficient, deemed-to-satisfy types of carpentry, glazing and shutters);
- heating (heating system efficiency, minimum insulation, thermostatic valves and metering);
- domestic hot water (water heater maximum standby loss, minimum thermal performance);
- cooling (solar shading devices, minimum energy class and efficiency of cooling systems, metering);
- mechanical ventilation (maximum consumption);
- lighting (basic features of light fixtures in non-residential buildings);
- renewables (efficiency of wood burning heating appliances).

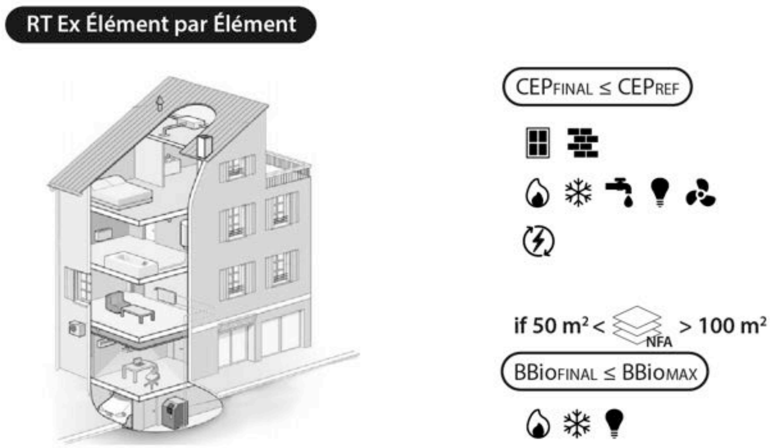


Figure 29: RT Existant Élément par Élément

As of 1 January 2015, RT Ex Élément par Élément also applies in some cases of building extensions - both side extensions and rooftop elevations -, instead of the more restrictive RT 2012 [Arrêté du 11 décembre 2014]. Besides building renovations, it applies to:

- single-family buildings, if the net floor area of the extension is either a) lower than 50 m^2 or b) between 50 m^2 and 100 m^2, regardless of the pre-existing net floor area. If b), then the additional calculation of the

Bioclimatic Needs Factor (**BBio - Coefficient de Besoin Bioclimatique**)[12] is required and the $BBio_{FINAL}$ value must be less or equal than $BBio_{MAX}$;
- multi-family housing and non-residential buildings, if the net floor area of the extension is either a) lower than 50 m^2, regardless of the pre-existing net floor area or b) lower than 150 m^2 and lower than 30% of the pre-existing net floor area.

If these conditions do not occur, in order to comply with the law, the project has to meet all the RT 2012 requirements for new buildings, but with some exemptions regarding:

- renewable energy production, to be satisfied only if the extension includes a bathroom, equipped with a shower/bathtub;
- air leakage, to be considered only if minimum openings between existing and new spaces;
- thermal bridges reduction, to be considered only if side extensions;
- glazing, to be satisfied only if the extension includes a living room.

4.3 Loi relative à la Transition Énergétique pour la Croissance Verte

Following the Paris Agreement on Climate Change, signed on 12 December 2015, one of the latest provisions of the French government in the field of climate change is the 'LTECV - Loi relative à la Transition Énergétique pour la Croissance Verte' [Loi n° 2015-992], or Energy Transition for Green Growth Act in English.

Through this act, France set down in law a number of goals and operational solutions aimed at speeding up the energy renovation of buildings. By passing some amendments to the existing regulations and providing building owners with massive incentives for investment, the LTECV created a lot of new opportunities for stakeholders to take action.

As far as regulations are concerned, the act introduced both obligations and simplifications.

Pursuant to Article 14 of the LTECV and its implementing decrees [Décret n° 2016-711; Décret n° 2017-919], a first obligation requires that all properties

[12] The BBio is the RT 2012 indicator that replaces the RT 2005 Ubat (overall envelope thermal resistance). It is calculated as a weighted sum of the building heating, cooling and lighting needs: Bbio = 2 x Q_h + 2 x Q_c + 5 x Q_l.

undertaking major renovation works to envelope elements improve insulation (**Obligation d'isolation en cas de travaux importants**). As established by Articles R131-28-7 to R131-28-11 of the CCH, from 1 January 2017, all residential and non-residential buildings (e.g. education buildings, offices, hotels and commercial properties) subject to:

- building façade repairs, affecting at least 50% of the façade area;
- roof refurbishments, affecting at least 50% of the roof area;
- building extensions (or conversions), creating at least 5 m^2 of new habitable space,

must be complemented by an improvement in the thermal performance of the corresponding building component such as to meet the RT Ex Élément par Élément requirements. Exemptions are possible in cases where specific technical or legal impossibilities, architectural qualities, or economic disadvantages are detected and reported to the planning authority with supporting documents, compiled by a qualified architect.

A second obligation, contained in Article 5 of the LTECV, mandates that all private dwellings consuming more than 330 $kWh/m^2.y$, namely residential buildings falling in class F or G of the French EPC, are retrofitted by year 2025 (**Obligation de rénovation énergétique**). Despite the potential impact of the measure, no further specifications (e.g. on the required level of renovation) are given.

Besides the above mentioned retrofit obligations, Article 7 of the LTECV and its implementing decree [Décret n° 2016-802] also introduced relevant simplifications aimed at removing some planning constraints that could otherwise hinder the implementation of certain building retrofit projects (**Dérogations aux règles du PLU pour l'isolation par l'extérieur ou la protection contre le rayonnement solaire**).

According to the new Articles R152-5 to R152-9 of the CCH, all buildings older than 2 years and subject to the external insulation of walls/roof or installation of solar shading devices, can to a certain extent depart from the regulations set by the local plan (PLU - Plan Local d'Urbanisme) in relation to site coverage, building height, location and appearance. Since 18 June 2016, a derogation up to 30 cm compared to the limits contained in the PLU can be granted by the local planning authority.

In any case, these derogations are not cumulative, they should be motivated and may include prescriptions to ensure a good integration of the project in its surroundings.

In addition to amended regulations, the LTECV extended and strengthened some existing financial incentives. For residential buildings, the two main instruments addressed by the act are the Energy Transition Tax Credit, or **CITE - Crédit d'Impôt pour la Transition Énergétique** in French, and the Zero-Rate Eco-Loan, or **Éco-PTZ - Éco-Prêt à Taux Zéro** [MEEM, 2016].

The **CITE** [Odyssee-Mure, 2015a] is a tax credit scheme available to property owners and tenants for purchasing materials and equipment to be used in the energy renovation of their main residence. It replaces the former Sustainable Development Tax Credit (CIDD - Crédit d'Impôt Développement Durable), in force from 2005 to 2014, relaxing some restrictions such as the income conditions or the obligation to set up combined actions.

Up to the limit of €8,000 for a single person and €16,000 for a couple (plus €400 per dependent) the scheme entitles French taxpayers to benefit from a 30% refundable credit on the reported amount of works. This means that if the credit amount is greater than the taxes owed, the difference is paid to the owner.

Eligible expenses can be sorted in three main categories: thermal insulation, heating/hot water production from renewable sources and non-mandatory energy certification/assessment. In principle, all labor costs are excluded from refund.

The **Éco-PTZ** [Odyssee-Mure, 2015b] is an interest-free loan scheme managed by commercial banks and available to property owners, occupiers or lessors, for financing major renovation work of dwellings used as main residence and built before 1 January 1990. The loan is not subject to any income condition and can be used to finance up to €30,000 per household (Table 16).

In order to benefit from it, the owner must either:

- carry out a 'bunch of actions' including at least 2 of the following: external wall insulation, roof insulation, windows and doors insulation, installation or replacement of heating/hot water equipment, installation of heating/hot water production equipment from renewable sources;
- achieve, on the basis of a thermal assessment (**Étude Thermique**) performed by an independent expert, a minimum level of overall energy performance (i.e. 150 $kWh/m^2.y$ if the energy consumption of the dwelling before retrofit is greater than or equal to 180 $kWh/m^2.y$, or 80 $kWh/m^2.y$ if the consumption is lower than 180 $kWh/m^2.y$);
- replace an individual sewerage system with another system which does not consume energy.

The repayment period ranges from 3 to 10 years, but it can be extended up to 15 years in the case of renovations covering from 3 to 6 measures. From 1 July

2016, a complementary loan can be granted within 3 years from the issue of the offer of the first loan. The sum of the two loans cannot exceed €30,000.

Table 16: LTCEV. Éco-Prêt à Taux Zéro

	single action	**bunch of actions**		**overall energy performance**	**sewerage system**
		2 actions	**3 or more actions**		
Maximum loan amount	10,000 €	20,000 €	30,000 €	30,000 €	10,000 €
Maximum loan repayment period	10 years	10 years	15 years	15 years	10 years

The Éco-prêt à taux zéro can also be granted to association of co-owners (**Éco-PTZ Copropriété**) carrying out energy efficiency works on common areas and facilities. In this case, the maximum amount is given by multiplying the number of individual properties by €10,000 per renovation action financed, up to a maximum of €30,000.

Within a year from the issue of the 'collective' eco-loan, each co-owner has the possibility to complement it by an 'individual' eco-loan, possibly comprising a single action.

From 1 March 2016, the CITE and Éco-PTZ schemes can be combined with no restrictions applying. Nevertheless, a general condition for profiting from them is that works are performed by RGE-certified (Reconnus Garant de l'Environnement) professionals and enterprises, and that the installed equipment and materials conform to the technical characteristics and minimal performance requirements fixed in the General Taxes Code (CGI - Code Général des Impôts).

Finally, it is to be noted that all works eligible for, but not limited to, the CITE and Éco-PTZ schemes can also take advantage of VAT rate reductions.

In France, the standard VAT rate in 20% but, provided that the materials are bought from and/or the interventions are carried out by professionals on dwellings which are more than 2 years old, different VAT rates apply depending on the type of works. As stated by Articles 278-0 bis and 279-0 bis of the CGI:

- a 5% reduced VAT rate (**TVA à taux réduit 5.5%**) applies to energy conservation works (e.g. thermal insulation, heating/hot water production, renewable energy generation) and complementary works;
- a 10% intermediate VAT rate (**TVA à taux intermédiaire 10%**) applies to other improvement and maintenance works (e.g. attic conversion,

roofing, wall painting) or professional services (e.g. energy audits, energy certifications).

In both cases, 5.5% and 10% rate, the property can be either a primary residence or second home, and the client can be an occupant owner, a lessor, a tenant, an association of co-owners, or a real estate company. The only condition to benefit from the VAT reduction is that the works should not involve: building elevation, renovation of more than half of first fix elements (e.g. foundations, supporting walls), renovation of more than two third of second fix elements (e.g. plumbing, electricity), extension of more than 10% of the building floor area.

4.4 Diagnostic de Performance Énergétique

The EPC policy has been transposed into French legislation through Articles R134-1 to R134-5 of the CCH [Arrêté du 15 septembre 2006, as modified by the Arrêtés du 8 février 2012].

The certificate is called Energy Performance Diagnosis (**DPE - Diagnostic de Performance Énergétique**) and has become mandatory at the time of sale, of residential and non-residential buildings, or rental, of residential buildings only, respectively from 1 November 2006 and 1 July 2007. It must be issued by an independent expert [Arrêté du 16 octobre 2006, as modified by Arrêté du 13 décembre 2011], displayed in all sale/rental advertisements, and shown to the prospective new owner or tenant. Its validity is of 10 years from the date of issue.

Since 1 November 2007 the DPE has become an integral part of the Technical Diagnosis File (**DDT - Dossier de Diagnostic Technique**) [Décret n° 2006-1114; Décret n° 2006-1653], a collection of the various technical inspections reports that are compulsory when renting or selling a property (i.e. risk of exposure to lead, presence of asbestos or termites, status of gas and electricity fixtures, status of natural and technological hazards, check of individual sewerage).

Depending on the type of transaction (i.e. new build, sale or rent), building use (i.e. residential or non-residential), building age (i.e. pre- or post-1948) and heating system (i.e. central or not), different methods have been devised to issue the DPE certificate (Figure 30).

As regards the residential sector, DPE input data can be provided by utility bills (operational/measured consumption) or calculations (conventional/simulated consumption). In principle: for dwellings built before 1948, bills are to be preferred; for dwellings built after 1948, calculations must be used. Exceptions are multi-family buildings with a common space heating and/or domestic hot water system for which bills are required.

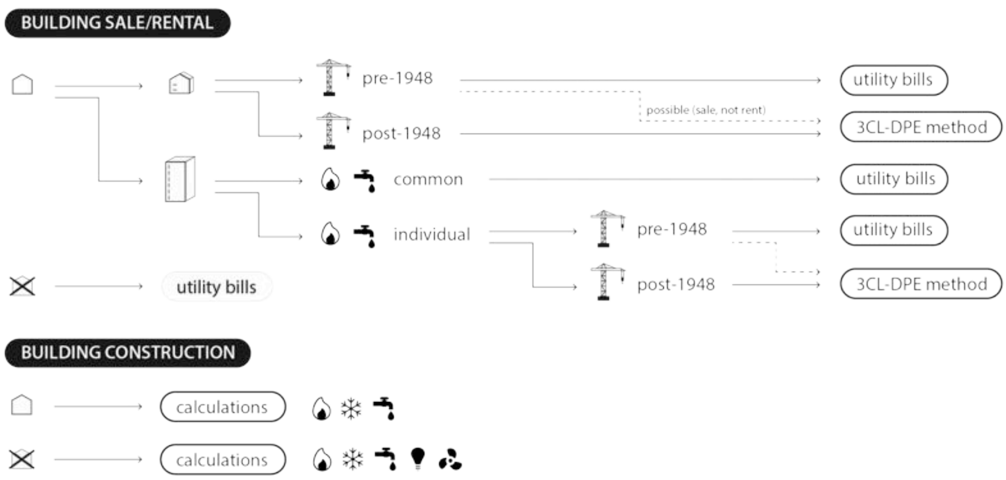


Figure 30: DPE. Methods used to issue the certificate

In the case of utility bills, the energy performance is derived from the consumption noted over the last three years or, failing that, over the actual duration of the domestic hot water/heating supply. In the case of calculations, three assessment methodologies have been developed jointly by experts and public authorities, and made available to professionals [Arrêté du 9 novembre 2006]:

- '3CL-DPE - Calcul Conventionnel des Consommations des Logements', the minimum required method based on standardized assumptions by class of building;
- 'DEL6-DPE - Dépenses Energétiques des Logements' and 'Pleiade-Comfie', more advanced methods based on thermodynamic simulations of the specific building.

Their algorithms are defined by decree, but no software is provided: as from 1 April 2013 developers are invited to have their software assessed for the inclusion in the official list of accepted software.

As regards the non-residential sector, utility bills must be necessarily used.

In practice, the DPE consists of a four-page document, whose content is established by decree and broadly organized as follows.

On the first page, it includes some general data about the building, a table summarizing estimated energy consumption and costs for heating, cooling and domestic hot water, and two ratings: the energy consumption rating, or **Étiquette**

Énergie (in kWh/m^2.y), and the GHGs emission rating, or **Étiquette Climat** (in kgCO_2/m^2.y). Both ratings include 7 classes (from A to G) but, depending on the building use, different scales apply (Table 17 and Table 18).

On the second page, it contains a technical description of the building elements and systems, and information about on-site energy production systems (to be deducted from the energy consumption rating). On the third and fourth page, it provides common usage/saving tips - or **conseils de comportement** - and specific/detailed improvement recommendations - or **recommandations de travaux**.

Table 17: DPE classes. Energy consumption rating (kWh/m^2.y)

Label	**Residential buildings**	**Non-residential buildings**		
		office, school, etc.	**hospital, hotel, etc.**	**theatre, sport, etc.**
A	≤ 50	≤ 50	≤ 100	≤ 30
B	≤ 90	≤ 110	≤ 210	≤ 90
C	≤150	≤ 210	≤ 370	≤170
D	≤ 230	≤ 350	≤ 580	≤ 270
E	≤ 330	≤ 540	≤ 830	≤ 380
F	≤ 450	≤ 750	≤ 1130	≤ 510
G	> 450	> 750	> 1130	> 510

Table 18: DPE classes. GHGs emission rating (kgCO_2/m^2.y)

Label	**Residential buildings**	**Non-residential buildings**		
		office, school, etc.	**hospital, hotel, etc.**	**theatre, sport, etc.**
A	≤ 5	≤ 5	≤ 12	≤ 3
B	≤ 10	≤ 15	≤ 30	≤ 10
C	≤ 20	≤ 30	≤ 65	≤ 25
D	≤ 35	≤ 60	≤ 110	≤ 45
E	≤ 55	≤ 100	≤ 160	≤ 70
F	≤ 80	≤ 145	≤ 220	≤ 95
G	> 80	> 145	> 220	> 95

To raise awareness among co-owners with regards to potential renovation works, by the end of 2016 a mandatory Energy Audit (**Audit Énergétique**)

[Décret n° 2012-111; Arrêté du 28 février 2013] is to be undertaken by all multi-tenant buildings built before 1 June 2001. Starting 2012, all buildings with more than 50 units, at least 50% of the net floor area intended for residential use, and more than 90% of the residential units served by a collective heating/cooling system, have to ask advice from a certified professional for the preparation of a report providing detailed data about achievable energy savings and suitable retrofitting scenarios. This audit should contain precise cost/benefit evaluations and information on available incentives. The recommendations given in the report are not binding, but all co-owners are to be made aware of the report content during a condominium meeting.

In multi-tenant buildings with less than 50 units, the Energy Audit is replaced by a mandatory DPE by the end of 2016.

4.5 Haute Performance Énergétique Rénovation

Besides the DPE, renovated buildings achieving higher energy performance levels than the regulatory requirements can apply for two voluntary labels.

The Haute Performance Énergétique Rénovation label is a state label introduced by Article R131-28-1 of the CCH [Arrêté du 29 septembre 2009], delivered by private certification bodies that have been recognised by the Government and accredited by the French Accreditation Committee (COFRAC - Comité Français d'Accréditation).

This label applies to residential and non-residential buildings completed after 1 January 1948 and at least 5 years old, certifying that the renovation meets minimum standards of energy performance and summer comfort that go beyond the current RT Ex Globale requirements.

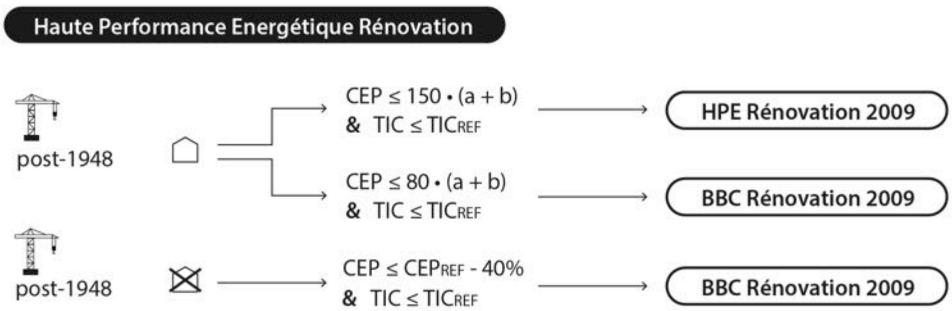


Figure 31: HPE Rénovation label

For single- or multi-family residential buildings, the label includes two levels (Figure 31):

- the '**HPE Rénovation 2009** - Haute Performance Énergétique Rénovation 2009' level, which applies to residential buildings that achieve a conventional primary energy consumption (CEP) equal to or under 150 kWh/m^2.y for the five regulatory uses (i.e. heating, cooling, domestic hot water, lighting, auxiliary appliances);
- the '**BBC Rénovation 2009** - Bâtiment Basse Consommation Rénovation 2009' level, which applies to residential buildings that achieve a CEP equal to or under 80 kWh/m^2.y for the same five uses.

Calculations are to be performed using the Th-C-E Ex method, with the maximum conventional primary energy consumption corrected by a factor of climate harshness that varies depending on the climatic zone and altitude where the building is located (Figure 32).

For non-residential buildings, instead, the label includes a single 'BBC Rénovation 2009 - Bâtiment Basse Consommation Rénovation 2009' level, which applies to all buildings that achieve a conventional primary energy consumption (CEP) equal to or lower than 40% $CEP_{REFERENCE}$.

Regardless of the building type and HPE level, the RT Ex Globale requirements about the conventional indoor temperature (TIC) must always be satisfied.

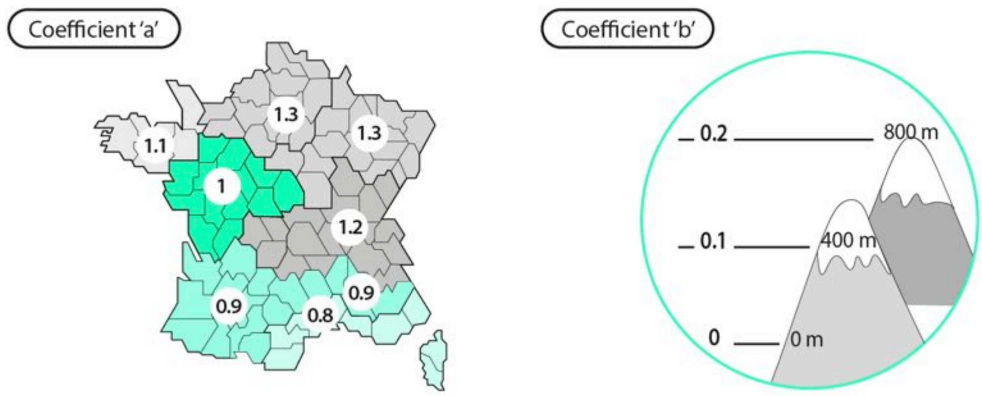


Figure 32: HPE Rénovation. Climate zone and altitude factors

4.6 Effinergie Rénovation

The Effinergie Rénovation label is a private label handled by the 'Collectif Effinergie', a non-commercial association which gathers building industry professionals and local authorities.

This label applies to renovated residential and non-residential buildings, regardless of their construction year (Figure 33). It entails the same conventional primary energy consumption requirements as the BBC Rénovation 2009 label[13] plus, only for residential buildings, additional requirements about renewable energy production and building envelope performance [Effinergie, 2011]. In particular, the aim being to promote the energy efficiency:

- for single-family housing, a renewable energy production to be deducted from the conventional primary energy consumption up to the limit value of 35 or 12 kWh/m^2.y depending on the type of domestic hot water system (electric or not);
- for multi-family housing, a renewable energy production to be deducted from the conventional primary energy consumption up to a limit value calculated on the base of a weighted average of the floor areas, by type of domestic hot water system (electric or not);
- for both type of buildings, an overall heat transfer coefficient UBât ≤ $UBât_{MAX}$ - 30%.

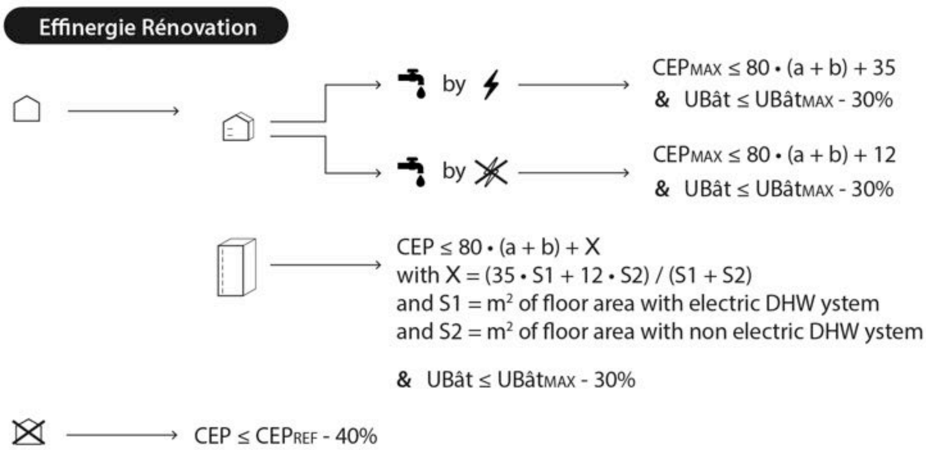


Figure 33: Effinergie Rénovation label

[13] Indeed, for buildings built after year 1948, the label benefits of the BBC-Effinergie Rénovation designation.

Although no specific requirements are established, a measure of air permeability is mandatory for residential buildings, and recommended for non-residential ones.

At the time of writing about 69,000 dwellings have already been certified under the BBC-Effinergie Rénovation label. For the purpose of dissemination and promotion, a national observatory [Observatoire BBC, 2017] collects up-to-date statistics and factsheets on labelled projects.

CASE #4
Résidence Saint-Hilaire | LAN Architecture

Rehabilitation (in occupied site) of 709 apartments in four different estates, landscaping of public open spaces and creation of new parking areas.

LOCATION: 16, 17 & 18 Rue Henri Dunant, Lormont - 44°52’19.5”N, 0°30’52.1”W

DATE: 1960-75 construction; 2009, competition; 2012 - 2014, renovation

CLIENT: Domofrance

DESIGN TEAM: LAN Architecture (mandatory architect), Agence Franck Boutté Consultants (environmental engineering), BASE (landscape architect), Beterem Ingénierie (all-trades engineering)

BUDGET: 21.3 Mio EUR excl. VAT

AWARDS: 2016, ArchMaraton Awards (nomination); 2016, Venice Architecture Biennale (exhibition)

PLOT SIZE: 5,729 m^2

BUILDING SIZE: 1) Total floor area: 34,270 m^2 > 36,528 m^2; 2) Heated floor area: 30,877 m^2 > 30,693 m^2

ENERGY CONSUMPTION: approx. 164 > 79 kWh/m^2.y (primary energy)

EPC class: D > B

The project is located in Lormont, in the southern part of the Quartier Génicart, a city district consisting of primarily multi-family social housing. Originally designed by the French architects Jean Fayeton and Francisque Perrier, and built between 1960 and 1975, the site covers an area of around 7 ha and comprises of four different housing estates:

- Saint-Hilaire, three buildings and 387 units;
- Leroy, two buildings and 114 units;
- La Boétie, two buildings and 104 units;
- Villon, two buildings and 104 units,

for a total of 9 buildings and 709 housing units.

Building types include low-rise apartment blocks (4 storeys) and high-rise apartment towers (19 storeys), with flat roofs and uninsulated concrete walls. Surrounding the buildings are green and paved shared spaces.

Through a so-called *résidentialisation* programme, each estate was given a distinctive character and the presence of unused public open spaces was reduced. The renovation of the façades, which was initially intended to thermally insulate the buildings, opened up opportunities to extend the living space. The rationalisation and concentration of parking areas at the site's edges and in the underground parking permitted the creation of an urban park with street furniture, pedestrian pathways, meeting places, etc.

The three towers of Résidence Saint-Hilaire are a prime example in this regard.

Situated at the core of the site, they stand as an urban landmark, distinguishing themselves through their light and bright envelopes. Sliding polycarbonate and aluminium shutters enliven the façades, and optimize the thermal and acoustic qualities of the buildings. Besides improving the aesthetics of the towers, the new cladding also transformed existing balconies into enclosed and sheltered loggias. As a result, the loggias became an extension of the interiors, accessible through swing doors directly from the new open plan kitchen and living room of each apartment.

Fixed precast concrete frames are attached to the original slabs, increasing their depth from about 93 to 160 cm, for additional 5-10 m^2 of usable space per unit. Tailor-made shutters are fitted to tracks that allow them to slide between open and closed. A sill conceals the concrete sections between the movable surfaces of adjacent storeys.

Behind the translucent skin, the old single-glazed timber frame windows and doors were replaced by PVC double-glazed units with low-emission glazing (U-value = 1,70 W/m^{2}K) and integrated roller shutters. On the roofs, a 70-cm thick insulation layer of polyurethane was added to achieve a thermal resistance of R = 3.05 m^{2}K/W.

Thanks to the above mentioned interventions on the envelope, the buildings' energy consumption was reduced by half: on average, the primary energy demand of the Saint-Hilaire towers dropped from 164.5 to 78.9 kWh/m^2.y. Acting as a thermal buffer zone, the loggias minimize the tower heat losses (from 4.75 to 2.42 m^{2}K/W) and enables passive solar gains. To ensure proper air quality, the existing mechanical ventilation system was upgraded to a new system with humidity-controlled inlets and outlets, and more energy-efficient ventilation units.

Space heating and domestic hot water are supplied by a local district heating plant.

Alongside the retrofit of the façades and refurbished interiors, the project also featured a totally redesigned esplanade. The plaza at the foot of the towers benefits from the absence of vehicles, becoming a meeting place and accommodating the Quartier Général, a new 3-storey structure (25 m long and 4 m wide) used as children's playground and public terrace.

Elevated from the ground, it appears as a semi-opaque box enclosing a variety of play equipment such as slides, climbing nets and a trampoline. Angled posts reveal the stairs and access ramps to the turrets, while timber frames cladded with perforated metal sheets provide safety and privacy for the users.

A captivating lighting concept allows the facility to be used also when it is dark.

Climate: 2034 heating degree days / 184 cooling degree days

Building energy regulation: RT-Ex Globale
Calculation method: Th-C-E Ex

Table 19: Résidence Saint-Hilaire. Building envelope U-values

	U-value before retrofit (W/m^2K)	**U-value after retrofit (W/m^2K)**
Roof	0.64	0.3
External walls	4.7	3.7
Floor over basement	1.5	1.5
Windows	5.3	1.6
Whole-building	**4.75**	**2.42**

Air exchange rate: unknown // **Air tightness n_{50}**: unknown

Table 20: Résidence Saint-Hilaire. Building energy demand

	Before retrofit ($kWh/m^2.y$)	**After retrofit ($kWh/m^2.y$)**
Space heating	122.6	45.8
DHW	22.9	23.1
Ventilation	8.9	2.4
Auxiliaries	4.2	2.1
Lighting	5.9	5.4
Total PE demand	**164.5**	**78.9**
RES production	-	-
PE demand - RES	-	-

Table 21: Résidence Saint-Hilaire. Building retrofit costs

	Mio €	**€/m²**
Building costs		
Landscaping		
Total	**21.3**	**372,2**

Funding sources: unknown

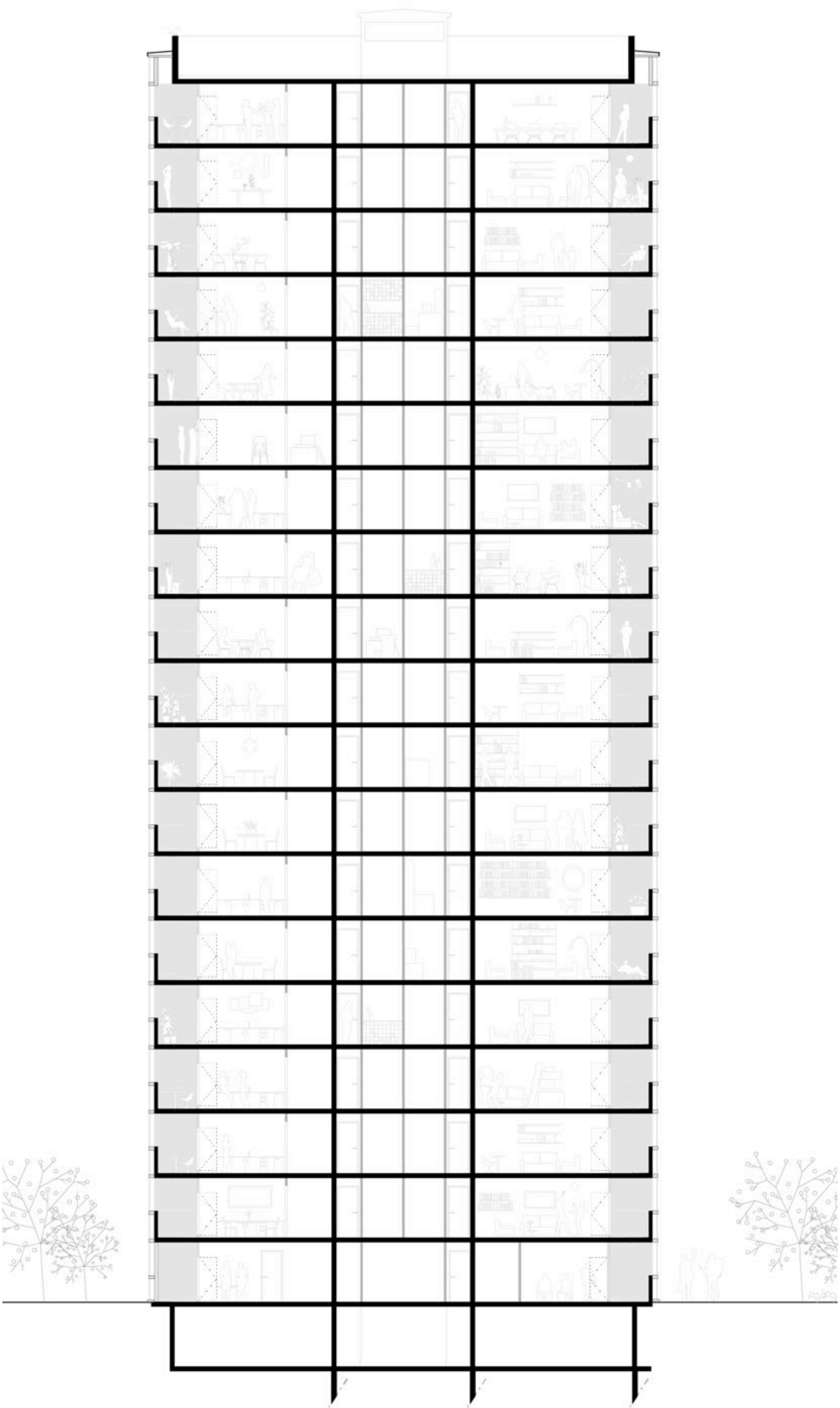


Figure 34: Résidence Saint-Hilaire. Section (1:250)

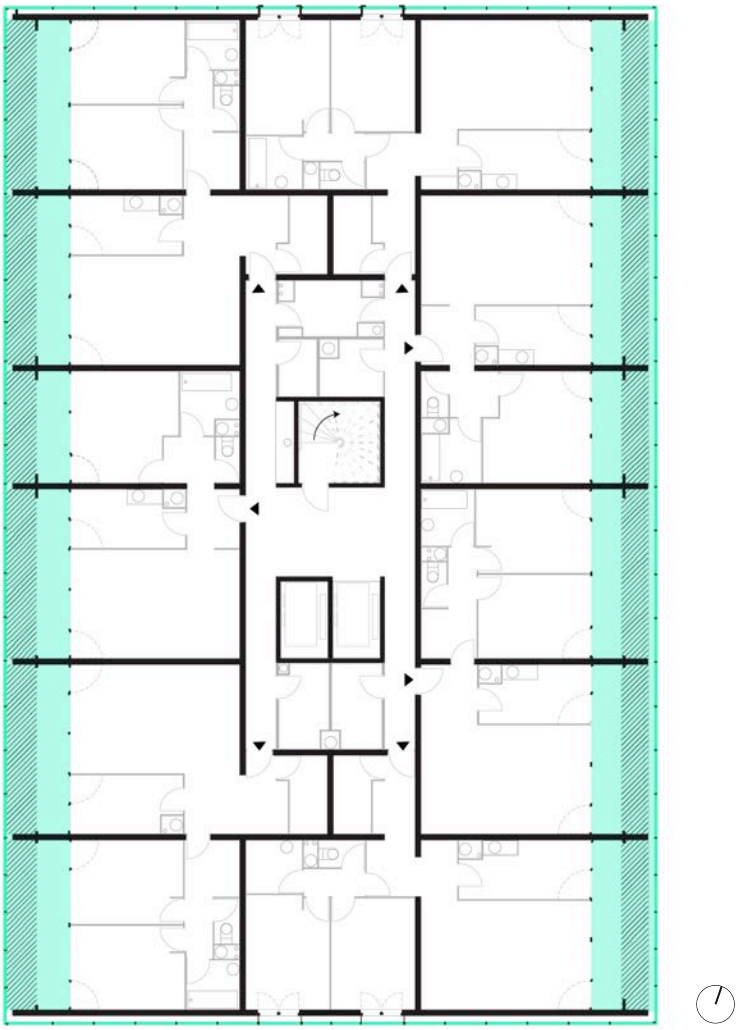


Figure 35: Résidence Saint-Hilaire. Floor plan (1:250)
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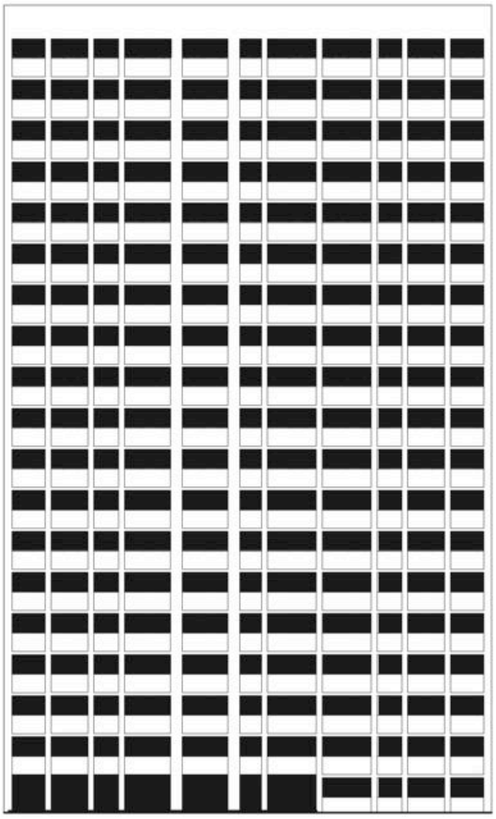

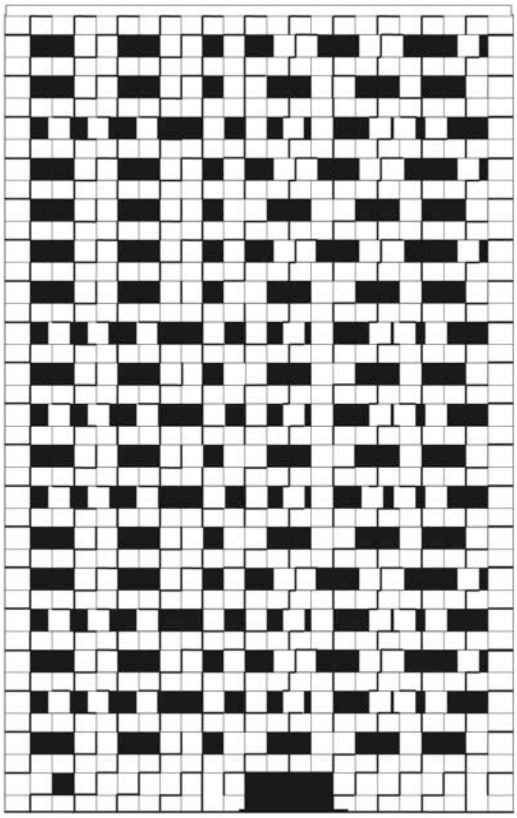

Figure 36: Résidence Saint-Hilaire. East elevation before and after retrofit (1:500)
© LAN Architecture

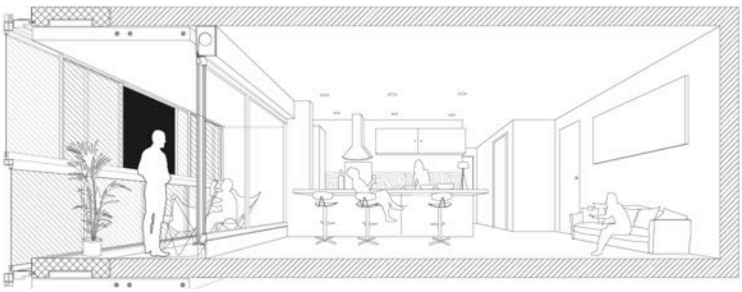

Figure 37: Résidence Saint-Hilaire. Perspective section before and after retrofit
© LAN Architecture

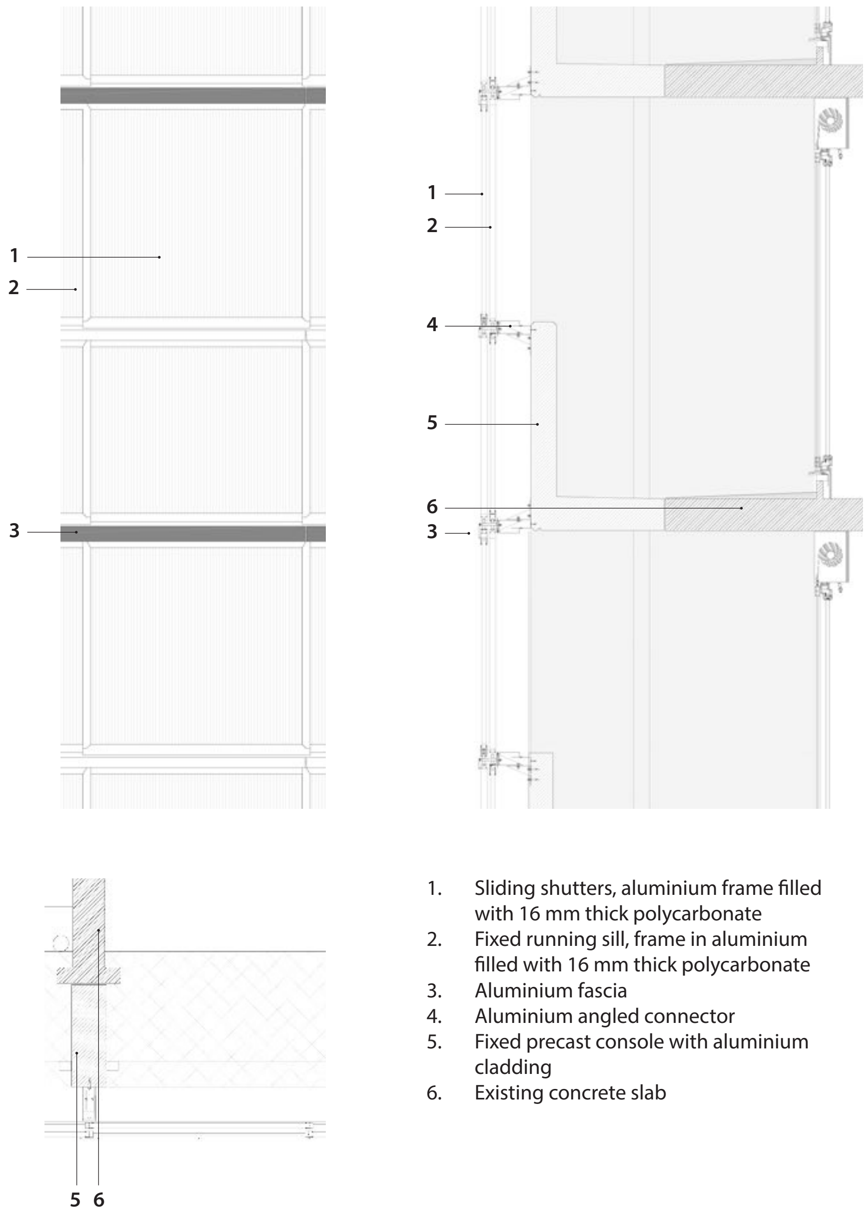

Figure 38: Résidence Saint-Hilaire. Construction sections (1:50)
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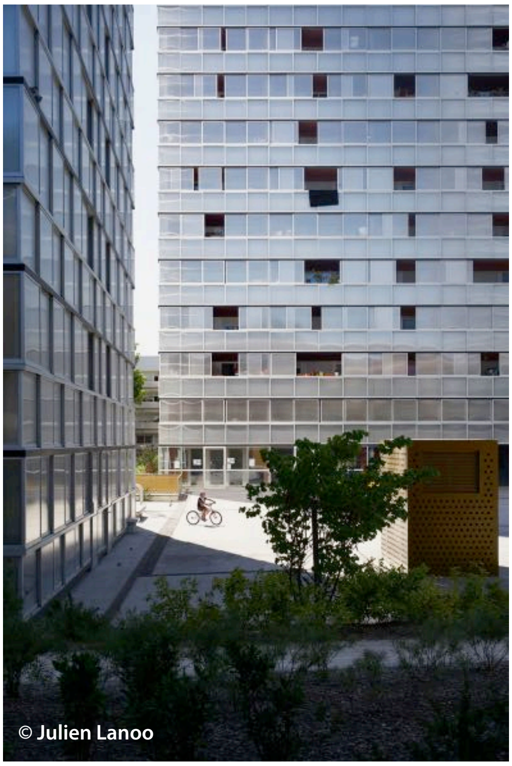
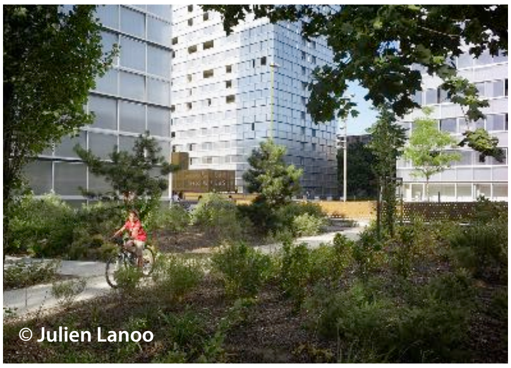
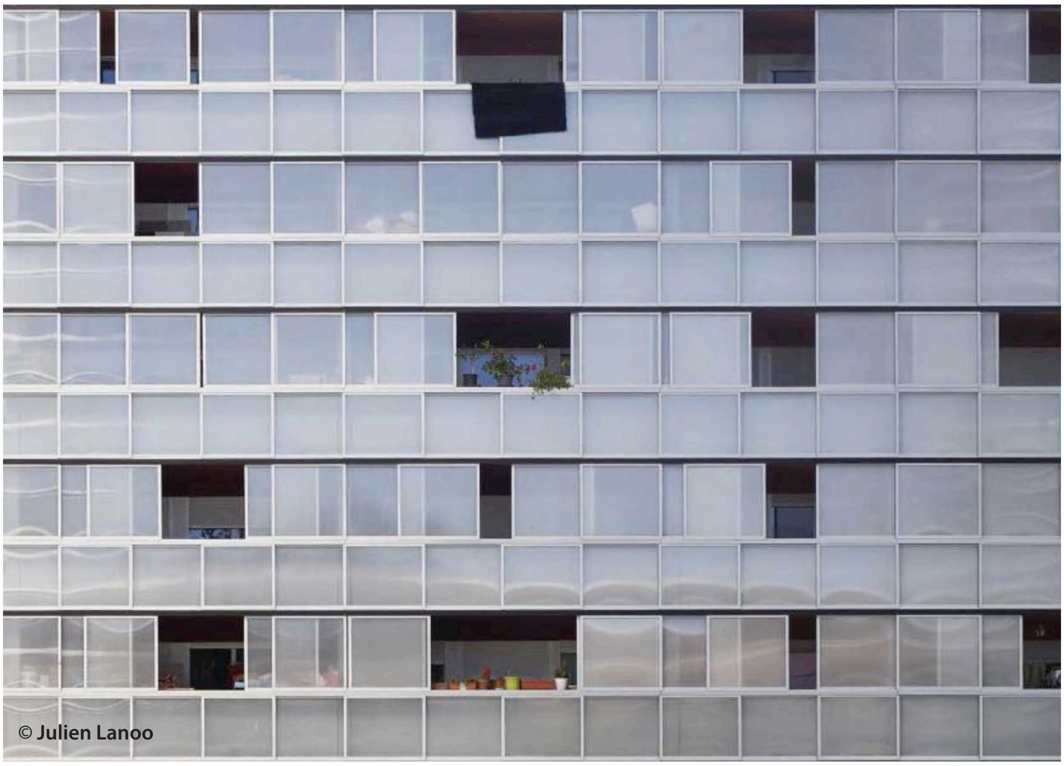
Buildings before retrofit





Top: Buildings after retrofit
Bottom left: Newly designed pedestrian square. Bottom right: Landscaped surroundings



Top: Front view of the retrofitted façade charachterised by movable polycarbonate shutters
Bottom: Interior view of a loggia

Top: Front view of the Quartier Général and square at the foot of the buildings
Bottom: Views of the children's playground and public terrace

© Luc Boegly

CASE #5
Square Vitruve | Atelier Du Pont

Renovation (in occupied site) of the envelope of a mid-rise apartment building with alterations to fenestration and addition of balconies.

LOCATION: Square Vitruve 1-7, Paris - 48°51'34.0"N, 2°24'30.2"E

DATE: 1974, construction; 2009, competition; 2010-2011, earlier renovation - plumbing and electrical systems; 2012 - Jun 2013, renovation - envelope

CLIENT: France Habitation

DEVELOPER: Semaest

DESIGN TEAM: Atelier Du Pont (mandatory architects), EVP Ingénierie (structural engineering), RPO (cost assessment), PLAN02 (environmental engineering), Eiffage (general contractor)

BUDGET: 1.8 Mio EUR excl. VAT

AWARDS: 2015, ArchiDesignClub Awards (finalist)

BUILDING SIZE: 1) Total floor area: 3,058 m^2 > 3,285 m^2; 2) Heated floor area: 3,058 m^2 (unchanged)

ENERGY CONSUMPTION: 194 > 98.5 $kWh/m^2.y$ (primary energy)

CO_2 EMISSIONS: 36 > 16 $kg/m^2.y$

EPC class: D & E > C

Other LABELS: (Paris Climate Protection Plan for existing buildings)

Square Vitruve is a co-ownership real estate located on the eastern outskirts of Paris, in the 20th arrondissement. Constructed on a concrete slab covering the site of a former settlement (the village of Charonne), it is characterized by the lack of vegetation and consideration of human scale.

In line with the ongoing urban renovation plan which is transforming the neighbourhood (i.e. the GPRU - Grand Projet de Renouvellement Urbain Saint-Blaise), the project involves the major rehabilitation of the envelope of one of two twin buildings comprising the estate, the other being demolished.

Built in the Seventies, Square Vitruve 1-7 consists of two adjoining but independent blocks for a total of 56 housing units over 4 upper floors, and a ground floor. Three floors of underground parking, lie below the slab.

Many constraints affected the site. Because of accessibility and bearing capacity issues, no heavy machinery (e.g. cranes or pods) was allowed to operate on the adjacent square, and all the materials and technical solutions employed needed to be designed to avoid overloading of the existing structure and disturbance to residents' daily life.

Sunlight conditions are also critical. In the close surroundings of the building, two high-rise residential towers of 30 and 35 stories overshadow its southern elevation for most of the day.

Following detailed sun studies, Atelier Du Pont decided for an integrated design approach: whole building insulation plus addition of louvered balconies on those parts of the building where shadow conditions made them advisable.

Thermal insulation was fixed to the original external walls and cladded with corrugated, coated steel panels with trapezoidal profiles. Attached by means of angled profiles, these panels provide weather protection to the 15/20-cm layer of mineral wool and leave an air gap for rear-ventilation, reaching a U-value of 0.123 W/m^2K on the SW-NE fronts and 0.238 W/m^2K on the SE-NW gable ends (the difference being due to the available space).

Balconies, instead, are suspended from the top of the building: on the south-west façade and south-east end wall, a steel structure anchored to concrete blocks placed on the roof, serves as support for (1.2 m wide) cantilevered walkways in metal chequered plates. Along the railings, solar screens alternate with voids, in a pattern of full and empty planes that generate a checkerboard effect, highlighted by the contrast of vertical and horizontal lines.

New double-glazed, low-emission windows with aluminium-clad timber frames and external roller shutters replaced the old ones. Swing doors, with the same technical features, provide access to the added balconies.

At the ground level, steel panels with integrated blinds hide entrance halls and some service premises. On the top level, an extensive green roof (15-20 cm soil depth) retains rainwater and helps reduce the building's heating/cooling demand. A 10-cm deep layer of polyurethane foam with waterproof covering ensure proper thermal insulation.

The result is an increase of the total floor area from 3,058 to 3.285 m² and an energy consumption that, provided the boilers are replaced, reaches the target sets by the Paris Climate Protection Plan[14] for existing buildings (i.e. 79 kWh/m².y primary energy, or Class B of the DPE). A newly installed humidity controlled ventilation system contributes to indoor air quality and energy savings.

The appearance of the building is equally enhanced. Its orthogonal design respects the original architecture, maintaining similar dimensions but adding dynamism to the previously flat façade and barren urban landscape. Balconies and screens open up the building to the square while ensuring a certain level of privacy for residents.

Conceived as a kit-of-parts system, the relatively small pre-fabricated components that make up the envelope were transported, dry assembled and fitted using scaffolding in about a year. The 12-month renovation project followed previous plumbing and electrical works, giving back to the residents a totally renovated building.

[14] According to the Climate Protection Plan (Plan Climat Air Énergie de Paris) adopted by the city of Paris in 2007, a building primary energy consumption must not exceed 50 kWh/m^2.y in the case of new constructions, and 80 kWh/m^2.y in the case of major renovations.

Climate: 2702 heating degree days / 114 cooling degree days

Building energy regulation: RT-Ex Globale
Calculation method: Th-CE Ex

Table 22: Square Vitruve. Building envelope U-values

	U-value before retrofit (W/m^2K)	U-value after retrofit (W/m^2K)
Roof	2.703	0.220
External walls	0.544	0.123 SW-NE / 0.238 SE-NW
Floor over basement	1.667	0.240
Windows	4.95	1.80
Whole building	**2.228**	**0.636**

Air exchange rate: unknown / **Air tightness n_{50}**: unknown

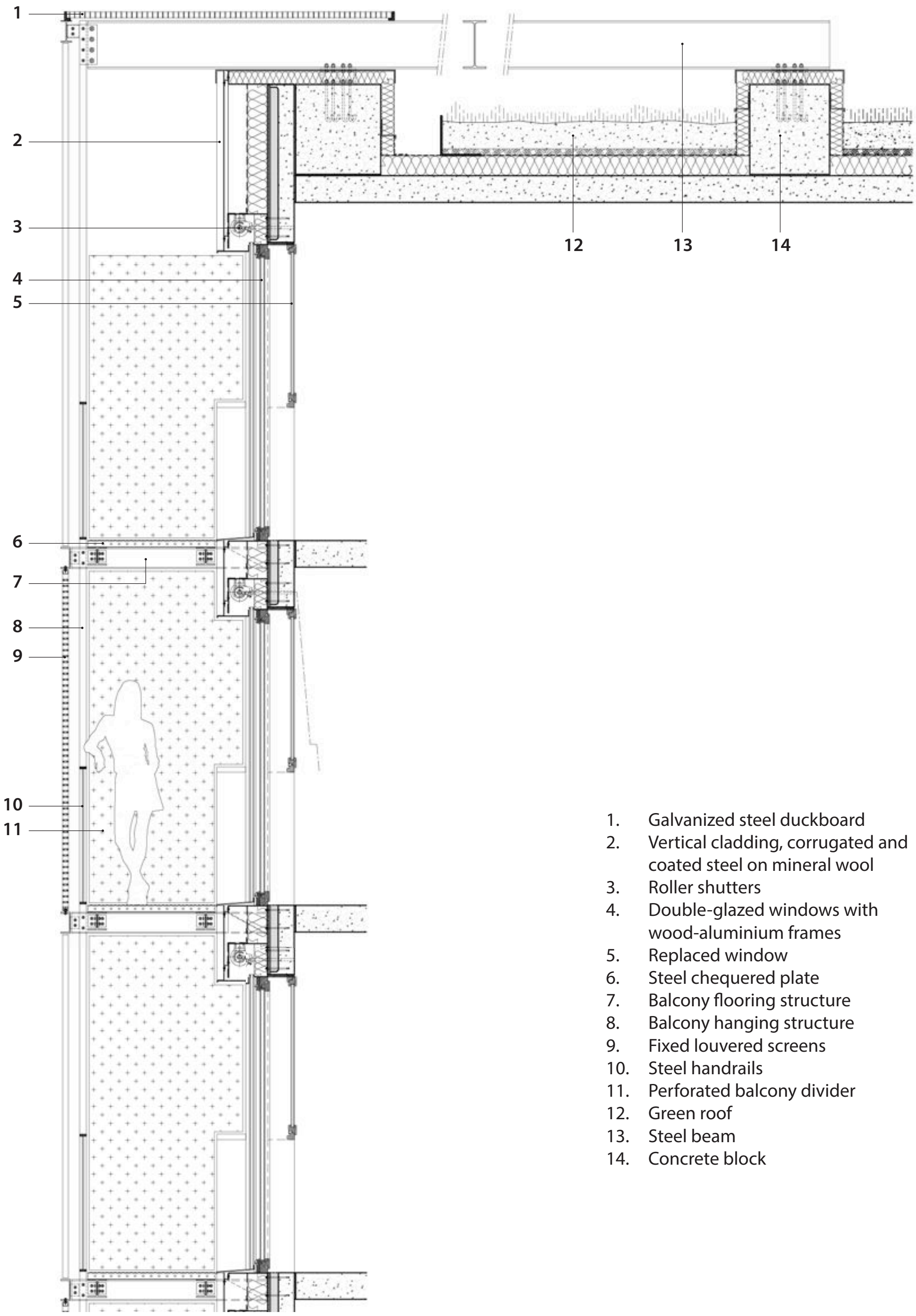
Table 23: Square Vitruve. Building energy demand

	Before retrofit ($kWh/m^2.y$)	After retrofit ($kWh/m^2.y$)
Space heating	127.6	35.0
DHW	41.6	41.6
Auxiliaries (fans)	10.8	10.8
Auxiliaries (pumps)	4.5	1.7
Lighting	9.5	9.4
Total PE demand	**194**	**98.5**
RES production	-	-
PE demand - RES	-	-

Table 24: Square Vitruve. Building retrofit costs

	Mio €	€/m^2
Building costs		
Landscape	-	-
Total	**1.8**	**548**

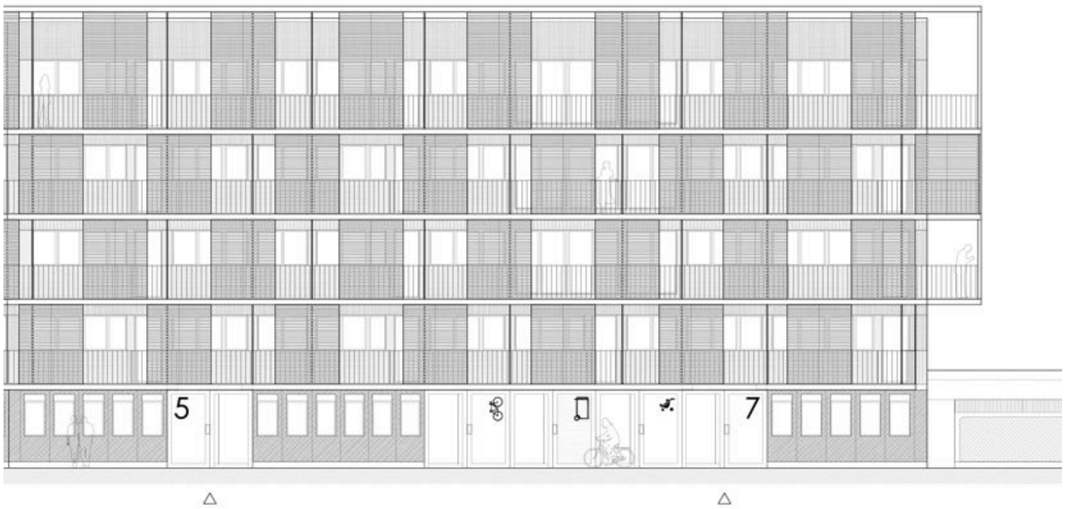
Funding sources: unknown



1. Galvanized steel duckboard
2. Vertical cladding, corrugated and coated steel on mineral wool
3. Roller shutters
4. Double-glazed windows with wood-aluminium frames
5. Replaced window
6. Steel chequered plate
7. Balcony flooring structure
8. Balcony hanging structure
9. Fixed louvered screens
10. Steel handrails
11. Perforated balcony divider
12. Green roof
13. Steel beam
14. Concrete block

Figure 39: Square Vitruve. Construction section through south-west elevation (1:50)
© Atelier Du Pont

Figure 40: Square Vitruve. South-west elevation (1:250)
© Atelier Du Pont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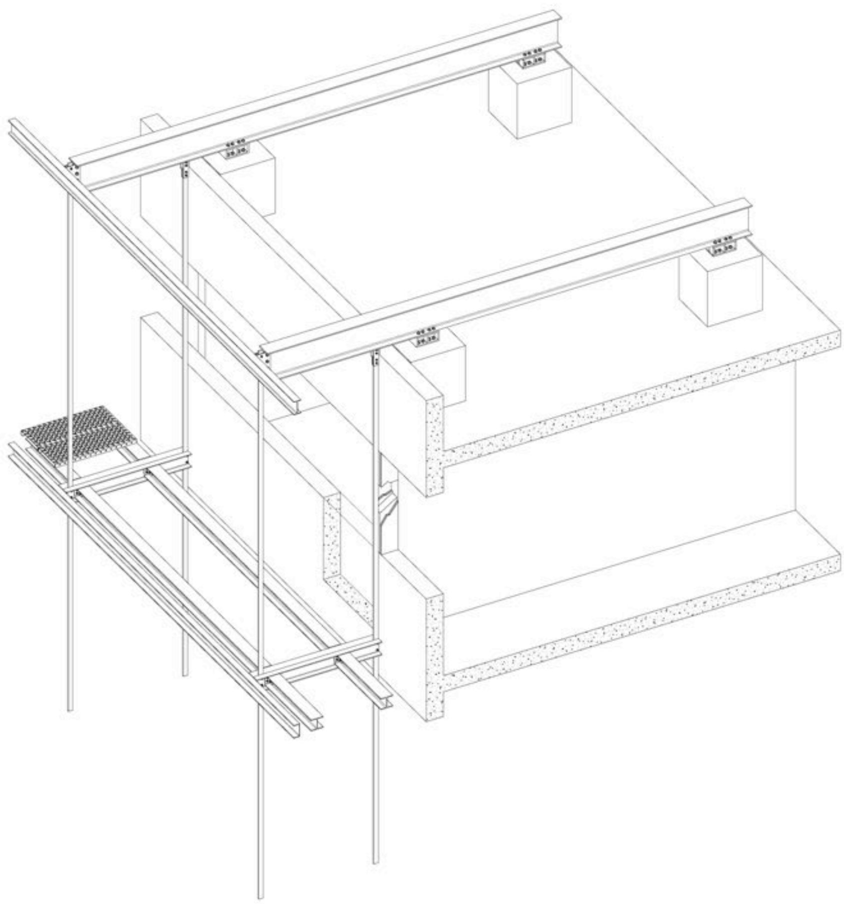

Figure 41: Square Vitruve. Axonometric detail

Top: Building before retrofit
Bottom: Building during retrofit (balcony flooring structure)

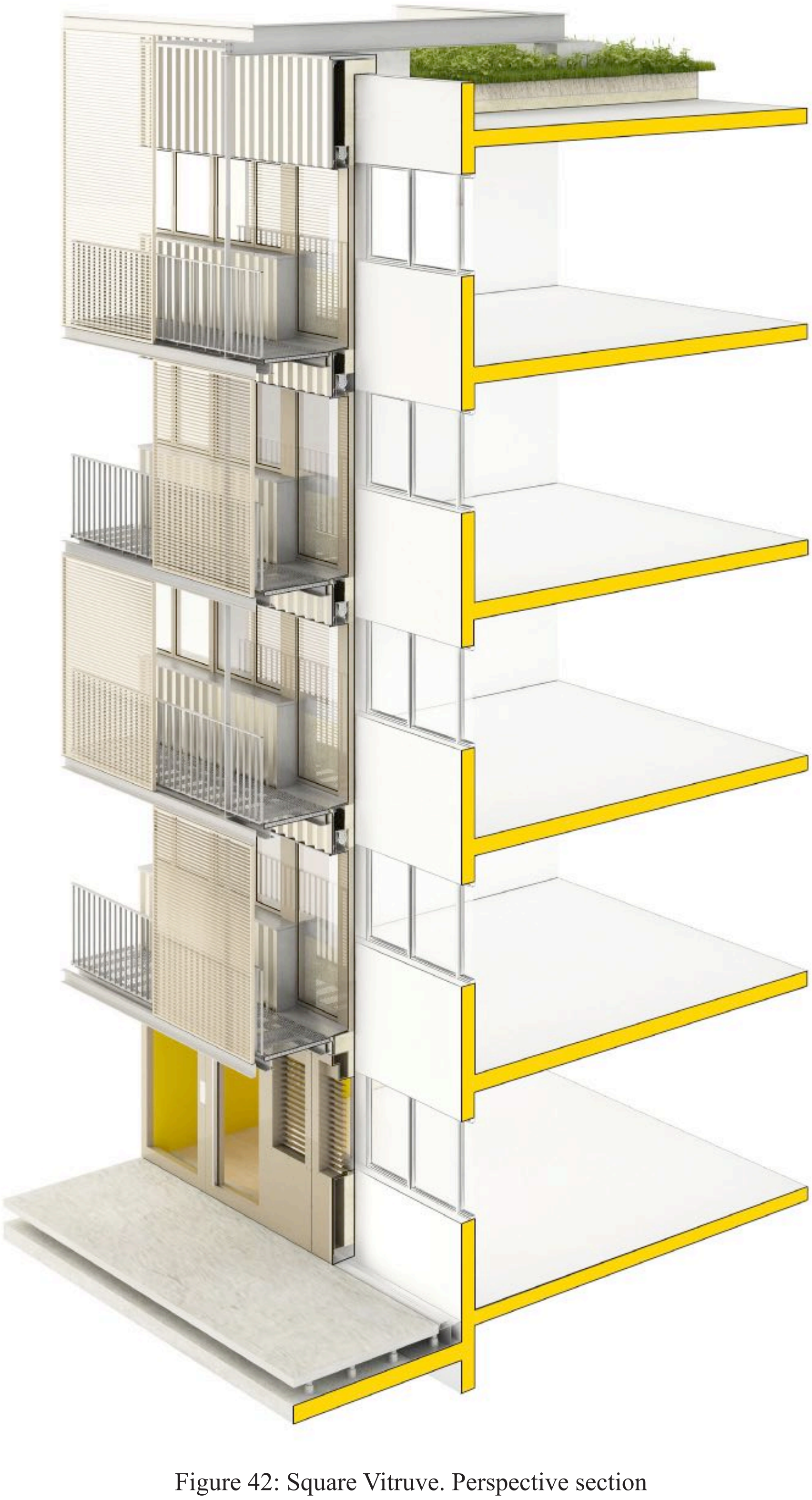

Figure 42: Square Vitruve. Perspective section
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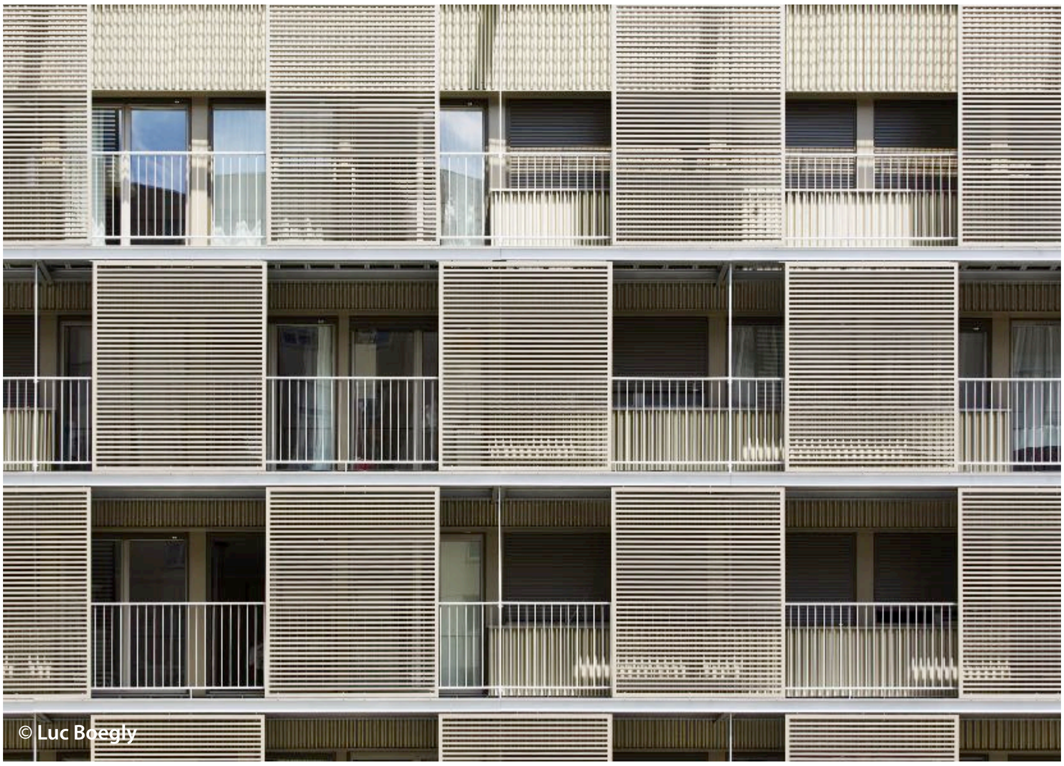
Building after retrofit
Different treatment of the façades



Top and bottom right: Details of balconies
Bottom left: Street view of the square

CASE #6
Bâtiments GHI | Lacaton & Vassal, Druot, Hutin

Transformation (in occupied site) of 530 housing units in three different buildings and construction of 8 new units.

LOCATION: 2-4 Rue Camille Claudel, 10-18 Rue des Frères Portmann, 1-5 Place de l'Europe, Bordeaux - 44°51'34.5"N, 0°34'43.0"W

DATE: 1960-1961, construction; 2011, competition; Mar 2014 - Jan 2016, renovation

CLIENT: Aquitanis O.P.H. de la CUB - Communauté Urbaine de Bordeaux

DESIGN TEAM: Anne Lacaton & Jean Philippe Vassal Architectes, with Frédéric Druot Architecture and Christophe Hutin Architecture (mandatory architects), Cyrille Marlin (landscape architect), BATSCOP (on-site coordination), SECOTRAP Ingénierie (structural engineering - concrete and technical installations engineering), CESMA (structural engineering - steel), CARDONNEL Ingénierie (energy studies), Vincent-Pourtau Economie et Associés (cost assessment)

BUDGET: 28.35 Mio EUR excl. VAT (renovation) + 1.25 Mio EUR excl. VAT (new construction)

AWARDS: 2016, Living Places - Simon Architecture Prize; 2017, Prix d'Architecture de la Ville de Bordeaux - Logement collectif

PLOT SIZE: 23,745 m^2

BUILDING SIZE: 1) Total floor area: 43,030 m^2 > 65,690 m^2; 2) Heated floor area: 33,100 m^2 > 36,730 m^2

ENERGY CONSUMPTION: 189.5 > 61.6 $kWh/m^2.y$ (primary energy)

EPC class: D > A

Cité du Grand Parc is a social housing estate in Bordeaux. Located just north of the city centre, it comprises of 3,953 units arranged in high-rise buildings that spread over an area of about 60 ha. The urban layout follows the typical Modernist principles: blocks and towers up to 22-storey high surround a 10-ha urban park, and are in their turn surrounded by 20 ha of green spaces, parking lots and traffic routes.

The Bâtiments GHI - Gounod, Haendel and Ingres are part of this estate. Built in the early Sixties, they comprise of 530 housing units divided as follows: 225 units over 15 floors and 5 entrances in the H and I buildings, and 80 units over 10 floors and 2 entrances in the G building. Apartment types range from one- to four-bedroom apartments, with cellars and storage rooms on the ground floor.

Starting phase of a wider regeneration programme, the project applies many of the strategies first laid out in the PLUS manifesto [Druot, Lacaton & Vassal, 2007]. Definitely rejected the demolition option, the architects opt for leveraging on the buildings' transformation potential.

While on the north façades of the H and I buildings external insulation was fitted to the walls and new double-glazed windows with electric shutters were installed, on the south façade of the H and I buildings, and east and west façades of the G building, winter gardens and balconies were added. Large enough to accommodate different uses, they extended the apartments by complementing them with a 3.8 m deep buffer space that serves multiple purposes.

Besides increasing the floor area of each flat by approximately one-third and giving residents the opportunity to enjoy more daylight and views, winter gardens also improved the thermal performance of the building envelope. Acting as a heat buffer, they significantly contribute to a reduction in primary energy consumption from 190 to 61,6 kWh/m^2.y.

With the aim of reducing as much as possible the duration of the works, the construction technique was based on the use of prefabricated modules, erected like scaffolding around the building envelope. Except for the foundations, no concrete was poured in situ: precast slabs and pillars were transported to the site and lifted into position by means of a crane moving on rails to form a freestanding structure.

On one side of the winter gardens, the original concrete walls were taken down and replaced by new floor-to-ceiling, double-glazed sliding doors. Behind these doors, thermal curtains provide extra insulation to the heated interiors. On the other side, a lightweight façade of transparent, corrugated polycarbonate sheets in aluminium frames was assembled and equipped with reflective solar curtains. Glazed hand railings run along the balconies.

A proper planning and scheduling of the construction site allowed to achieve the transformation in just 12-16 days per apartment: half a day for laying the concrete slab, 2 days for adapting the old façade, 2 days for placing the new façade, and 8-12 days for renovating the interiors (i.e. bathrooms and toilets refurbishment, drying rooms conversion into laundry rooms, electrical system upgrade). To offset the reduction in natural ventilation caused by the new double façade, mechanical ventilation ducts are installed.

Further interventions addressed the buildings common spaces. Entrance halls were renovated, staircases and landings were enclosed. In the H and I buildings, vertical circulation was enhanced with the installation of additional, panoramic elevators. At the ground floor, bicycle premises and stroller rooms were created.

On the top floor of the H and I buildings, 8 new penthouses of about 93 m^2 were built. Almost entirely glazed, with decked terraces and polycarbonate-cladded winter gardens, they offer exceptional living conditions. From there, the views over a city whose buildings rarely exceed four storeys are stunning.

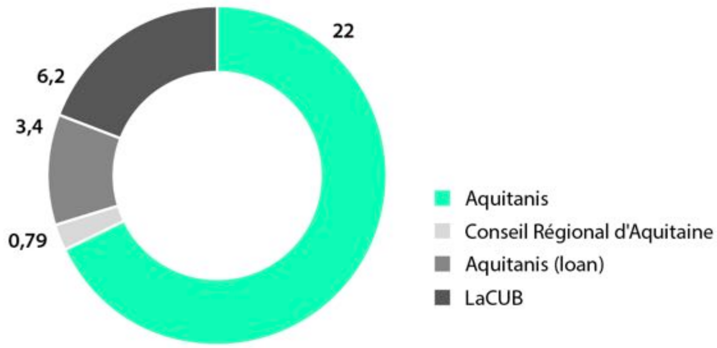


Figure 43: Bâtiments GHI. Funding sources
Source: Aquitanis, 2017

Climate: 2034 heating degree days / 184 cooling degree days

Building energy regulation: RT-Ex Globale
Calculation method: Th-C-E Ex

Table 25: Bâtiments GHI. Building envelope U-values

	U-value before retrofit (W/m^2K)	U-value after retrofit (W/m^2K)
Roof	0.740	0.181
External walls	2.118	0.239
Floor over basement	2.273	0.386
Windows	4.20	1.70

Air exchange rate: not measured / **Air tightness n_{50}**: 1.7
Thermal lag: 0.8

Table 26: Bâtiments GHI. Building energy demand

	Before retrofit ($kWh/m^2.y$)	After retrofit ($kWh/m^2.y$)
Space heating	157.3	33.4
DHW	21.9	21.9
Other	5.5	6.3
Total PE demand	**189.5**	**61.6**
RES production	-	-
PE demand - RES	-	-

Table 27: Bâtiments GHI. Building retrofit costs

	Mio €	€/m²
Renovation	28.35	427
Extension	1.25	970
Total	**29.6**	**437**

Funding sources: €6.2 Mio CUB + €3.4 Mio Aquitanis (own funds) + €22 Mio Aquitanis (loan) + €0.79 Mio Conseil Régional d'Aquitaine = €34.2 Mio or 64,500 €/unit

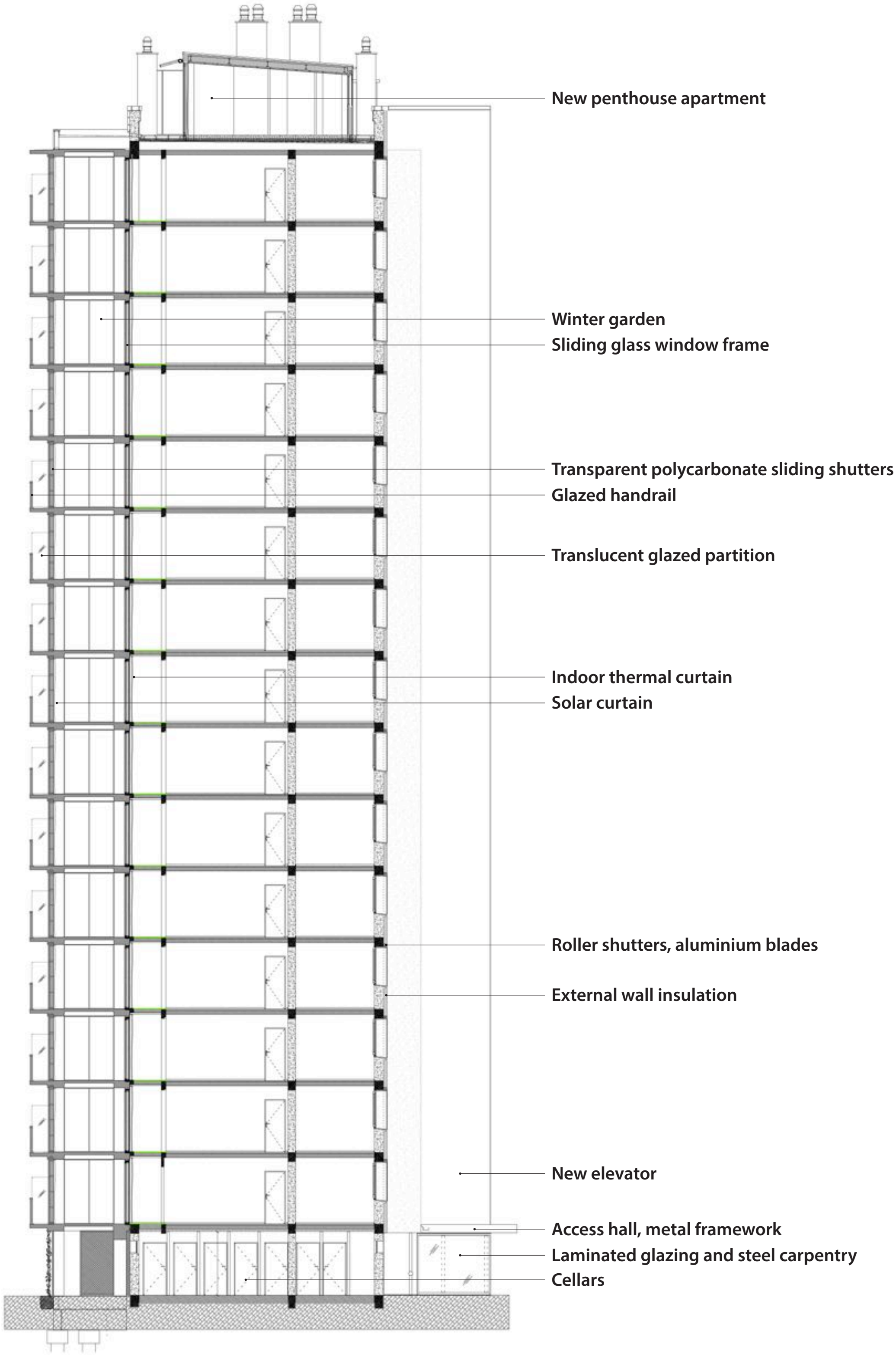


Figure 44: Bâtiments GHI. Section (1:250)
© Lacaton & Vassal, Druot, Hutin

Before retrofit

After retrofit

Figure 45: Bâtiments GHI. Floor plan before and after retrofit (1:250)
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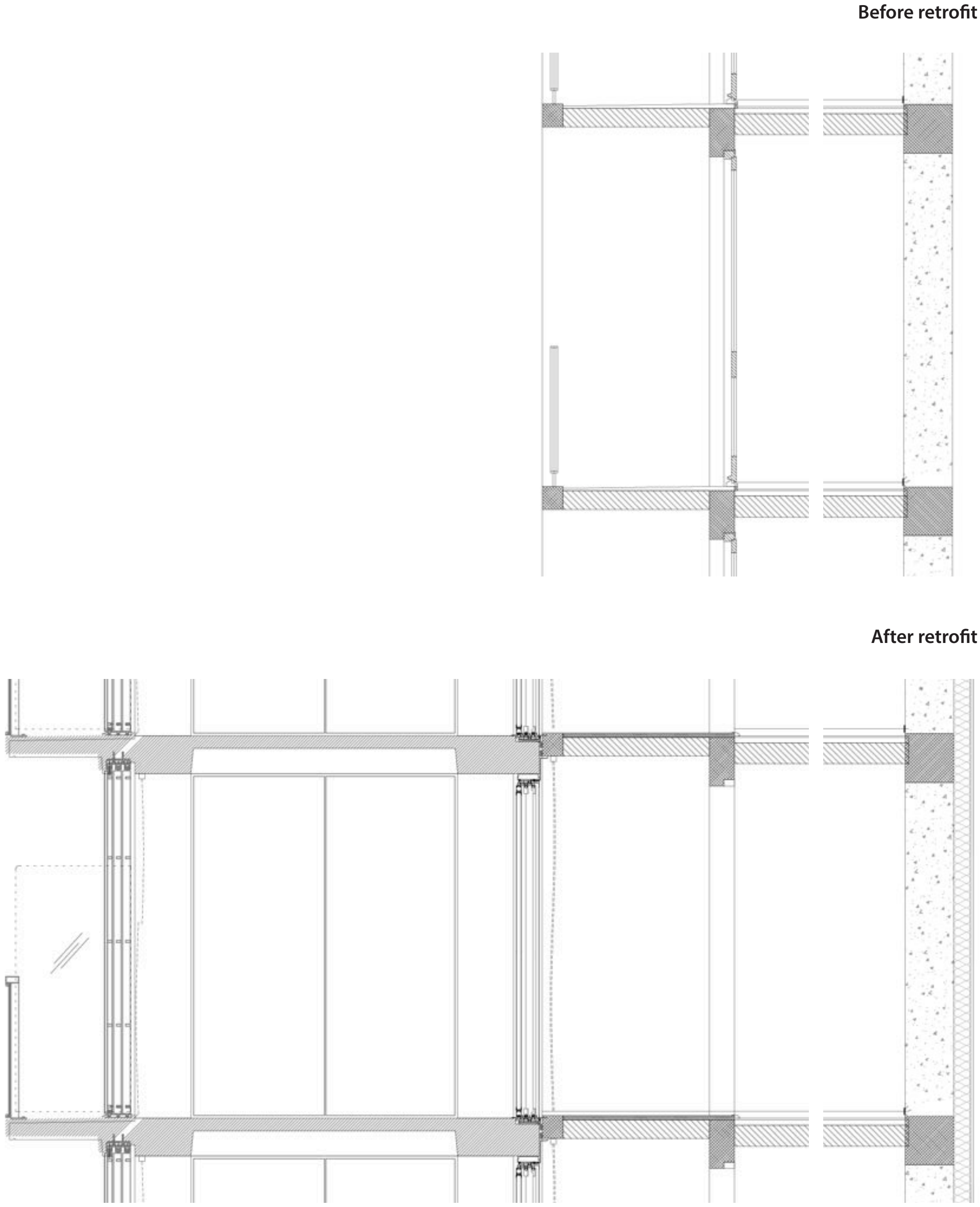


Figure 46: Bâtiments GHI. Construction section through south and north elevations (1:50)
© Lacaton & Vassal, Druot, Hutin

Top: Buildings before retrofit
Bottom: Loggias under construction

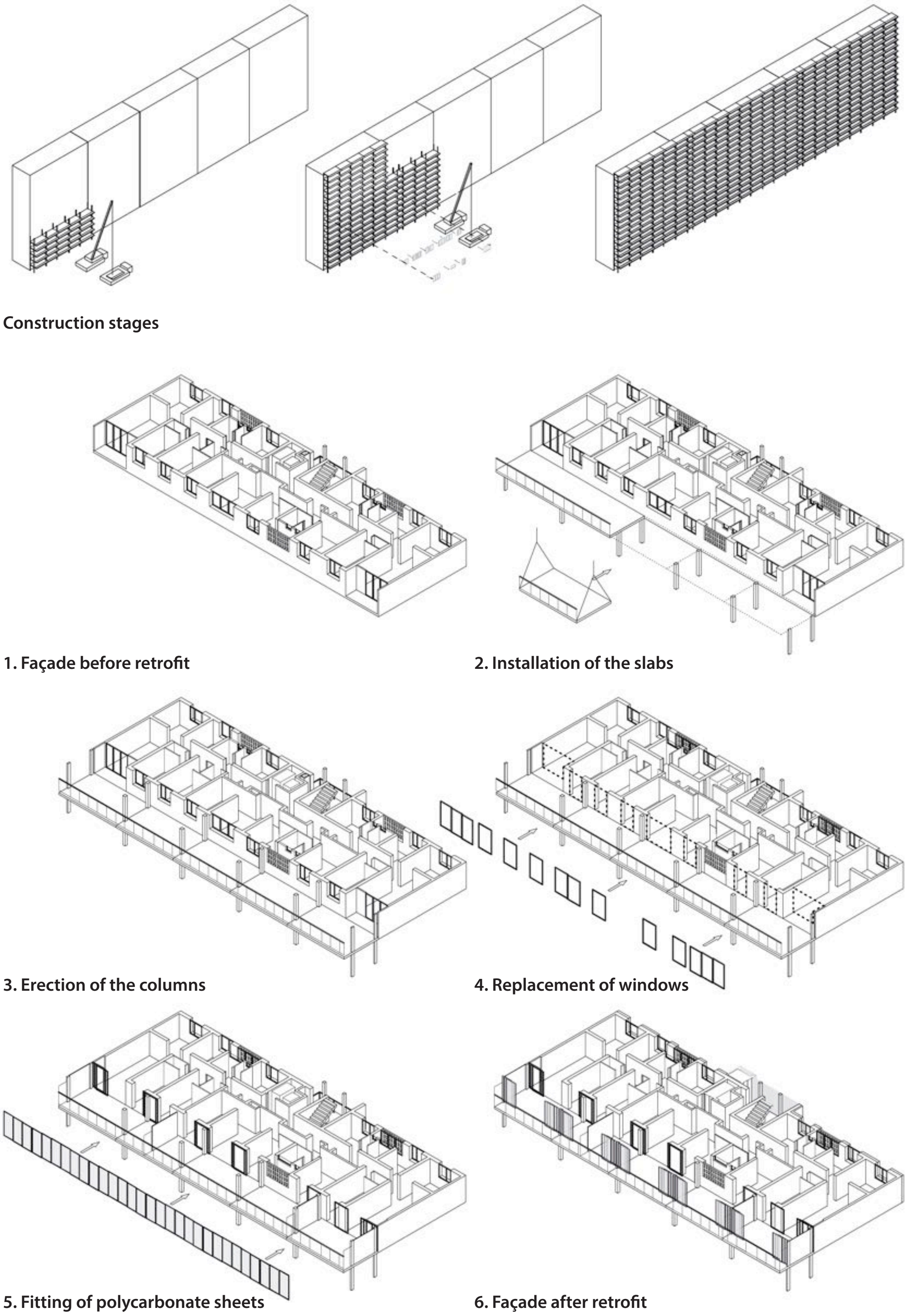
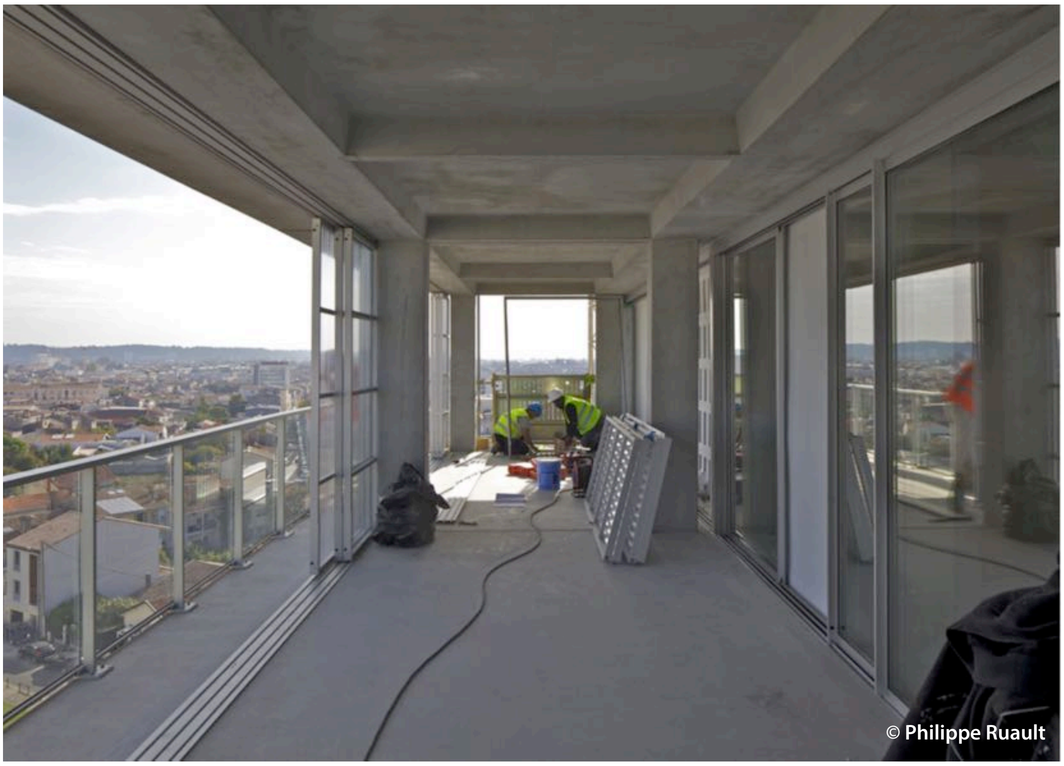
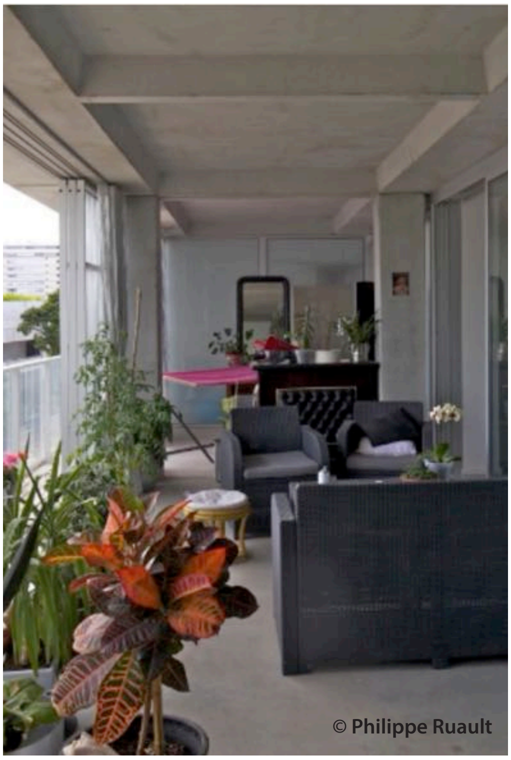
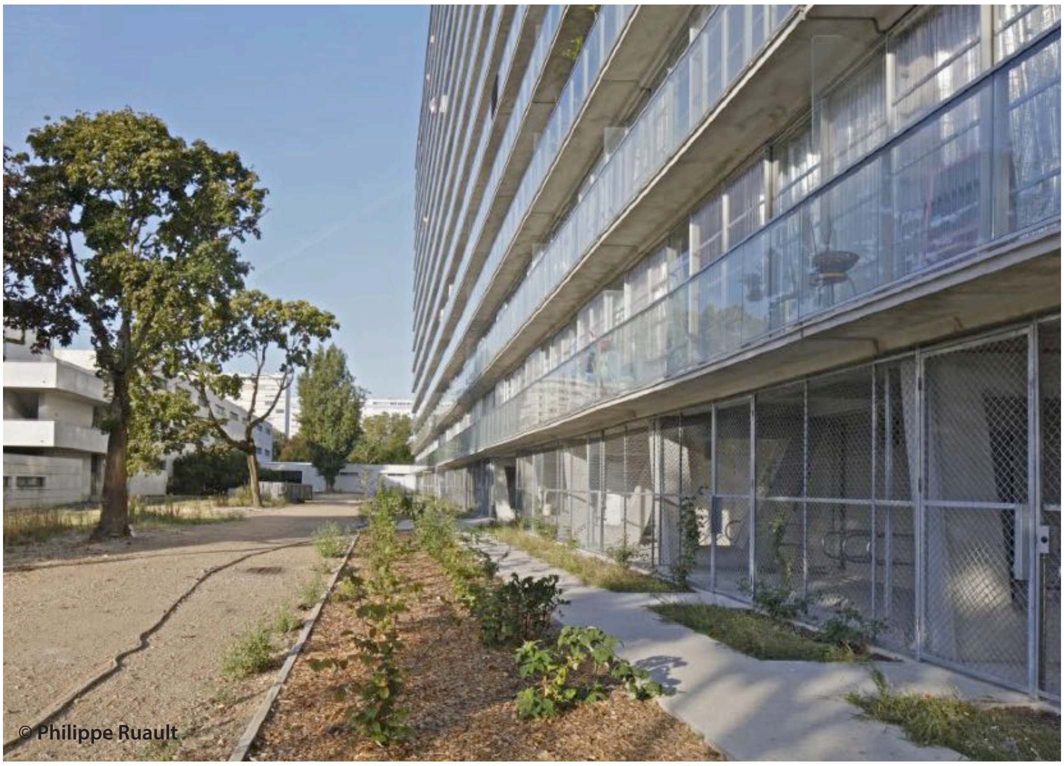


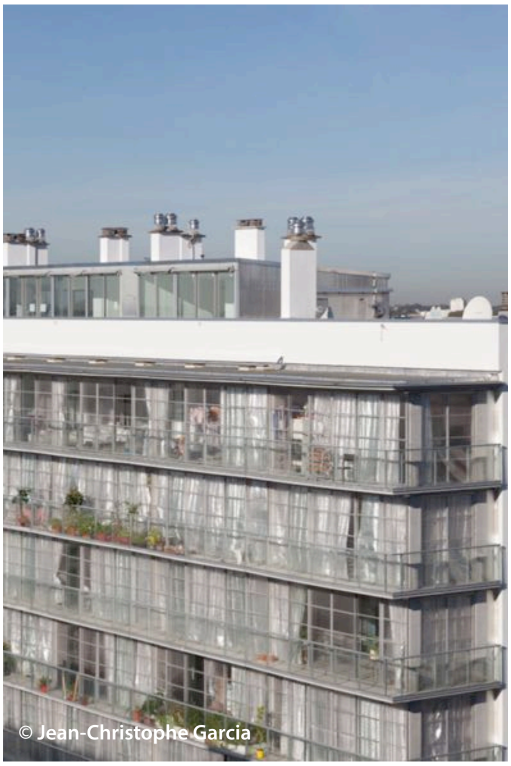
Figure 47: Bâtiments GHI. Construction process diagrams
© Lacaton & Vassal, Druot, Hutin





Top: Loggias during conversion process Bottom left: A furnished loggia.
Bottom right: Views from exterior to interior and from interior to exterior of a typical apartment





Top: View of the ground floor after retrofit
Bottom: South façade after retrofit with winter gardens and balconies

Top and bottom: Interior of the new penthouse apartments on the top of H and I buildings

Chapter 5

Germany

The Federal Ministry of Transport, Building and Urban Development (BMVBS - Bundesministerium für Verkehr, Bau und Stadtentwicklung) and the Federal Ministry for Economic Affairs and Energy (BMWi - Bundesministerium für Wirtschaft und Energie) are the authorities in charge of transposing the EPBD into German legislation.

Since 2002, the reference regulation for the energy performance of buildings is the Energy Saving Ordinance, **EnEV - Energieeinsparverordnung** [EnEV, 2015a]. Enacted on the basis of the Energy Saving Act, **EnEG - Energieeinsparungsgesetz** [EnEG, 2013], it merges together the previous two separate regulations for thermal insulation, Wärmeschutzverordnung, [WärmeschutzV, 1994] and heating systems, Heizungsanlagenverordnung [HeizAnIV, 1994]. A set of DIN standards provides for further technical rules.

It should be noted that, in Germany, the issue of energy saving in buildings is subject to federal legislation, whereas building codes fall under regional legislation [Schettler-Köhler, 2015]. The enforcement of both kind of provisions, instead, is the sole responsibility of the regional governments. The discussion in this chapter focuses on federal initiatives, as these set the boundaries for other authorities.

5.1 EnEV 2014

Last amended in 2013, the current EnEV 2014 applies to building permit applications, for either residential or non-residential buildings, filed after 1 May

2014. Sometimes referred to as EnEV 2014/2016[15], it sets requirements for buildings, building components and technical building systems, prescribes calculation methods and regulates energy performance certificates [BBSR, 2017a; DENA, 2017a].

Renovation and extension of existing buildings are addressed in EnEV Part 3, 'Existing Buildings and Systems'.

According to it, a building renovation is defined as the modification (**Änderung**) of a building envelope component that exceeds 10% of the total building area of the same component. If so, two alternative compliance approaches are possible:

- a 'component approach', whereby the modified component does not exceed the requirements for newly placed or replaced components;
- a 'whole-building approach', whereby the modified building does not exceed the requirements for newly constructed buildings by more than 40%.

If not (i.e. if less than 10% of the total building area of the component is concerned, and the threshold is not exceeded), no specific requirements are imposed by the EnEV: only technical specifications and DIN standards must be complied with.

A building extension/expansion (**Erweiterung und Ausbau**), instead, is defined as an addition of heated and/or cooled spaces to an existing building. Depending on the usable floor area of the addition (larger or smaller than 50 m^2), and on the presence or not of a heat generator, different requirements apply to the envelope. As illustrated in Figure 48, these range from compliance with the 'component approach' (e.g. extensions without a new heat generator and less than 50 m^2 of added space) to compliance with the 'whole-building approach', as applied to the construction of new buildings (e.g. extensions with a new heat generator and more than 50 m^2 of added space).

[15] As of 1 January 2016, a strengthening factor of 0.75 applies to the annual primary energy demand of all new building permit applications. After that date, the Q_P of a building constructed according to the 'whole-building approach' may not exceed 75% of the primary energy demand of the reference building. This does not apply in the case of renovation or extension of existing buildings.

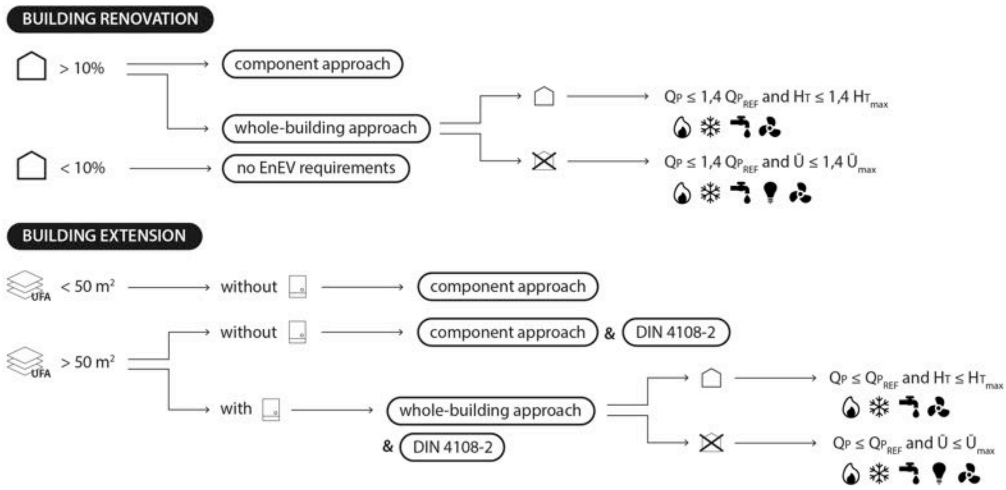


Figure 48: EnEV 2014. Compliance options

As regards the ‘component approach’, requirements are expressed in terms of maximum Heat Transfer Coefficients (**U_{max} - Höchstwerte der Wärmedurchgangskoeffizienten**). For each of the components that form part of the building envelope, the EnEV prescribes limit U-values that must not be exceeded by the component concerned. Depending on the building use and indoor temperature, U-values are as in Table 28.

As regards the ‘whole-building approach’, requirements are regulated by two main metrics [Galvin & Sunikka-Blank, 2013]:

- the Transmission Heat Loss (**H_T - Transmissionswärmeverlusts**) or Heat Transfer Coefficient (**Ū - Wärmedurchgangskoeffizienten**), for residential or non-residential buildings respectively, that is the measure of the rate of transmission heat loss through the building envelope (expressed in W/m^2K);
- the Annual Primary Energy Demand (**Q_P - Jahres-Primärenergiebedarf**), that is the estimated measure of primary energy required by a reference building of the same geometry, floor area, orientation and use, but whose technical features are defined according to EnEV specifications (expressed in $kWh/m^2.y$).

Table 28: EnEV 2014. Maximum heat transfer coefficients

Building envelope component	**U_{max} (W/m^{2}K)**	
	Residential buildings and zones of non-residential buildings with target indoor temperature ≥ 19°C	**Zones of non-residential buildings with target indoor temperature 12 - 19°C**
Exterior walls	0.24	0.35
Ceilings, roofs, attics	0.24	
Flat roofs	0.20	1.9
Windows	1.3	
Exterior doors	1.8	
Skylights	1.4	1.9
Windows and doors with folding, sliding, or lifting mechanism	1.6	1.9
Walls and ceilings against unheated rooms or ground	0.24 - 0.3	-

In the case of residential buildings, Q_P measures the annual primary energy demand for heating, domestic hot water, cooling and ventilation, and H_T corresponds to the maximum values of the specific transmission heat loss related to the type of building (ranging from 0.40 to 0.65 W/m^{2}K). In the case of non-residential buildings, Q_P measures the annual primary energy demand for heating, domestic hot water, cooling, lighting and ventilation, and $\bar{U}$ corresponds to the maximum values of the average heat transfer coefficient related the type of envelope components (ranging from 0.35 to 3.1 W/m^{2}K).

Maximum H_T and $\bar{U}$ values are given in Table 29 and Table 30 respectively.

For the calculation of Q_P values in residential buildings, the EnEV provides a choice between two methodologies:

- DIN V 4108-6:2003-06 along with DIN V 4701-10:2003-08 and DIN V 4701-12:2003-06;
- or the more recent DIN V 18599-1:2016-10.

Laid down by the German Institute of Standards (DIN - Deutsches Institut für Normung), both methodologies calculate the building primary energy demand using monthly quasi-steady state methods, but whereas the first applies a simplified approach, the second offers a much more comprehensive approach. In

DIN V 18599, the zoning of the building, and the iterations between different zones and systems, results in realistic values also for complex buildings.

Table 29: EnEV 2014. Maximum specific transmission heat loss in residential buildings

Type of building	Maximum H_T (W/m^2K)	
Detached residential building	$A_N \leq 350\ m^2$	0.40
	$A_N > 350\ m^2$	0.50
Semi-detached residential building		0.45
All other residential buildings		0.65
Extensions of residential buildings		0.65

Table 30: EnEV 2014. Maximum average heat transfer coefficient in non-residential buildings

Building envelope component	Maximum Ū (W/m^2K)	
	Zones with target indoor temperature ≥ 19°C	Zones with target indoor temperature 12 - 19°C
Opaque exterior components	0.35	0.50
Transparent exterior components	1.90	2.80
Curtain walls	1.90	3.00
Glass roofs, light bands, dome lights	3.10	3.10

For non-residential buildings, DIN V 18599 is the only acceptable method. A simplified (single-zone) method is nevertheless possible in buildings that meet specific limitations of size and use.

To perform the calculations, different tools have been made available to professionals. When applying DIN V 4108-6 and DIN 4701-10, calculations can be done either by hand or with the help of 'EnEV-XL', a software developed by the IWU - Institut Wohnen und Umwelt. When applying DIN 18599, the choice is between two tools by the Fraunhofer IBP - Institut für Bauphysik: a freeware based on Microsoft Excel, or the 'IPB:18599', a commercial software developed in partnership with a private IT company.

For proof of compliance, the same calculation method must be applied to both the reference and real building.

Irrespective of the abovementioned calculation methods, a proof of minimum summer heat protection (**Mindestanforderungen an den sommerlichen Wärmeschutz**) should also be provided for building extensions of more than 50 m^2. According to DIN 4108-2:2013-02, the requirement is deemed to be met in all buildings where:

- the window-to-floor ratio does not exceed 35% for the critical room;
- windows and glazed conservatories facing from east to west, via south, are equipped with solar shading devices with a reduction factor FC ≤ 0.30.

If these conditions are not verified, then the summer heat protection requirement must be satisfied by either limiting the solar irradiation indicators or reducing the over-temperature degree hours.

As far as existing buildings are concerned, the EnEV contains also a number of compulsory retrofitting measures (**Nachrüstpflichten**), that is mandatory upgrades which must be fulfilled by building owners within a specific timeframe, even without any renovation work taking place [Schettler-Köhler, 2015].

With reference to the building envelope components, only one compulsory measure applies. By the end of 2015, top floor ceilings of rooms located below unheated attics or the roof above, that do not comply with the minimum thermal insulation requirements (i.e. U-Value ≤ 0.24 W/m^2K) must be insulated according to DIN 4108-2. Further measures regard the replacement of boilers that are more than 30 years old, and the insulation of heating and hot water pipes in unheated spaces.

Exemptions apply to one- and two-family residential buildings, continually occupied by the owner since the reference date of 1 February 2002. In these cases, the obligation only arises two years after the first change of ownership.

5.2 KfW-Förderprogramme and KfW-Effizienzhaus-Standard

Requirements and obligations of EnEV are associated with grants and soft loans from the KfW- Kreditanstalt für Wiederaufbau, the German government-owned development bank which runs the well-known KfW-Energieeffizienzprogramm.

Introduced in April 2009[16], the **KfW-Förderprogramme 'Energieeffizient Sanieren'**, Energy-Efficient Refurbishment programme in English, provides

[16] Superseding the former CO_2 Building Rehabilitation programme (CO_2 Gebäude Sanierungsprogramm), started in 2001 and closed by March 2009.

funds to builders and building owners investing in the energy-efficient refurbishment of an existing residential building, the purchase of a newly refurbished one, or the change of use from non-residential to residential space [KfW, 2017f]. It applies to single- and multi-family houses whose building application has been submitted before 1 February 2002 and requires the involvement of an energy efficiency expert[17] to validate the application process.

Under this programme, the amount of the funding depends both on the type of refurbishment and the type of financing (Table 31).

Table 31: KfW-Förderprogramme 'Energieeffizient Sanieren'

	Soft loan	**Grant**
KfW-Effizienzhaus 55	27.5% up to €27,500	30% < €30,000
KfW-Effizienzhaus 70	22.5% up to €22,500	25% < €25,000
KfW-Effizienzhaus 85	17.5% up to €17,500	20% < €20,000
KfW-Effizienzhaus 100	15.0% up to €15,000	17,5% < €17,500
KfW-Effizienzhaus 115	12.5% up to €12,500	15,0% < €15,000
KfW-Effizienzhaus Denkmal	12.5% up to €12,500	15,0% < €15,000
Heating and Ventilation Packages	12.5% up to €6,250	15,0% < €7,500
Individual measures	7.5% up to €3,750	10,0% < €5,000

With respect to the type of refurbishment, funded projects are divided into:

- comprehensive refurbishments into a **KfW-Effizienzhaus** (KfW-EH);
- individual refurbishment measures (**Einzelmaßnahmen**), and packages (**Maßnahmenpaketen**).

In case of comprehensive refurbishments, funds are directed to refurbished buildings achieving one of the voluntary KfW-Effizienzhaus standards.

KfW-Effizienzhaus is the technological standard introduced in 2009 by the KfW to run its promotional programmes [KfW, 2017b]. It covers both new and

[17] Selected from the Energieeffizienz-Expertenliste für Förderprogramme des Bundes, listed at www.energie-effizienz-experten.de.

existing residential buildings, setting different thresholds of annual primary energy demand (Q_P) and transmission heat loss (H_T) reduction, measured against a comparable house meeting the regulatory requirements for new-builds established in the EnEV 2009 (Table 32). The better the building energy performance, the higher the standard (or the lower the figure), and the greater the financial support.

The standards defined by KfW in relation to refurbishments are six: the KfW-Effizienzhaus 55, 70, 85, 100 and 115, plus a separate standard for listed historic buildings (i.e. the KfW-Effizienzhaus Denkmal), set at 160.

KfW-EH 100 level is used as benchmark, being equivalent to the annual primary energy demand and transmission heat loss of a new building with the same geometry, floor area and orientation. All the other levels are expressed as the percentage of primary energy required by the assessed building with respect to the benchmark. For instance, a KfW-EH 70 only uses 70% of the primary energy required by a KfW-EH 100 and is affected by 85% of its transmission heat losses, while a KfW-EH 115 uses 15% more of the primary energy required by a KfW-EH 100 and is affected by 130% more of its transmission heat losses.

Table 32: KfW-Effizienzhaus standards

Standard	Q_P	H_T
KfW-Effizienzhaus 55	55%	70%
KfW-Effizienzhaus 70	70%	85%
KfW-Effizienzhaus 85	85%	100%
KfW-Effizienzhaus 100	100%	115%
KfW-Effizienzhaus 115	115%	130%
KfW-Effizienzhaus Denkmal	160%	-

In case of individual refurbishment measures and packages, funds are directed to, single or multiple, building component improvements meeting minimum technical requirements [KfW, 2017a]. Eligible individual measures include:

- thermal insulation of walls, roof, and floors;
- renovation of windows and doors;
- renovation or optimization of the heating system;
- renovation or installation of the ventilation system.

Besides these, the following refurbishment packages are possible:

- the ‘heating package’ (**Heizungspaket**), consisting of the installation of a new heating system and optimisation of the heat distribution system;
- the ‘ventilation package’ (**Lüftungspaket**), consisting of the installation of a new ventilation system, plus at least one eligible measure on the building envelope.

With respect to the type of financing, two forms of financial support are possible: soft loans including a grant element (**Kredit 151/152**), or investment grants (**Investitionszuschuss 430**).

In case of soft loans [KfW, 2017d], applicants are provided with low-interest loans covering up to 100% of their investment, with a maximum of €100,000 for KfW-Efficiency House (Kredit 151), or €50,000 for individual measures and packages (Kredit 152), per housing unit. A grant element (Tilgungszuschuss), ranging from 7,5 up to 27,5% of the credit amount, is deducted from the original debit.

Payback periods range from 4 to 30 years, with up to 5 repayment-free start-up years. The interest rate is fixed for the first 10 years of the loan (0,75% effective interest rate) and then adjusted.

Loan applications are processed via local commercial banks and insurance companies, which assume liability on behalf of KfW. Grant elements are paid to the applicant bank account.

In case of investment grants [KfW, 2017e], applicants benefit from a grant covering from 10 up to 30% of the eligible costs, with a maximum of €100,000 for KfW-Efficiency House, or €50,000 for individual measures and packages, per housing unit.

Grant applications are submitted to the KfW, through the online portal. Upon completion of the refurbishment, applicants must hand in all relevant information to KfW, which reserves the right to conduct spot checks. The grant amount is then paid by KfW to the applicant bank account.

Provided that some conditions are respected (e.g. that the amount of funding does not exceed the eligible costs), the combination with other public funding is possible. In particular, this is the case for advice from a building energy consultant. For such a consultation, additional funding might be provided in the form of a grant for construction support and supervision (**Zuschuss für Baubegleitung 431**) [KfW, 2017c]. The non-repayable grant amounts to 50% of the eligible costs, with a maximum of €4,000 per project.

Applications must be submitted by post to KfW once the consultation has been completed, but before the refurbishment works have started.

At least from a numbers point of view, the success of the KfW promotional programmes is indisputable. According to the annual monitoring report [Diefenbach et al., 2018], in 2016 about 276,000 housing units benefitted from a KfW grant or loan, bringing up the total number of retrofitted units to 2.6 million, that is about 7% of the German total housing stock.

Nevertheless, about 80% of the renovations funded concern individual building components, while only 20% of them reach a KfW- Effizienzhaus standard.

5.3 Individuelle Sanierungsfahrplan

Starting from 1 July 2017 the Individual Building Renovation Roadmap (**iSFP - individuelle Sanierungsfahrplan für Wohngebäude**) has been made available to home owners and energy consultants as a voluntary tool for building renovations [DENA, 2017b]. Developed by the BMWi, in cooperation with the Federal Office for Economic Affairs and Export Control (BAFA - Bundesamt für Wirtschaft und Ausfuhrkontrolle), and an external consortium composed by the German Energy Agency (dena - Deutsche Energie-Agentur), the Institute for Energy- and Environmental Research Heidelberg (ifeu-Heidelberg - Institut für Energie- und Umweltforschung Heidelberg), and the Passivhaus Institut (PHI), it consists in a software-based tool specifically conceived to support the step-by-step rehabilitation (Schritt-für-Schritt Sanierung) of existing buildings.

Drawing on previous experience[18], the iSFP offers a well-structured and standardized way to present the results of energy consulting for privately-owned residential buildings, both single- or (small) multi-family. By means of easy to understand language and graphics, it enables consultants to convey to owners the results of their consultations and technical elaborations in a user-friendly format [Fabbri et al., 2016].

Distinctive feature of the iSFP tool is the use of colour classes (**Farbklassen**) to represent the energy performance of building components (i.e. walls, roof, floor, windows, heating, DHW, heating distribution, ventilation), and of the building as a whole. Though with differences in values and units, all the scales follow the same rationale: from dark green (highest efficiency level, even in the foreseeable future) to dark red (lowest efficiency level), with each of the seven classes corresponding to a lower level of efficiency (Table 33).

[18] In particular, the 'Sanierungsfahrplan-BW' by the UM - Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg [UM Baden-Württemberg, 2017], a first pilot of individual building renovation roadmap launched at the state level in 2015.

As a general rule, the target of the renovation measures should be the achievement of the dark green class. If this is not possible, the Best Possible Principle (**Best-Möglich-Prinzip**) applies: in this case, the target class can be lowered to the extent required for achieving the optimal final result. Below the second-best colour class, standing for the level of KfW individual measures, reasons for deviation must be explained.

Reference materials for consultants are the Handbook for Energy Advisors [BMWi, 2017b], the Quick Guide to iSFP [BMWi, 2017c] and the Checklist [BMWi, 2017a].

Table 33: iSFP. Farbklassen thresholds

Farbklasse	Primary energy demand	Class description
	≤ 30 kWh/m^2.y	EH Plus; EH 55; PassivHaus; Renovated buildings, KfW-individual measures
	≤ 60 kWh/m^2.y	EH 70; EH 85; New buildings, EnEV 2014 from 1 January 2016; Renovated buildings EnEV 2014, Appendix 3, Table 1
	≤ 90 kWh/m^2.y	EH 100; EH 115; New buildings, EnEV 2002/2009; Renovated buildings, EnEV 2002, Appendix 3, Table 1; Renovated buildings, EnEV 2014, 140% rule
	≤ 130 kWh/m^2.y	Partially renovated buildings from WärmeschutzV 1995
	≤ 180 kWh/m^2.y	Partially renovated or non-renovated buildings before WärmeschutzV 1995
	≤ 230 kWh/m^2.y	Partially renovated or non-renovated buildings before WärmeschutzV 1984
	> 230 kWh/m^2.y	Partially renovated or non-renovated buildings before WärmeschutzV 1978

Outputs of the process are two booklets in PDF format.

The 'My Renovation Roadmap' (**Mein Sanierungsfahrplan**) summarizes the main knowledge about the present and future status of the building, and offers an overview of the renovation process in a fixed number of pages [BMWi, 2017d]. Out of the whole document, the most important contents are the energy assessment of the building and building components (according to the current EnEV), and the graphic representation of the Sanierungsfahrplan (Figure 49).

This last consists in a tailor-made schedule of the implementation steps, with broad instructions on when and how to implement measures with respect to the overall renovation concept, and basic information about final and primary energy demand, energy costs, and carbon emissions. Suggestions on how to save energy during operation by changing behaviour are also included.

The ‘Implementation Guide’ (**Umsetzungshilfe für meine Maßnahmen**), instead, provides details on the renovation measures and packages [BMWi, 2017e]. It illustrates each package of measures (Maßnahmenpaket) by means of data, technical descriptions, free-text fields, icons, pictures and diagrams (Figure 50). No formal indicators of comfort (e.g. noise or indoor air quality) are included, with the comfort level being assessed only in a qualitative way, in terms of the expected benefits that the occupant will gain after the building renovation (i.e. ‘warmer feet’ or ‘better light’) [Fabbri et al., 2018].

Cost estimates and foreseeable subsidies are also taken into account. The costs of each measure and package of measures are estimated and their average annual total cost calculated over a period of 20 years. Summary tables and diagrams allow for direct comparison between the maintenance and renovation (with or without subsidies) options.

At the owner’s request, information about financing may be included.

Figure 49: iSFP. Mein Sanierungsfahrplan
Left: Building assessment before renovation. Right: Renovation roadmap overview

Although devised to support ‘step-by-step’ renovations, the iSFP can also be used in case of ‘all-at-once’ renovations (Gesamtsanierung). Only slight differences exist between the booklets in the two cases.

Since the iSFP fulfils the criteria of the BAFA On-site Energy Advice (**BAFA-Vor-Ort-Beratung**), it can be submitted for funding under the related programme [BAFA, 2017]. BAFA pays up to 60% of the eligible consultation costs, with a maximum of €800 for one- or two-family homes, and €1,100 for apartment buildings with three or more units. Additional €500 are allocated to housing owners' associations if the report is presented at an owners' meeting.

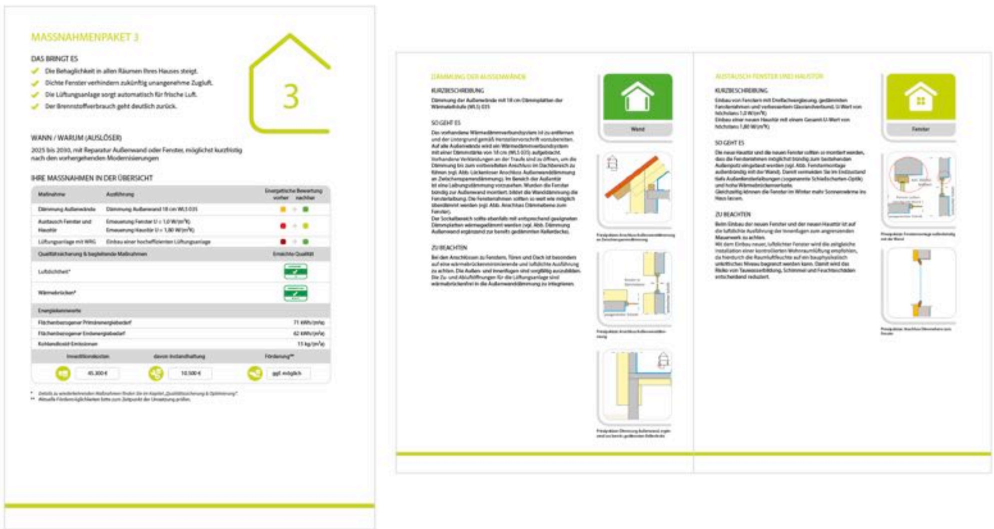


Figure 50: iSFP. Umsetzungshilfe für meine Maßnahmen
Package of measures with recommendations

5.4 Energieausweis

In Germany, the regulation on energy performance certification of buildings has been laid down as part of the EnEV Part 5 [EnEV, 2015a]. Before the EPBD came into effect, energy certificates for new buildings were already enforced by earlier ordinances since 1995 but it is with the issuance of the EnEV 2007 that EPCs have been introduced also for renting or sale of existing buildings, and for certain public buildings [BBSR, 2017b].

The issue of the relevant certificate has become mandatory since 1 July 2008 for residential buildings built until 1965, since 1 January 2009 for all other existing residential buildings, and since 1 July 2009 for existing non-residential buildings. New buildings and major renovations require an EBA certificate (see below) from 1 October 2007. Private buildings of more than 500 m^2 which are frequently visited by public are subject to a duty to display the EPC.

While transposing the European directive, the German government opted for a so-called 'dual system' (Figure 51), which foresees the coexistence of certificates based either on an energy demand- or consumption-based assessment method

[Schettler-Köhler, 2015]. Depending on the building use, size and construction year, two different types of EPCs (**EA - Energieausweise**) are then possible:

- the Energy Demand Certificate (**EBA - Energiebedarfsausweis**) based on calculated energy demand, to be necessarily issued in case of new residential and non-residential buildings, or existing residential buildings which have less than 5 units and for which the building application has been filed before 1 November 1977;
- the Energy Consumption Certificate (**EVA - Energieverbrauchsausweis**) based on measured energy consumption, to be alternatively issued in case of existing non-residential buildings, and residential buildings which have at least 5 units or for which the building application has been filed after 1 November 1977.

For existing residential buildings which have less than 5 units and where the building application has been filed before 1 November 1977 but that already complied with the requirement level of the Thermal Insulation Ordinance of 11 August 1977 (WSVO - Wärmeschutzverordnung 1977) upon completion or through later renovation, the EVA is also allowed.

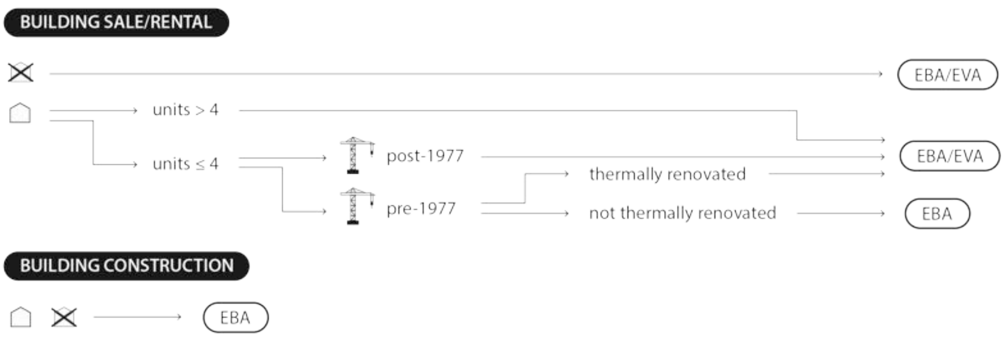


Figure 51: Types of EA in case of sale/rental and construction

To convey the energy rating, the EBA uses the Q_P value, determined by the energy performance of the building elements and installations, expressed in primary energy consumption. The EVA (uses a measured value, determined by the average energy consumption of the last three years' energy bills for heating and water heating (plus electricity in non-residential buildings), adjusted for weather conditions. It follows that while the EBA, is based on standard assumptions for climate and usage, the EVA is influenced by users' behaviour patterns and local weather conditions.

The CO_2 emission rating is optional.

With the EnEV 2014, the certificate changed significantly and different EPC formats were introduced [EnEV, 2015b; EnEV, 2015c]. Each certificate consists of five pages: page 1, contains information about the building, the assessment method and the assessor; page 2, shows the rating in case of calculated energy demand (Table 34); page 3, shows the rating in case of metered energy consumption; page 4, includes recommendations for cost-effective modernisation; page 5, provides explanations about the values and scales used in the certificate.

Table 34: Energieausweis classes (kWh/m^2.y)

Label	Residential buildings	Non-residential buildings
A+	≤ 30	0
A	≤ 50	
B	≤ 75	
C	≤ 100	
D	≤ 130	sliding scale
E	≤ 160	
F	≤ 200	
G	≤ 250	
H	> 250	> 1000

CASE #7
Grüntenstraße 30-36 | lattkearchitekten

Renovation (in occupied site) of 60 housing units in two different buildings with prefabricated large-sized timber framed elements.

LOCATION: Grüntenstraße 30-32 & 34-36, Augsburg - 48°21'20.5"N, 10°57'00.2"E

DATE: 1966, construction; 2009-2010, competition; Jun 2011 - May 2013, renovation

CLIENT: WBG - Wohnungsbaugesellschaft der Stadt Augsburg GmbH

DESIGN TEAM: lattkearchitekten (mandatory architect), bauart Konstrucktions GmbH & Co. KG (structural engineering), Emminger & Nagies Landschaftsarchitekten (landscape architect), IB Ulherr, IB Trieb and Rebholz Ingenieure (building systems engineering), Gumpp & Maier GmbH (façade manufacturer)

BUDGET: 5.06 Mio EUR excl. VAT

AWARDS: 2010, Wohnen in Bayern. Experimenteller Wohnungsbau (first place); 2012, Bayerischer Energiepreis (third place); 2013, Holzbau Plus Preis - Kategorie ‘Wohnungsbau Sanierung’ (first place); 2013, Deutscher Holzbaupreis 2013 (special mention); 2013, Deutscher Bauherrenpreis für Modernisierung; 2014, Hans-Sauer-Preis - ‘Kategorie Bestand’; 2015, Thomas Wechs Preis

PLOT SIZE: 6,291 m^2

BUILDING SIZE: 1) Total floor area: 7,124 m^2 > 7,730 m^2; 2) Heated floor area: 5,167 m^2 > 5,344 m^2

ENERGY CONSUMPTION: 246 > 70 kWh/m^2 (primary energy)

EPC class: G > A

Other LABELS: KfW-EH 70

Grüntenstraße 30-36 is a two-building social housing complex located in the south-east of Augsburg. Built in 1966, it comprises of 60 units divided as follows: Grüntenstraße 30-32, 12 units over 3 storeys and Grüntenstraße 34-36 (870 m^2 floor area), 48 units over 6 storeys (3,629 m^2). Apartments range in size and layout from about 35 to 100 m^2 and from 1 to 5 rooms, offering a wide mix of typologies.

In 2009, the participation as a demonstration site to the E2ReBuild research project[19] became an opportunity for the design team to develop an exemplary project, characterized by a high transferability potential.

For the building envelope, a prefabricated element system based on 'TES Timber Element System EnergyFaçade' was employed.

By adopting this system, the whole building was wrapped in large-sized timber framed panels (maximum size: 3.4 m height and 12 m length), with mineral wool being used only where technically unavoidable, e.g. in the exterior corridors.

Produced off-site-on the basis of a tachymetric survey, the panels combine a self-supporting structure with an infill of thermal insulation (cellulose fibre), inner (OSB board) and outer panelling (gypsum fibre board), cladding (spruce boards) and coating (white silicate paint). Triple-glazed windows with wood-aluminium frames ($U = 0.98\ W/m^2K$) were integrated as well.

Thanks to the high degree of prefabrication, construction time was drastically reduced, with on-site works limited to assembly and some preliminary operations. Additional concrete strip foundations carry the vertical loads, while anchoring wooden beams transfer the horizontal loads to the ceiling slabs. A soft adaptation layer of blown-in cellulose fibre compensate for possible deviations between the panels and walls.

On the south façade, the existing balconies were converted into winter gardens by partly removing side walls and balustrades, and integrating the cantilevered concrete slabs into the heated volume of the building to break thermal bridges. Enclosed by floor-to-ceiling glazed sliding doors, they extended the interiors by adding about 6,50 m^2 of extra space to living rooms and, at Grüntenstraße 34-36 only, providing access to the new loggias that have been created between the former balcony structures. Weather protected venetian blinds mitigate overheating.

[19] E2ReBuild - Industrialised energy efficient retrofitting of residential buildings in cold climates is a research project financed under the EU Seventh Framework Programme (FP7/2007-2013) that investigates innovative solutions in industrial construction processes for retrofitting.

On the north façade, exterior corridors were renovated: concrete was repaired and parapet walls were replaced with steel hand railings and glass panels. At Grüntenstraße 34-36, newly installed elevators ensure barrier-free access to all units. Roofs were waterproofed and the concrete ceiling over the unheated basement was insulated from the underside with 10 cm of EPS insulation.

Inside the apartments, bathrooms were fully refurbished, ductwork and vertical shafts included. For the convenience of the tenants, a container unit with toilets was installed in the courtyard for the duration of the works.

Outside, landscaping and gardening works complete the project. In particular, the ground levelling of the rear side of Grüntenstraße 34-36 bridged the difference in height between the street and the yard levels. A paved surface fills the former pit, converting it into an attractive open space.

In order to maximise energy efficiency, the highly insulated envelope was complemented by upgraded technical building systems and installations. A central wood pellet heating plant replaces the old gas boilers. A cellar in Grüntenstraße 34-36 accommodates the plant and pellet storage, while ground pipes transfer the heat and hot water to Grüntenstraße 30-32. A mechanical ventilation system was also installed. Fresh air inlets and exhaust air valves, pre-fitted into the panels, connect to the ventilation units placed on the roofs of the respective buildings.

Through the seamless application of TES EnergyFaçade elements, both blocks were given a thermal bridges-free and air-tight envelope, with a U-value of 0.11 W/m^2K. The KfW-Effizienshaus 70 standard was achieved and a primary energy requirement of 70 $kWh/m^2.y$ reached. Noise protection was also enhanced.

After the renovation, the monthly rent registered only a slight increase (Figure 52), the most of it being offset by the lower heating and maintenance costs.

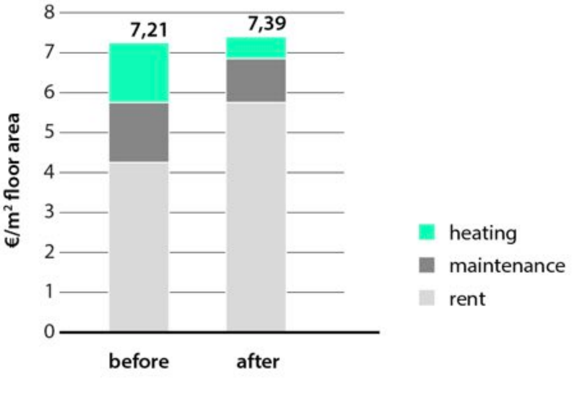


Figure 52: Grüntenstraße 30-36. Monthly rent costs before and after retrofit
Source: Lattke & Boonstra, 2014

Climate: 3872 heating degree days (Augsburg, 2017)

Building energy regulation: EnEV 2009
Calculation method: DIN 18599

Table 35: Grüntenstraße 30-36. Building envelope U-values

	U-value before retrofit (W/m^2K)	U-value after retrofit (W/m^2K)
Roof	0.38	0.38
External walls	1.16	0.13
Floor over basement	unknown	0.24
Windows	1.3 U_w	0.98 U_w - 0.6 U_g

Air exchange rate: not measured / **Air tightness n_{50}**: not measured

Table 36: Grüntenstraße 30-36. Building energy demand

	Before retrofit ($kWh/m^2.y$)	After retrofit ($kWh/m^2.y$)
Space heating	157	27
DHW	89	12
Auxiliaries (pumps)	-	5
Losses	-	26
Total PE demand	**246**	**70**
RES production	-	-
PE demand - RES	-	-

Table 37: Grüntenstraße 30-36. Building retrofit costs

	Mio €	€/m^2
Interiors	0.56	117
Envelope	1.53	323
Technical building systems	1.40	296
Landscaping	0.14	30
Other	1.43	303
Total	**5.06**	**1,069**

Funding sources: KfW Energy-Efficient Refurbishment programme

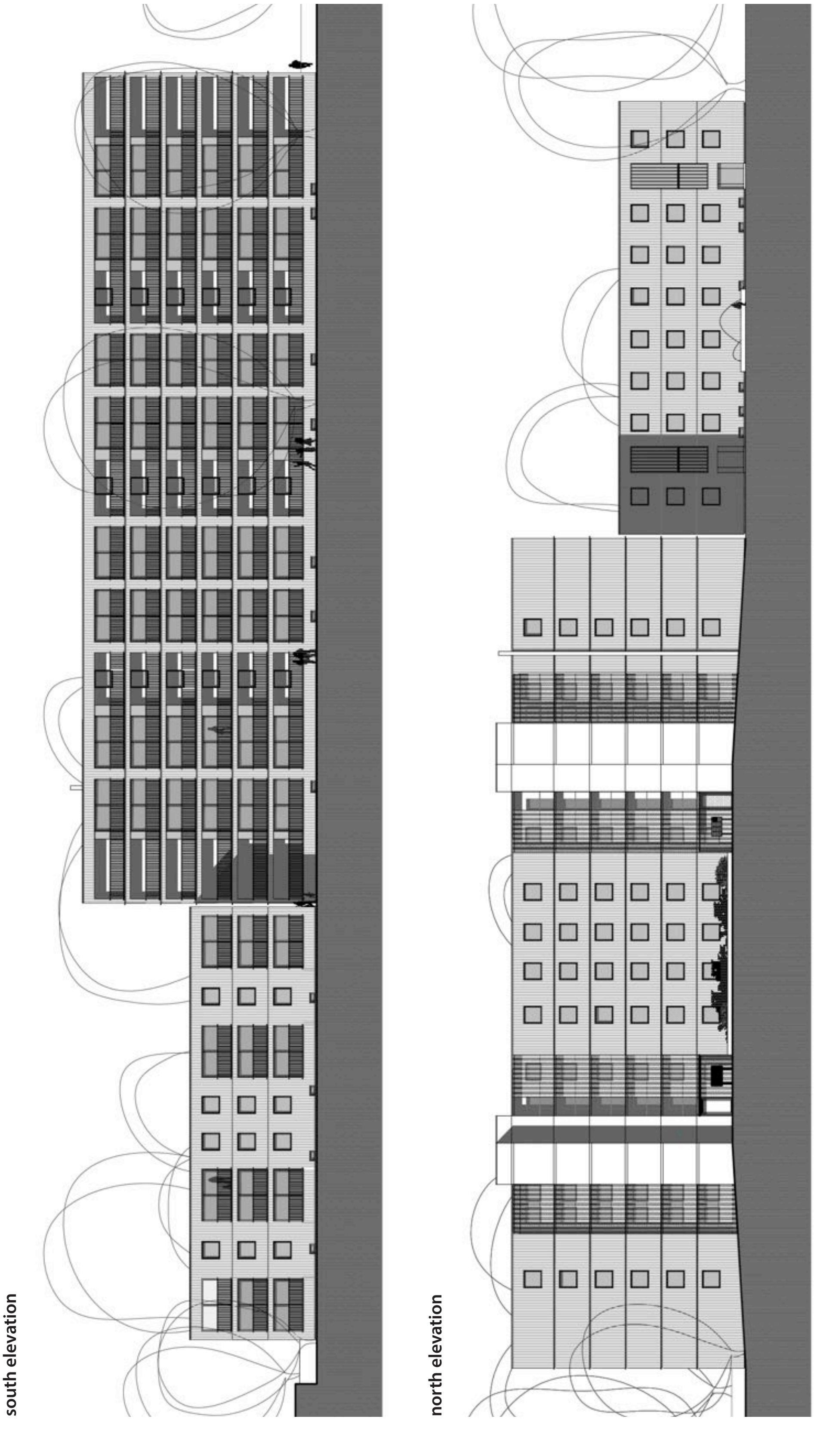
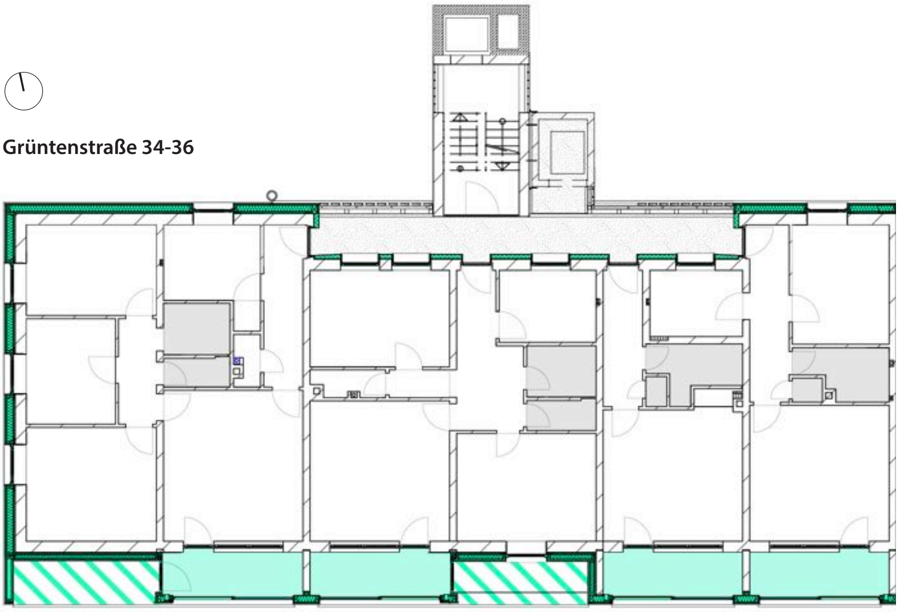


Figure 53: Grüntenstraße 30-36. Elevations (1:500)
© lattkearchitekten

Grüntenstraße 34-36



Grüntenstraße 30-32

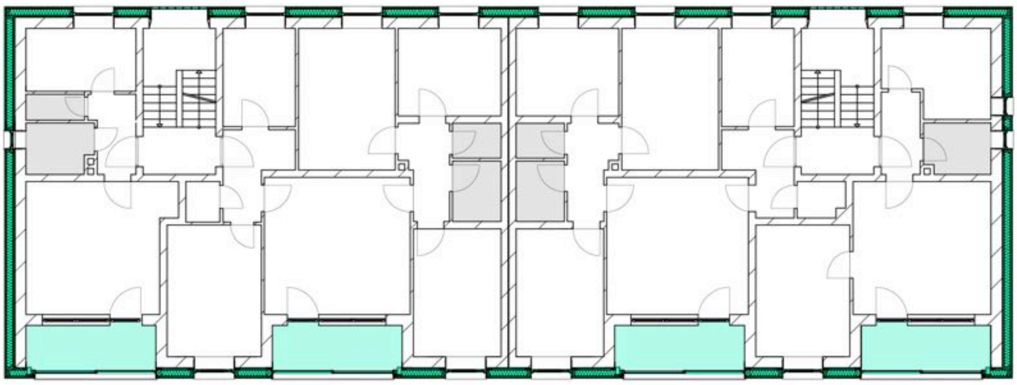


Figure 54: Grüntenstraße 30-36. Floor plans (1:250)
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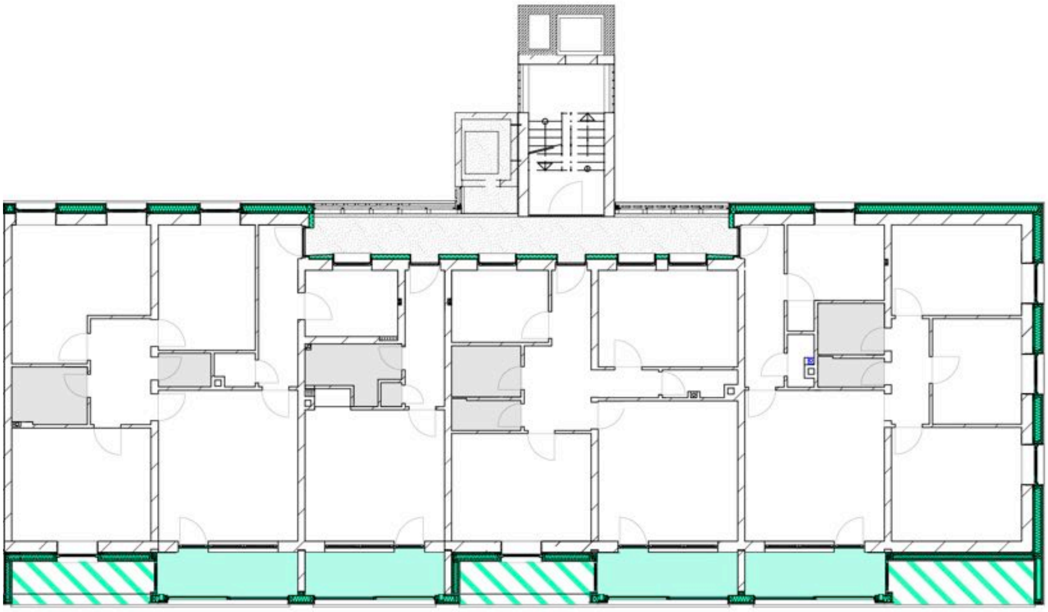

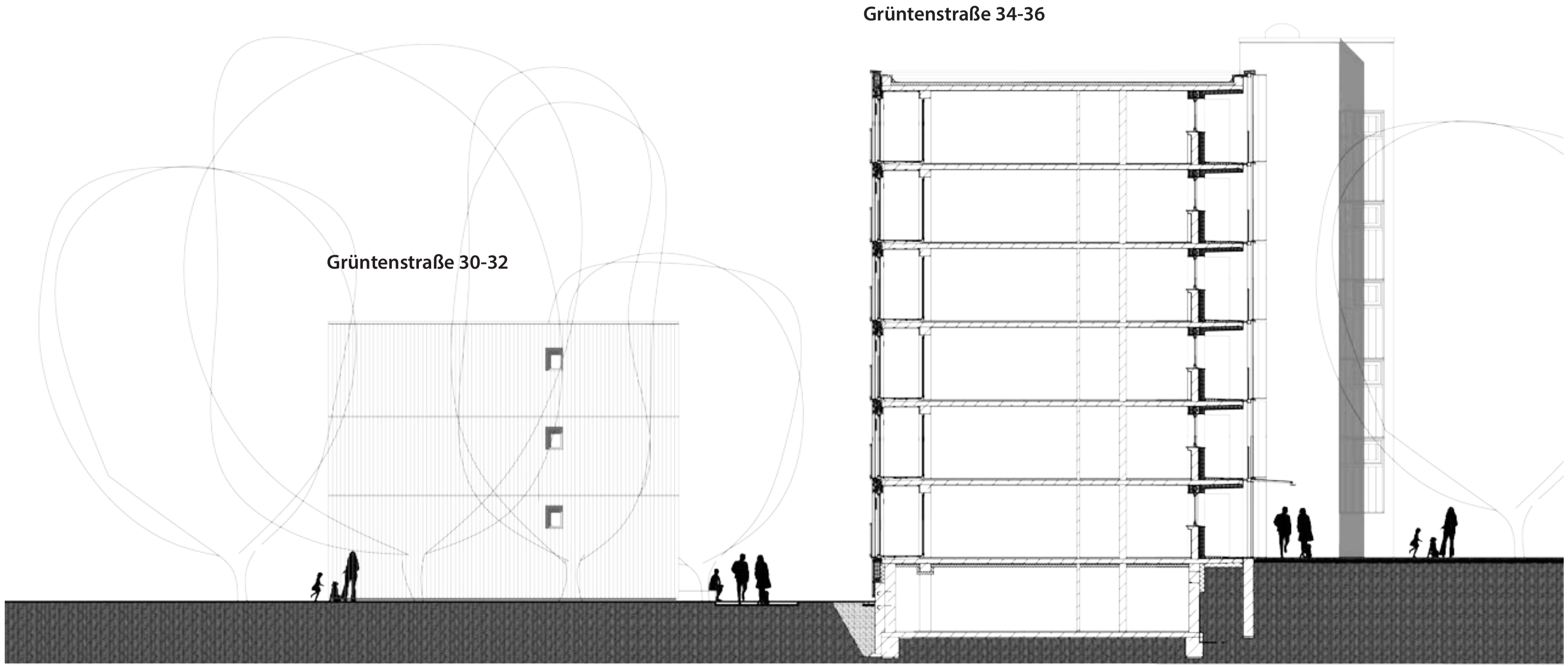

Figure 55: Grüntenstraße 30-36. Section (1:250)
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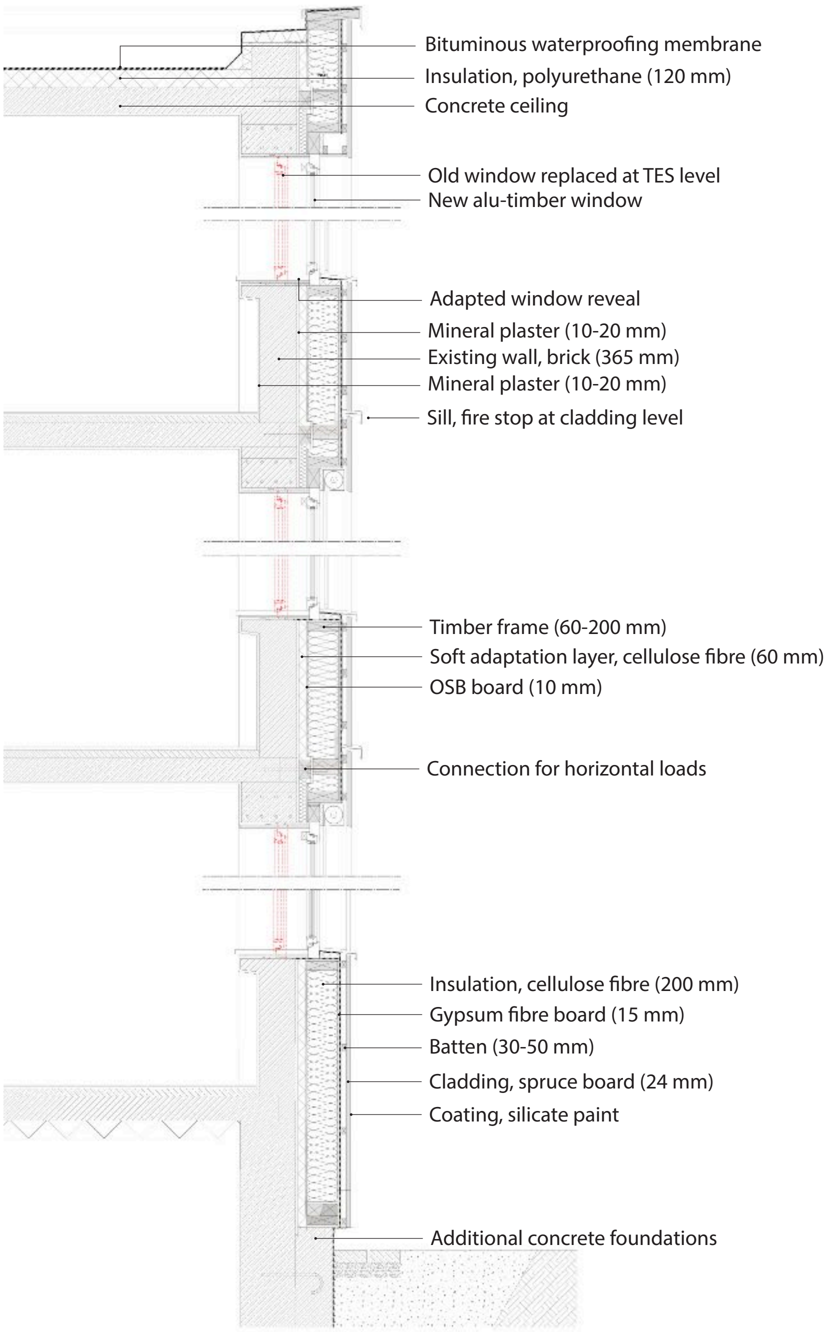


Figure 56: Grüntenstraße 30-36. Construction section through north elevation (1:50)
© lattkearchitekten

Grüntenstraße 34-36, building before retrofit

Top: Grüntenstraße 34-36, south façade after retrofit
Bottom left: On-site assembly of TES elements. Bottom right: Grüntenstraße 34-36, added loggias

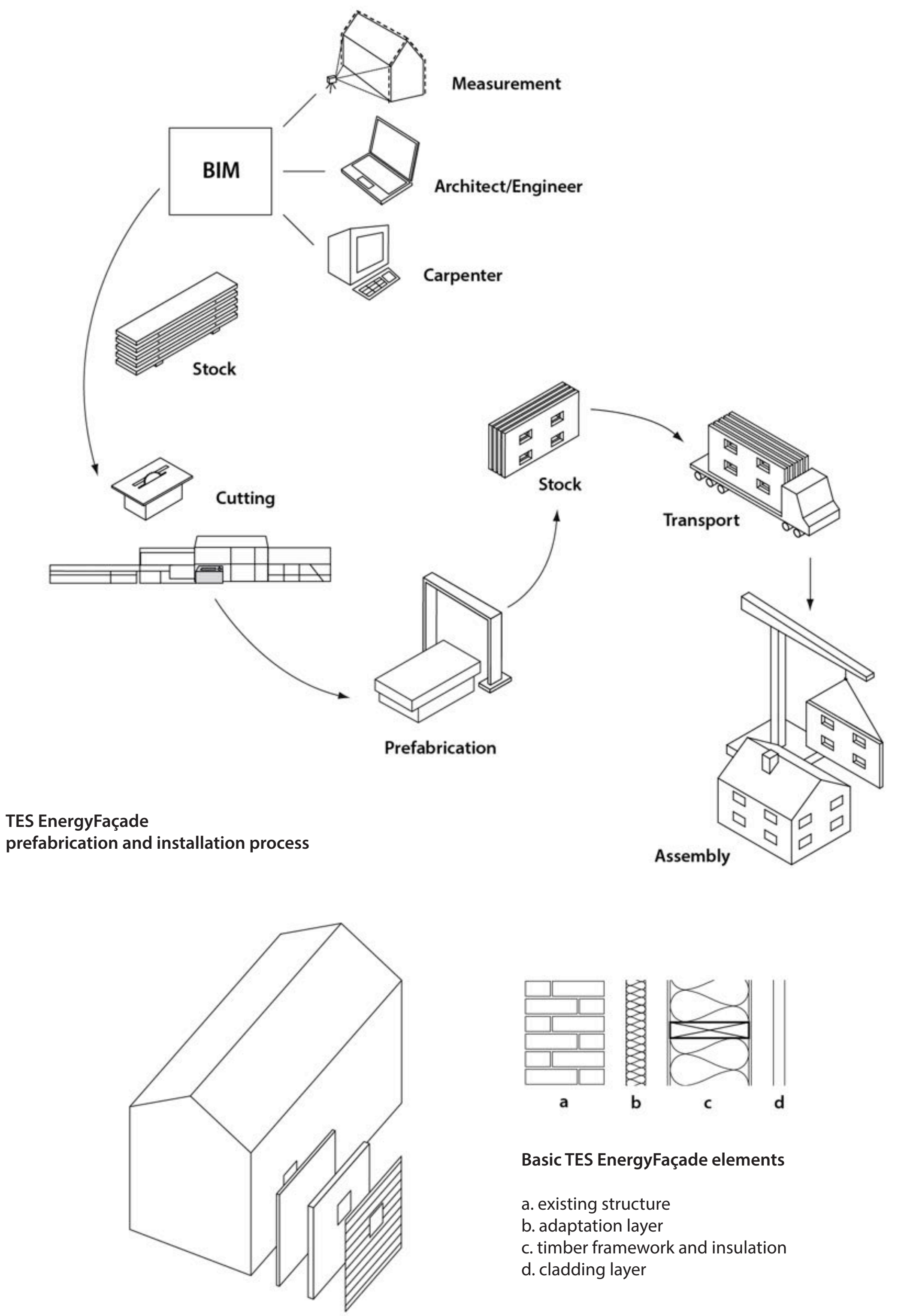


Figure 57: Grüntenstraße 30-36. TES EnergyFaçade diagrams
© TES EnergyFaçade

Off-site fabrication of TES elements at Gumpp & Maier
Top: Timber frame structure. Bottom: Integrated window frames and glasses

Top: Grüntenstraße 34-36, retrofitted north façade
Bottom left: Grüntenstraße 30-32, retrofitted north façade. Bottom right: Access walkways

CASE #8
Pfuhler Straße 4-8 | Werner Sobek

Renovation to plus energy house of a low-rise building with prefabricated, timber-based elements.

LOCATION: Pfuhler Straße 4-8, Neu Ulm - 48°24'16.5"N, 10°01'16.7"E

DATE: 1938, construction; 1975, earlier renovation; 2012, competition; Nov 2012 - Dec 2015, renovation

CLIENT: NUWOG - Wohnungsgesellschaft der Stadt Neu-Ulm GmbH

DESIGN TEAM: Werner Sobek Design GmbH (mandatory architect); Werner Sobek Green Technologies GmbH (energy systems engineering); RWTH Aachen University - Lehrstuhl für Energieeffizientes Bauen E3D (energy monitoring)

BUDGET: 3.2 Mio EUR excl. VAT

AWARDS: -

PLOT SIZE: 1,240 m^2

BUILDING SIZE: 1) Total floor area: 1,039 m^2 > 1,380 m^2; 2) Heated floor area: 438 m^2 > 656 m^2

ENERGY CONSUMPTION: 507 > 12.5 kWh/m^2.y (primary energy) + 8,824 kWh/y electricity surplus

EPC class: H > A+

Pfuhler Straße is a social housing complex situated to the north-east of Neu-Ulm. Built in 1938, it originally consisted of two row buildings, Pfuhler Straße 2-8 and Pfuhler Straße 10-16, each with two above-ground floors, a basement and a shared private garden to the rear.

In 2012, the 'EPA - Effizienzhaus Plus im Altbau' competition[20] was launched and the units at number 4-6 and 12-14 were selected as demonstration site. With the aim to prove the technical feasibility of the energy-plus approach also in the case of renovation, a number of collaborating teams of professional architects, engineers, and universities challenged themselves in the difficult task of developing a concept for the transformation of these inefficient buildings into buildings that, over the year, produce more energy than they consume.

At the end, two concepts and as many teams were awarded (Figure 58): Werner Sobek Stuttgart with HRW Mühlheim and Oehler Archkom Solar Architektur, for Pfuhler Straße 4-6, and O5 Architekten with Technische Universität Darmstadt and ina Planungsgesellschaft, for Pfuhler Straße 12-14. The units at Pfuhler Straße 8 and 10 were not included in the competition, but renovated to the KfW-Effizienzhaus 55 standard within the wider project. Instead, the units at Pfuhler Straße 2 and 16 were excluded from the contract.

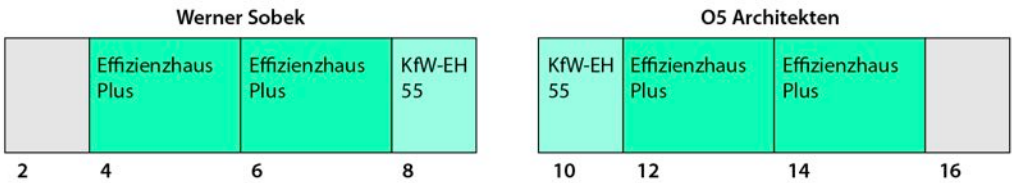


Figure 58: Pfuhler Straße 4-8 & 10-14

As regards Pfuhler Straße 4-8, the first phase of the project implied the cladding of the whole building envelope with a prefabricated, highly-insulated timber frame façade that significantly reduced cold bridges and increased air tightness.

Original roof trusses were completely removed and replaced by foil-coated sloping elements, supported by a new cast in-situ concrete knee wall. Exterior solid walls were fitted with white-plastered elements which integrate ventilation ducts and rain gutters. The floors over the unheated basement were insulated on the underside with a 22-cm thick mineral wool layer. Basement walls were waterproofed on the outside and lined with a vapour barrier from the inside.

[20] A competition launched by the Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB), in collaboration with NUWOG.

In order to improve natural lighting conditions while controlling solar heat gain, all existing windows were enlarged, equipped with triple glazing. The south- and west-facing windows were protected with adjustable sun shading devices.

Besides the façade, further interventions concerned the building's interior and immediate surroundings.

At the ground and first upper floor, the existing one-bedroom apartments (10 units of 75-85 m^2) were renovated. To meet today's standards, all bathrooms were refurbished, some partitions walls demolished, and apartment layouts modified to create open plan kitchens and dining/living rooms.

On the attic floor, 218 m^2 of additional habitable space were obtained by converting what was previously storage space into three studio apartments. Characterized by spacious and flexible floor plans, the large studios are lit by a continuous dormer and a series of operable roof windows.

Through the dormer, tenants can access the new balconies. Built as a freestanding structure in galvanized steel, they run along the whole length of the (north-facing) garden side allowing residents to enjoy private outdoor space.

On the (south-facing) street side, stairs in the same material lead from the sidewalk to the building entrance doors. No elevator was provided as part of the project. Nonetheless, the installation of a wheelchair platform lift has been foreseen and ground floor apartments were designed to be barrier-free.

From a technical building systems point of view, Werner Sobek opted for centralized solutions. Space heating and domestic hot water are produced by a brine-to-water heat pump in the basement, connected to a geothermal probe in the garden. Fresh and exhaust air are supplied/extracted via a mechanical ventilation system with 80% heat recovery.

Electricity is generated from 214 m^2 of building-integrated photovoltaic panels (33.5 kWp capacity). Bolted to a metal structure on the roof, the plant has been sized not only to meet the building's electricity demand but also to produce an expected surplus of 8.824 kWh/y, corresponding to an annual mileage of a medium-sized e-car of approximately 52,000 km.

A smart home energy management system ensures that energy is used only where and when it is actually needed.

Climate: 3872 heating degree days (Augsburg, 2017)

Building energy regulation: EnEV 2009
Calculation method: DIN 18599

Table 38: Pfuhler Straße 4-8. Building envelope U-values

	U-value before retrofit (W/m^2K)	**U-value after retrofit (W/m^2K)**
Roof	1.4	0.10
External walls	1.7	0.10
Floor over basement	1.2	0.16
Windows	3.0	0.71

Air exchange rate: 0.5 1/h / **Airtightness n_{50}**: 1.5 $m^3/m^2.h$

Table 39: Pfuhler Straße 4-8. Building energy demand

	Before retrofit ($kWh/m^2.y$)	**After retrofit ($kWh/m^2.y$)**
Space heating		
…		
Total PE demand	**507**	
RES production	-	
PE demand - RES	-	**12.5**

Table 40: Pfuhler Straße 4-8. Building retrofit costs

	Mio €	**€/m²**
Building costs		
Landscaping		
Total	**3.2**	**2,557**

Funding sources: €0.6 Mio subsidies, €1.0 Mio client's own funds, €1.6 Mio capital market.

1 | Roof
Rear-ventilated PV modules (4 cm)
PV substructure (14 cm)
Waterproof membrane (0.3 cm)
OSB panel (1.5 cm)
Counter batten (2.4 cm)
DWD (1.6 cm)
Thermal insulation, mineral wool (40 cm)
OSB panel (1.5 cm)
Counter batten (2.4 cm)
Gypsum plasterboard (1.25 cm)

2 | External walls
Exterior plaster (0.3 cm)
Wood fibreboard (6 cm)
Thermal insulation, mineral wool (35-40 cm)
Existing plaster (2 cm)
Existing wall, perforated bricks (30 cm)
Interior plaster, gypsum (2.5-3 cm)

3 | Balconies
Galvanized steel structure

4 | Triple-glazed windows

5 | Ceiling over basement
Existing slab, reinforced concrete (20 cm)
Leveling layer (1-2 cm)
Thermal insulation, mineral wool (22 cm)

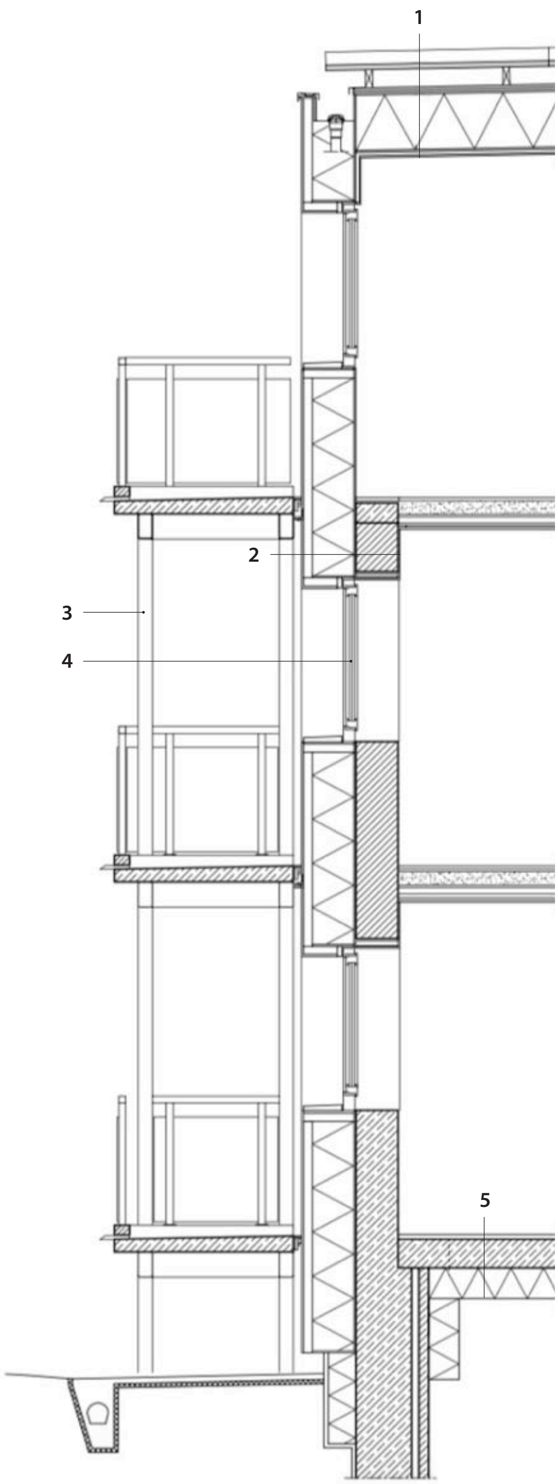


Figure 59: Pfuhler Straße 4-8. Construction section through north elevation (1:50)
© Werner Sobek

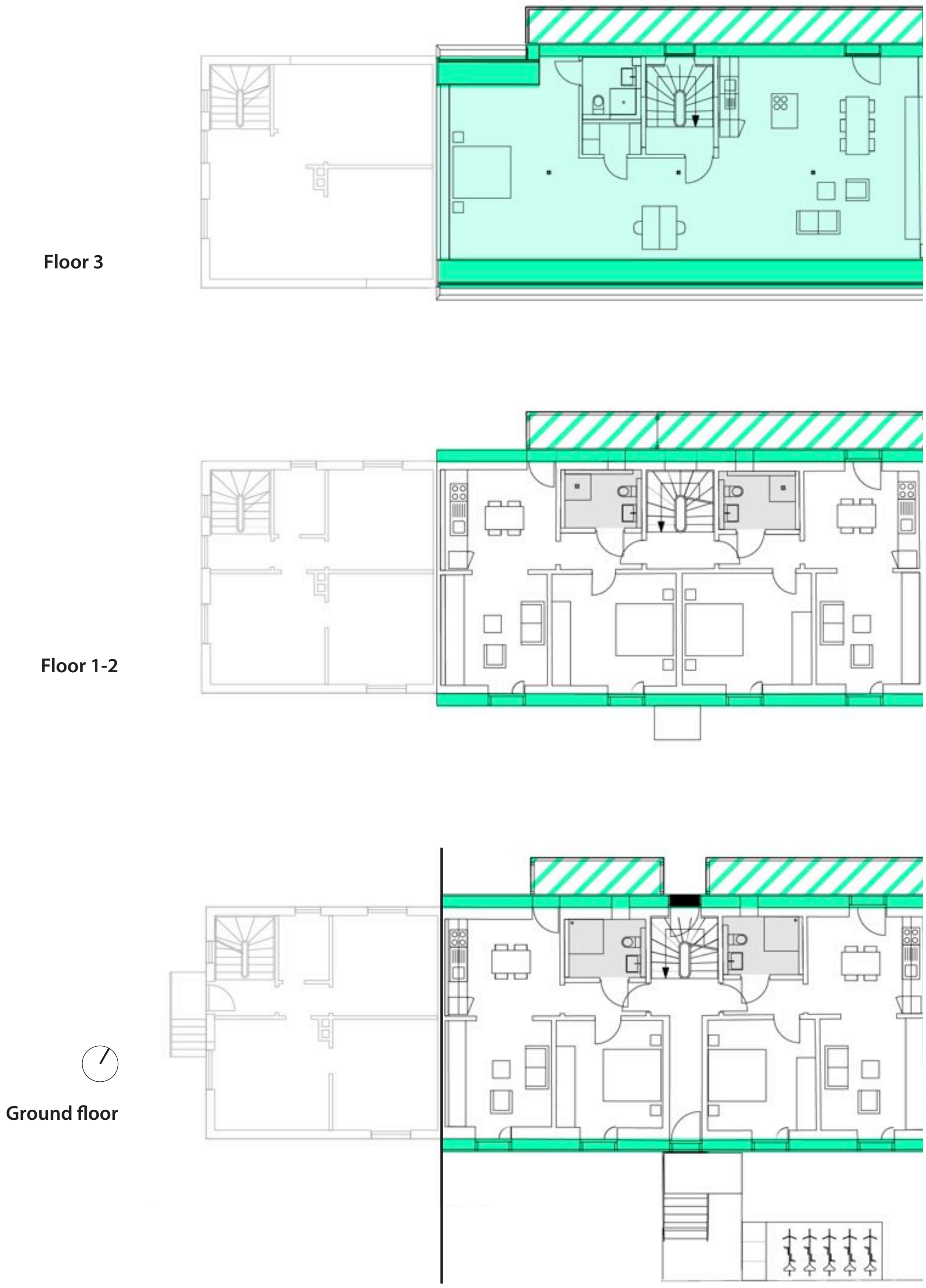
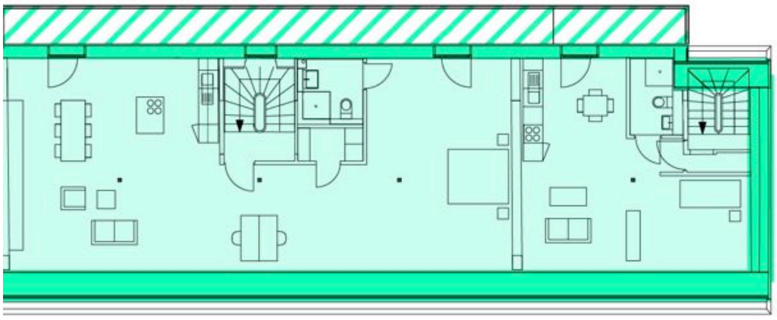
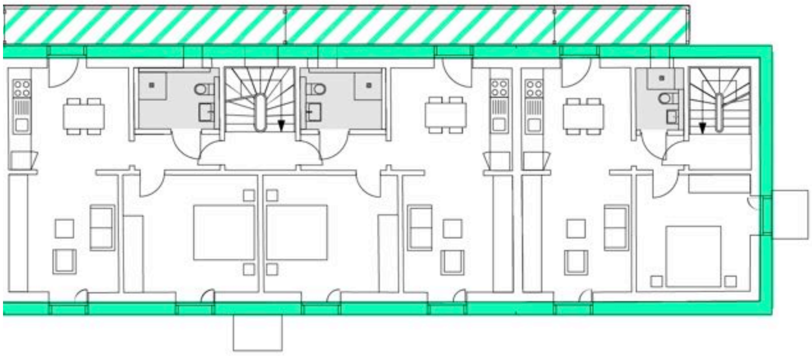
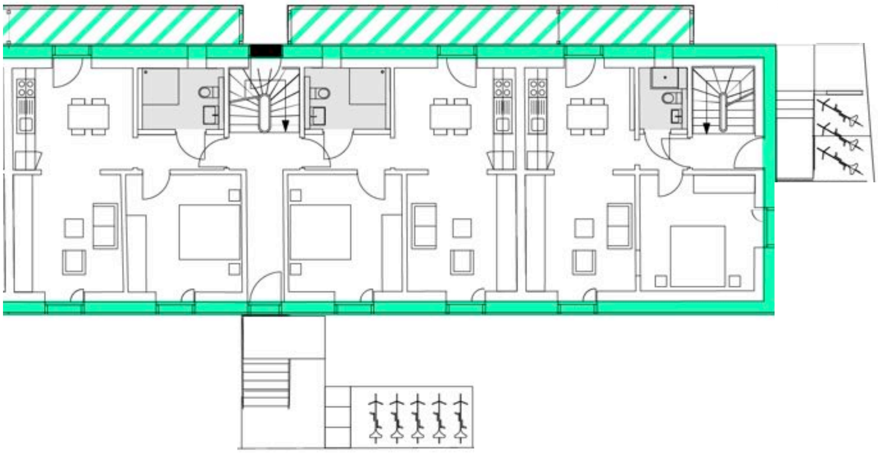


Figure 60: Pfuhler Straße 4-8. Floor plans (1:250)







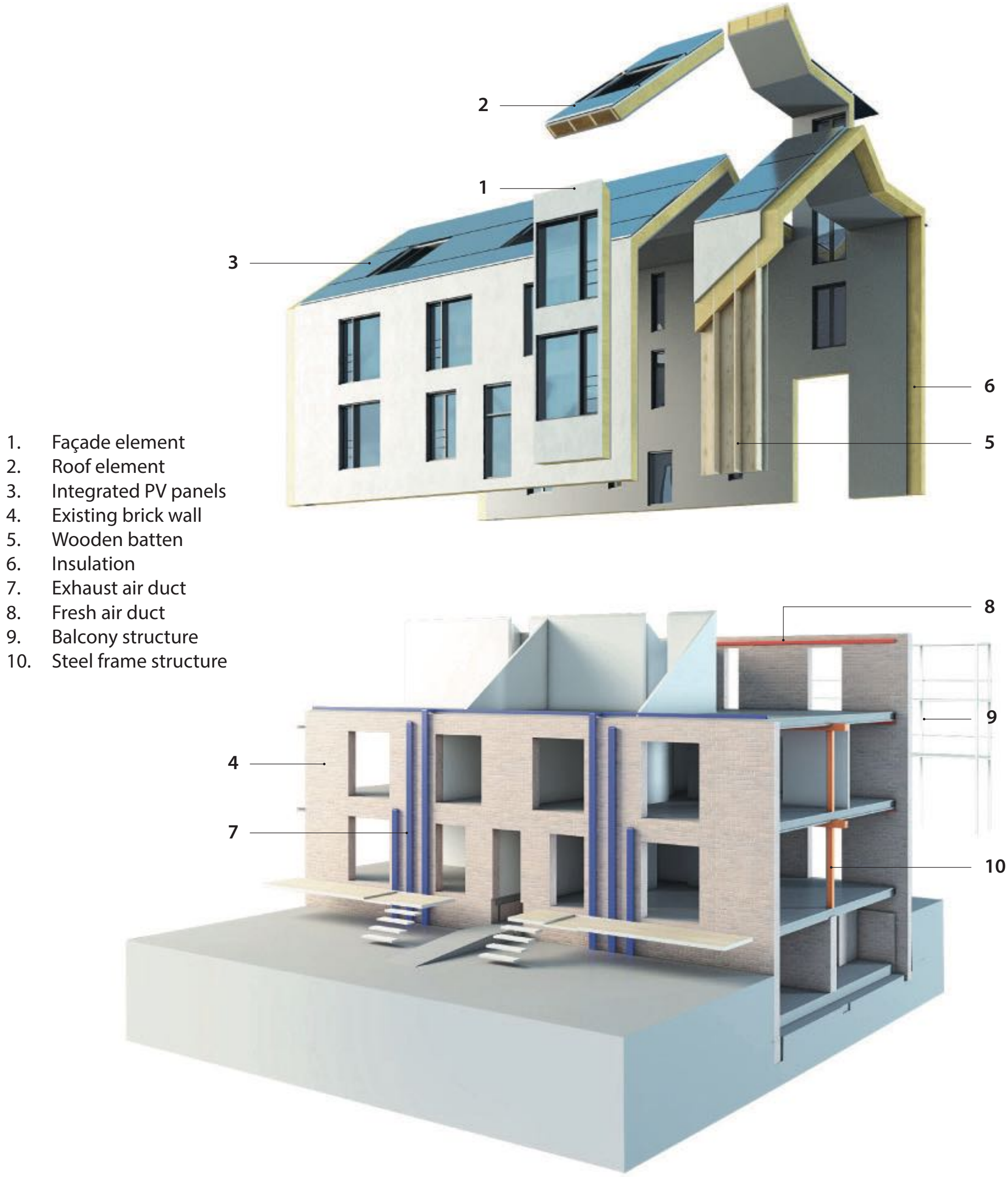


Figure 61: Pfuhler Straße 4-8. Exploded diagram
© Werner Sobek

Street view of the south façade after retrofit
Building integrated photovoltaic roof, floor-to-ceiling windows and main access

Top and bottom left: Interior view of the converted attic apartments
Bottom right: North façade after retrofit with added roof dormer and balconies

© Dietmar Strauß

CASE #9
Wohnhochhaus Güterstraße 30 | Freivogel Mayer Architekten

Renovation and rooftop elevation (in occupied site) of a mixed-use high-rise building with prefabricated concrete elements.

LOCATION: Güterstraße 30, Pforzheim - 48°53'40.9"N, 8°42'05.8"E

DATE: 1972, construction; 2011, competition; Apr 2013 - Aug 2014, renovation

CLIENT: Pforzheimer Bau und Grund GmbH

DESIGN TEAM: Freivogel Mayer Architekten (mandatory architects); IFT-S Ingenieurbüro für Tragwerksplanung Joachim Sommer (structural engineering); Transsolar KlimaEngineering (energy systems engineering and monitoring); IGP Ingenieurgesellschaft für technische Ausrüstung (MEP engineering)

BUDGET: 2.4 Mio EUR excl. VAT

AWARDS: 2015, Sonderpreis Nachhaltiges Bauen; 2015, Deutscher Architekturpreis; 2015, DGNB Preis 'Nachhaltiges Bauen'; 2015, Deutscher Bauherrenpreis, Modernisierung (special mention); 2015, Pforzheim-Enzkreis Sonderpreis Solar- und Energiepreis; 2016, Europäischer Architekturpreis 'Energie+Architektur'; 2016, Staatspreis Baukultur Baden-Württemberg, Wohnungsbau; 2017, DAM-Preis (finalist)

PLOT SIZE: 1,500 m^2

BUILDING SIZE: a) Total floor area: 2,920 m^2 > 3,440 m^2 (residential area 2,110 m^2 > 2,580 m^2); b) Heated floor area (residential): 1,540 m^2 > 1,720 m^2

ENERGY CONSUMPTION: 236.9 > 30.8 kWh/m^2.y (primary energy)

CO_2 EMISSIONS: 65.9 > 6 kg/m^2.y

EPC class: G > A+

Other LABELS: KfW-EH 55

Wohnhochhaus Güterstraße 30 is a social housing apartment building situated close to the centre of Pforzheim, just opposite to the city main railway station. Built in 1972 by the Deutsche Bundesbahn but sold to the Pforzheimer Bau und Grund GmbH municipal housing association in 2009, it originally comprised of 16 two and three-bedroom units over 8 above ground floors, a retail space at the ground floor, and 2 underground floors with service and technical rooms. Surrounding the building are some parking spaces, a green area and a ramp to the basement parking.

It was 2011 when, within the framework of the DENA - Deutsche Energie-Agentur GmbH nationwide competition for carbon neutral construction and renovation projects 'Auf dem Weg zum Effizienzhaus Plus', the refurbishment concept by Freivogel Mayer Architekten was funded.

With the aim of reaching the goal of 'aesthetic sustainability', existing small, individual balconies were removed and all building elevations provided with a new prefabricated façade system. Stacked up in front of the original outer walls, this consists of a 28-cm thick mineral wool insulation layer, protected by a rear-ventilated cladding in sandblasted precast concrete.

On the southern elevation, 1.8 m deep loggias replaced the dismantled balconies. Supported by independent foundations and fastened to the existing structure by means of steel lugged fixing plates, the loggias run almost over the entire length of the façade, at the same time offering residents outdoor private spaces, protected from the rain, and ensuring the building is shaded from the summer sun.

Enlarged, triple-glazed windows/doors with wood-aluminium profiles complement the overall design and minimize noise from the outside.

In the loggias, the bright concrete cladding gives way to dark gray fiber cement panels. As a result of the contrast, the depth of the perforated façade is emphasized and the structure characterized by a strong monolithic effect, an effect that is further enhanced by the building rooftop extension.

Taking advantage of some unused bearing capacity, a ninth storey could be added to the structure and two penthouse apartments were created on the roof, for 180 m^2 of extra floor area. Characterized by high ceilings, open plans and wide terraces, the penthouses feature particularly large living rooms, with oversized windows allowing views far beyond the city limits. Access is by means of two additional flights of stairs and an upgraded elevator, fitted into the existing shaft.

On the ground floor, the loggias turn into a modern portico, providing a transition space between the street and the floor-to-ceiling windows of the refurbished office premises.

Besides noticeably improved proportions and appearance, the tower benefits also from drastically reduced primary energy consumption (i.e. from 236.9 to 30 $kWh/m^2.y$) and carbon emissions (i.e. from 65.9 to 6 $kg/m^2.y$). In particular, a nearly climate-neutral operation has been achieved thanks to the low envelope thermal transmittance value (i.e. from 1.3 to 0.3 W/m^2K) and broad use of renewable energy sources.

Invisibly embedded into the cladding of the south façade, there are 92 m^2 of solar absorbers which, in combination with a heat pump, make solar energy usable for space heating and domestic hot water (6.5 kWp in winter, 16.4 kWp in summer). An ice storage tank of 85 m^3, located below the adjacent parking lot, serves as seasonal heating and cooling source.

On the extensive green roof, 66 m^2 of photovoltaic modules (13.5 kWp; 8,855 kWh/y) and a small vertical wind turbine (5 kWp; 2,092 kWh/y) provide for the building's power needs. Surplus electricity is fed into the public grid.

As regards technical building systems, the old electric night storage heaters are replaced by decentralized mechanical ventilation units with 86% heat recovery. New heating and cooling ceilings are installed in all the apartments, resulting only in a slight decrease in the height of the rooms.

Through all these measures, the total building primary energy demand dropped from about 237 to 31 $kWh/m^2.y$ and the KfW-EH 55 level was reached, delivering significant advantages in terms of energy costs. Despite the moderately adjusted rental fees, tenants are ultimately saving money.

Climate: 3477 heating degree days (Stuttgart, 2017)

Building energy regulation: EnEV 2009
Calculation method: DIN 4108-6 & DIN V 4701-10

Table 41: Wohnhochhaus Güterstraße 30. Building envelope U-values

	U-value before retrofit (W/m^2K)	**U-value after retrofit (W/m^2K)**
Roof	1.5	0.09
External walls	0.88	0.13
Floor over basement		0.21
Windows	5.7	0.98

Airtightness n_{50}: 1.3 1/h (refurbished); 0.5 1/h (newly constructed)

Table 42: Wohnhochhaus Güterstraße 30. Building energy demand

	Before retrofit ($kWh/m^2.y$)	**After retrofit ($kWh/m^2.y$)**
Space heating		12.6
DHW		15
Ventilation		3.2
Total PE demand	**236.9**	**30.8**
RES production	-	
PE demand - RES	-	

Table 43: Wohnhochhaus Güterstraße 30. Building retrofit costs

	Mio €	**€/m²**
Building costs	2.45	712
Landscaping		
Total	**2.9**	**843**

Funding sources: KfW Energy-Efficient Refurbishment programme

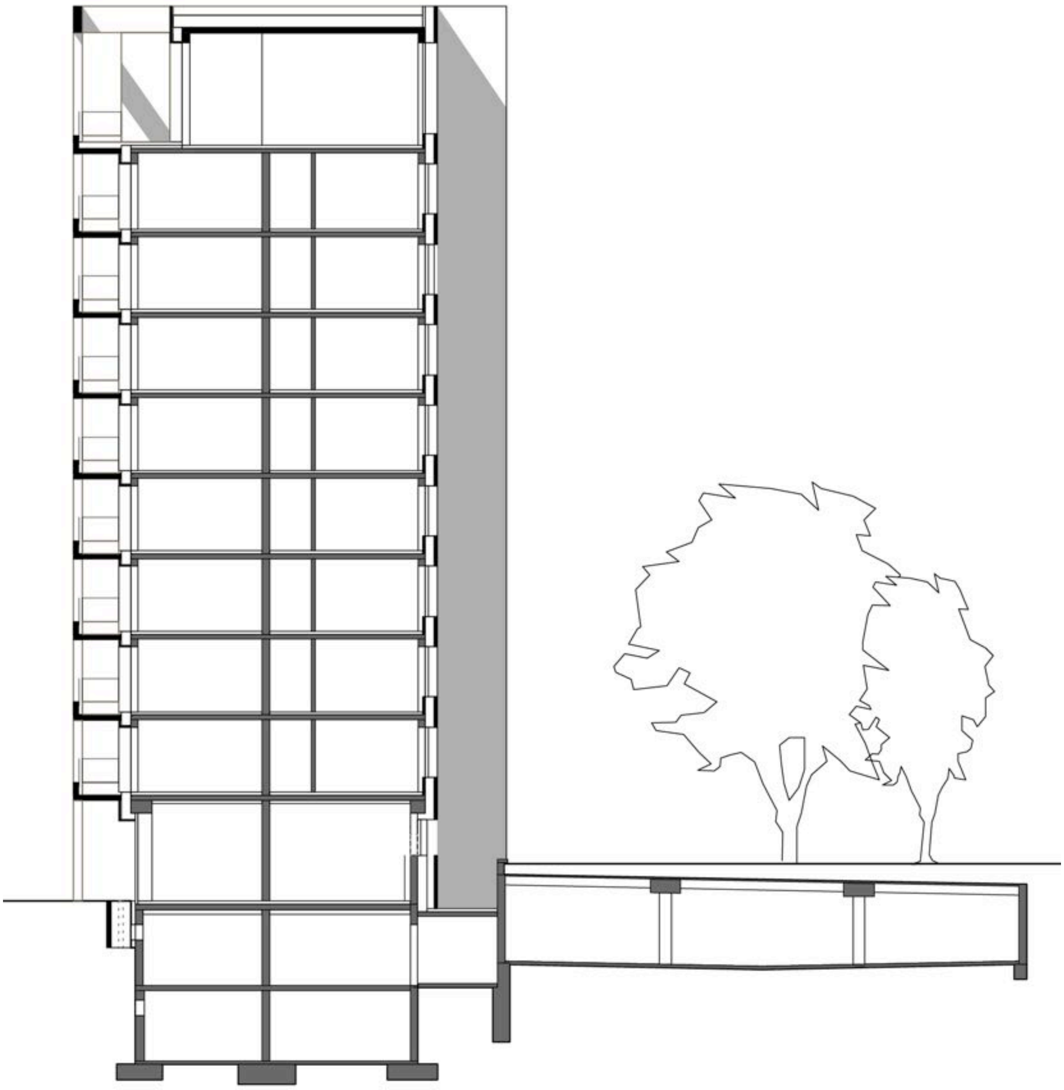


Figure 62: Wohnhochhaus Güterstraße 30. Section (1:250)
© Freivogel Mayer Architekten

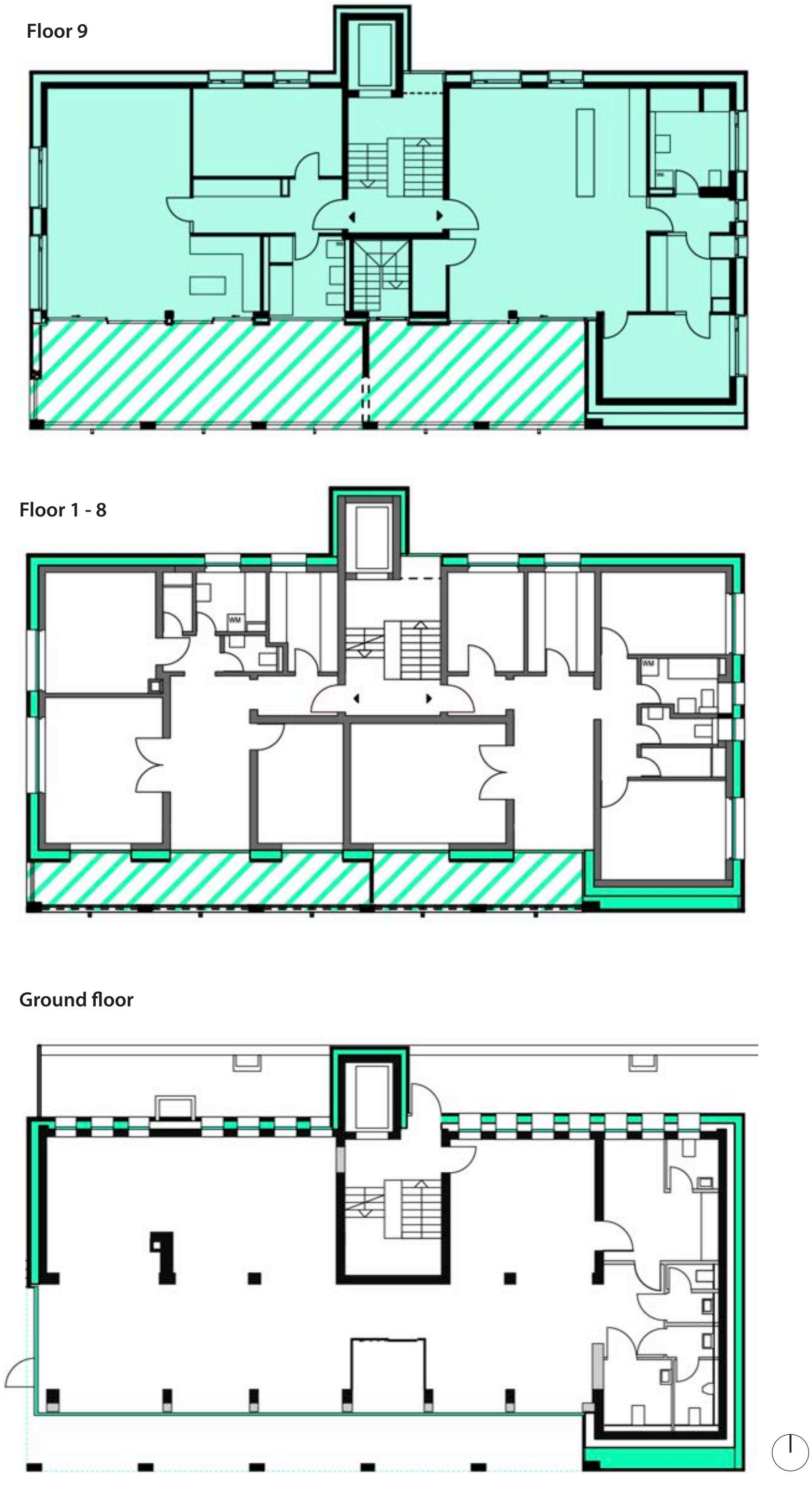


Figure 63: Wohnhochhaus Güterstraße 30. Floor plans (1:250)
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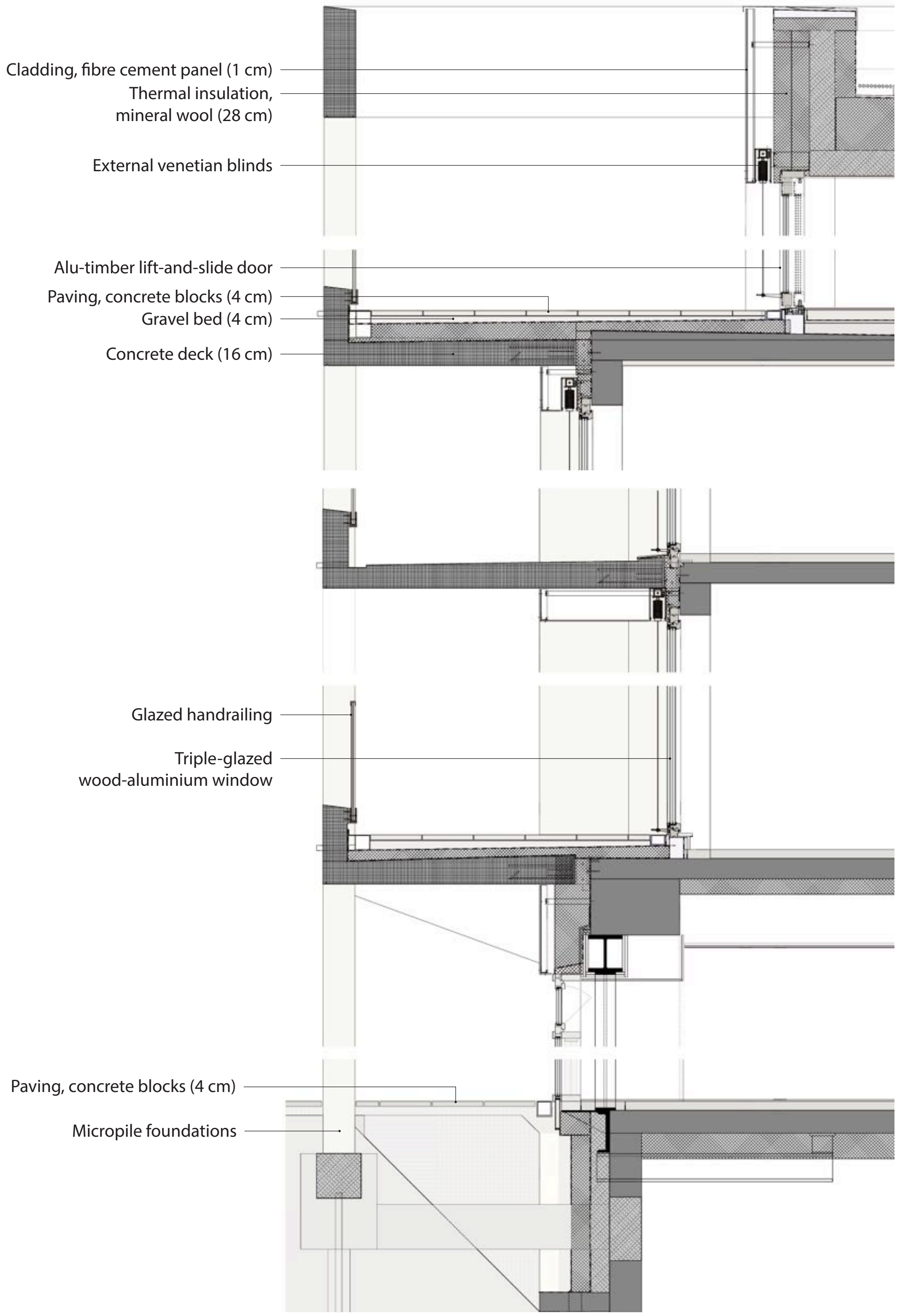


Figure 64: Wohnhochhaus Güterstraße 30. Construction section through south elevation (1:50)
© Freivogel Mayer Architekten

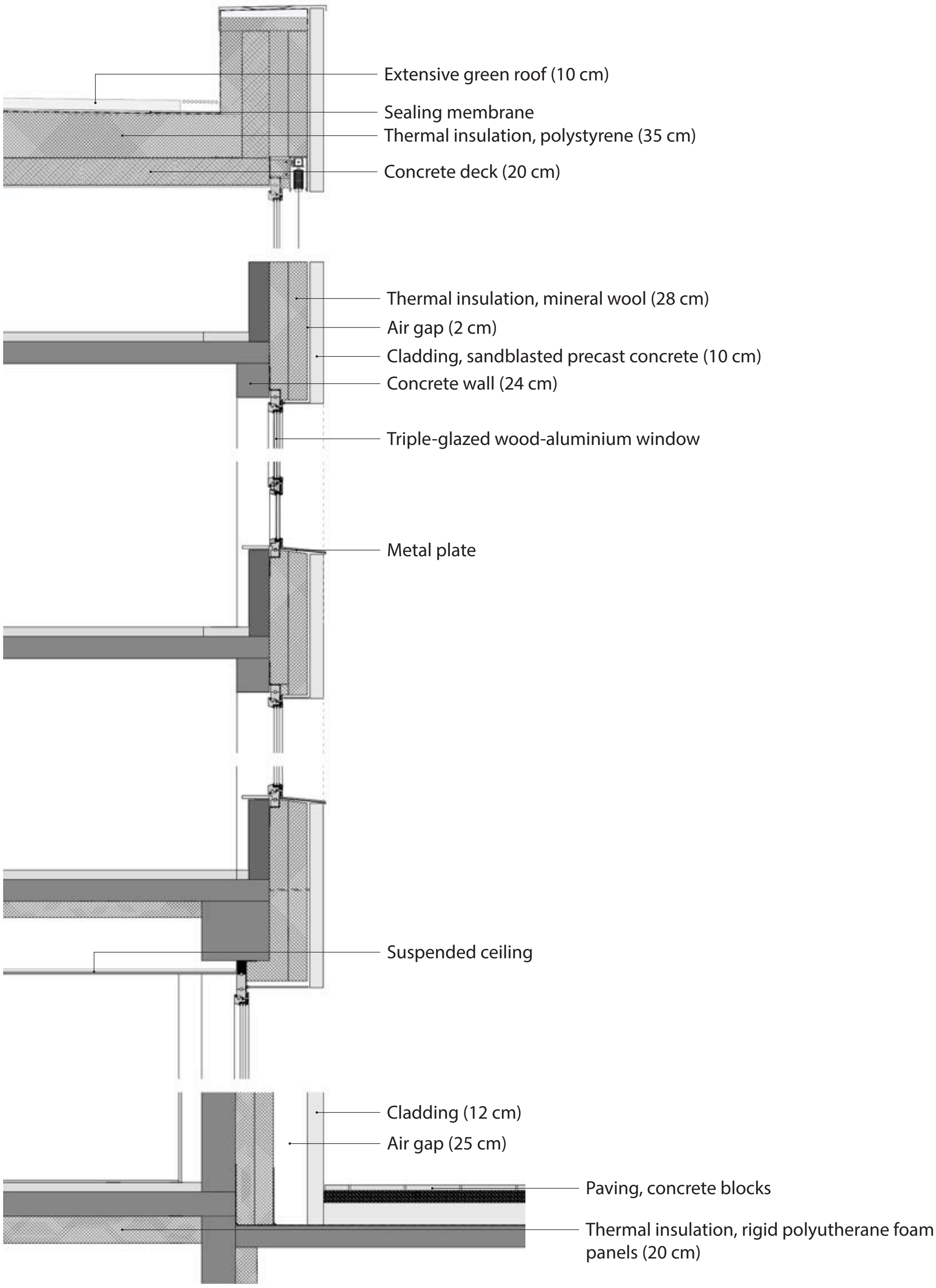
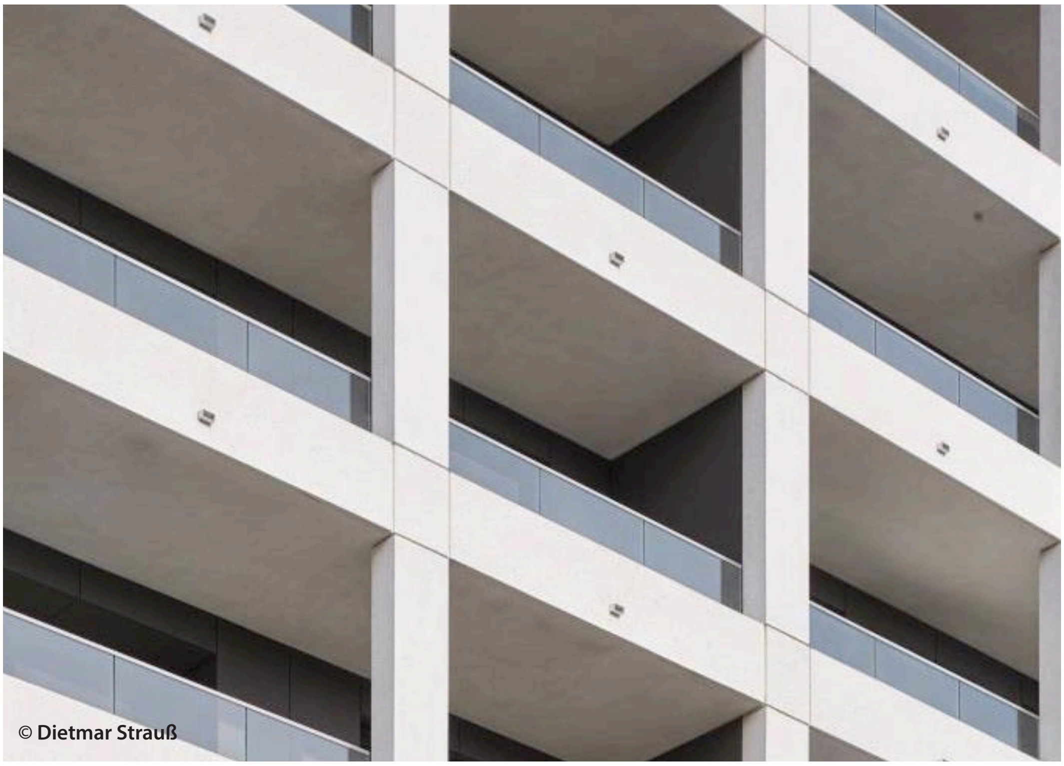
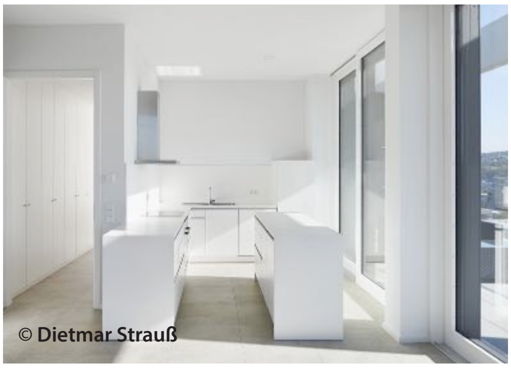


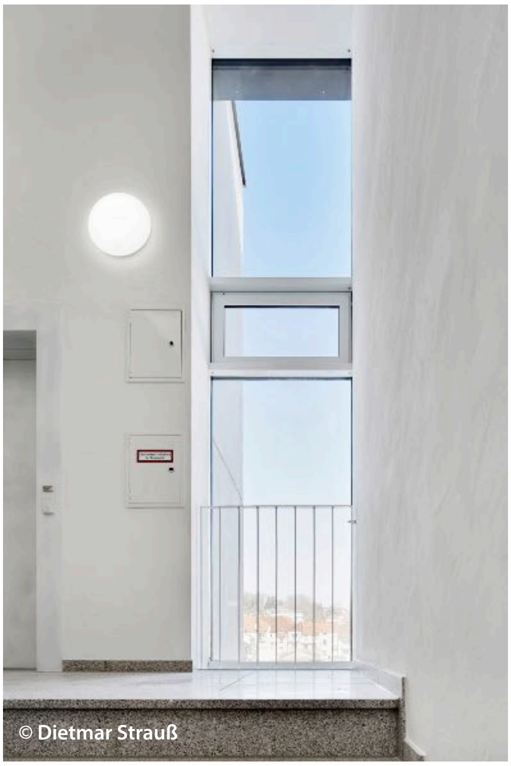
Figure 65: Wohnhochhaus Güterstraße 30. Construction section through north elevation (1:50) © Freivogel Mayer Architekten

Top left: Aerial view of the building before retrofit. Top right: Building after retrofit
Bottom: Building during retrofit (loggia details)

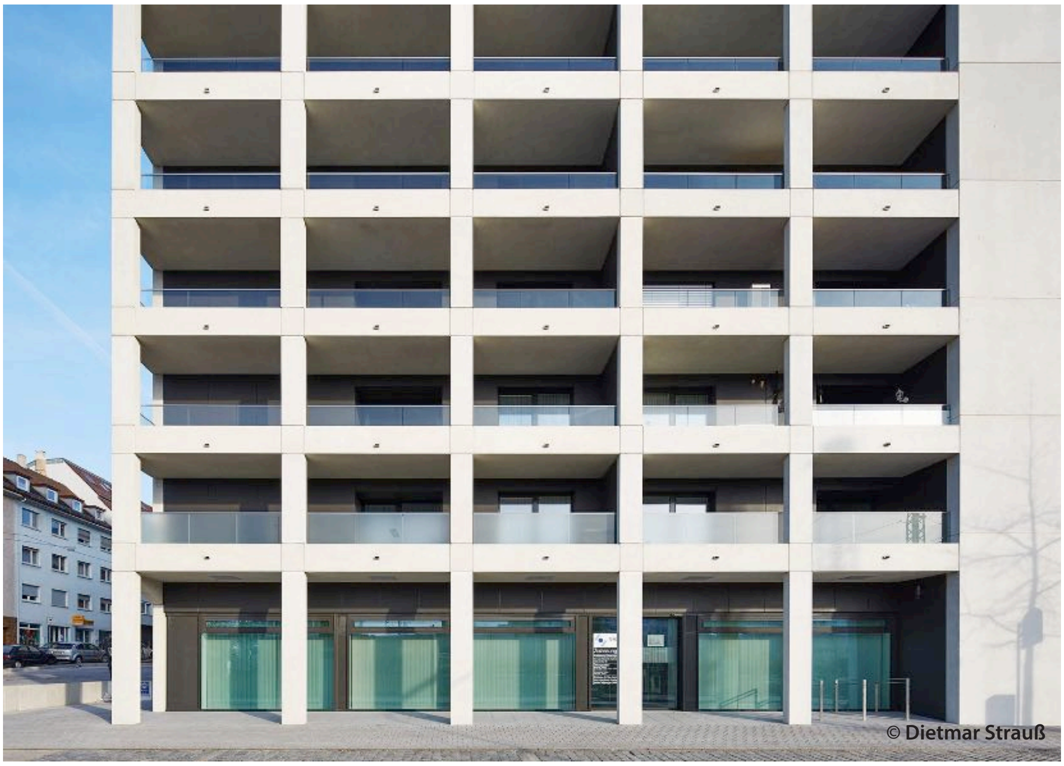


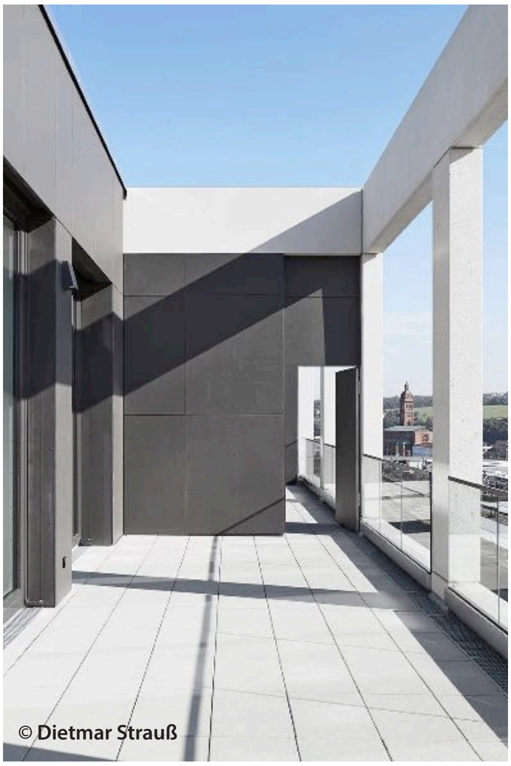
Top: South façade after retrofit with added loggias
Bottom left: East façade after retrofit. Bottom righ: West façade after retrofit





Top and bottom left: Interior of new penthouse apartments
Bottom righ: Refurbished stairwell





Top: Street view of south façade after retrofit
Bottom left: Penthouse terrace. Bottom right: Ground floor portico

Chapter 6

Conclusions

The thesis investigated policies and practices for the retrofitting of residential buildings in three European member states.

In doing this, it pinpointed the main national policy instruments and analysed some comprehensive renovation projects, putting the spotlight on the non-energy related aspects and benefits of building retrofits.

Findings from the case studies

Figure 66 summarizes and systemizes findings from the case studies. Lines, break down each project into its most basic retrofit measures, pointing out 'what' has been done (and what has not) across the different design domains. Columns, read through the case studies, showing 'how' the different projects have engaged with a specific design domain. As a whole, the figure identifies a set of retrofit measures that have proven to be effective in meeting, and in some cases exceeding, codes and/or labels requirements and, at the same time, in delivering improved standards of living and urban quality.

The measures can be broadly divided into: measures on the building envelope (both opaque and transparent components), measures on the technical building systems, and measures based on renewable energy sources.

As regards the **thermal performance of the building envelope**, the most commonly adopted measures are the addition of external wall insulation and/or the creation of buffer spaces, together with the replacement of windows.

External insulation reduces the overall heat transfer of the envelope by means of low thermal conductivity layers, fitted to the outside of walls and (flat) roofs. It prevents cold bridging and increases airtightness. Compared to internal insulation, it avoids reducing the floor area of the rooms and offers the opportunity to improve the aesthetics of the building.

As an alternative to the application of external insulation, the over-cladding of the existing envelope with off-site manufactured insulated wall and roof panels represents an advanced solution for speed of installation and high level of prefabrication. The two projects by lattkearchitekten and Werner Sobek, in Augsburg (D) and Neu Ulm (D) respectively, demonstrate the possibility of using timber based element system not only for improving insulation but also for integrating new services while keeping the ceiling height unchanged.

The project by Kullegaard A/S in Roskilde (DK) is the only one featuring the total demolition and re-construction of the walls, this having been possible because the building was uninhabited.

Buffer spaces contribute to the building performance by maximizing solar gains and retaining heat losses in winter, and mitigating gains in the summer.

Depending on the original design of the façade, buffer spaces can be obtained either by enclosing, and in certain cases extending, existing balconies, loggias, covered access walkways, etc. or by adding independent structures to create an intermediate space between the interior and the exterior of the building. Though unheated, these spaces offer the benefit of increasing the living area of dwellings and providing protection to the building fabric.

Examples from the case studies include the projects by LAN Architecture in Lormont (F), in which the existing loggias were extended and turned into enclosed loggias with operable polycarbonate shutters, and by Lacaton & Vassal, Druot, Hutin in Bordeaux (F), in which a prefabricated structure with cantilevered winter gardens and balconies was added to the otherwise flat fronts.

The projects by KAAI and C.F. Moller in Aalborg (DK) apply the same concept but to building common spaces instead of private ones. By enclosing (and widening) access walkways, they create semi-private spaces where inhabitants can gather and meet, protected from the weather.

The replacement of old windows and doors with high performance units (e.g. double- or triple-glazing, profiles with advanced thermal break, etc.) complete the measures on the envelope. Typically, the enlargement or addition of new openings to allow for greater natural light and cross ventilation is also pursued.

Larger glazed areas involve the risk of overheating. To mitigate this risk, sun shading devices (e.g. roller shutters, venetian blinds, thermal curtains, etc.) are often integrated to control daylight and reduce glare. Balconies and loggias can be used to shade adjoining areas of the façade too.

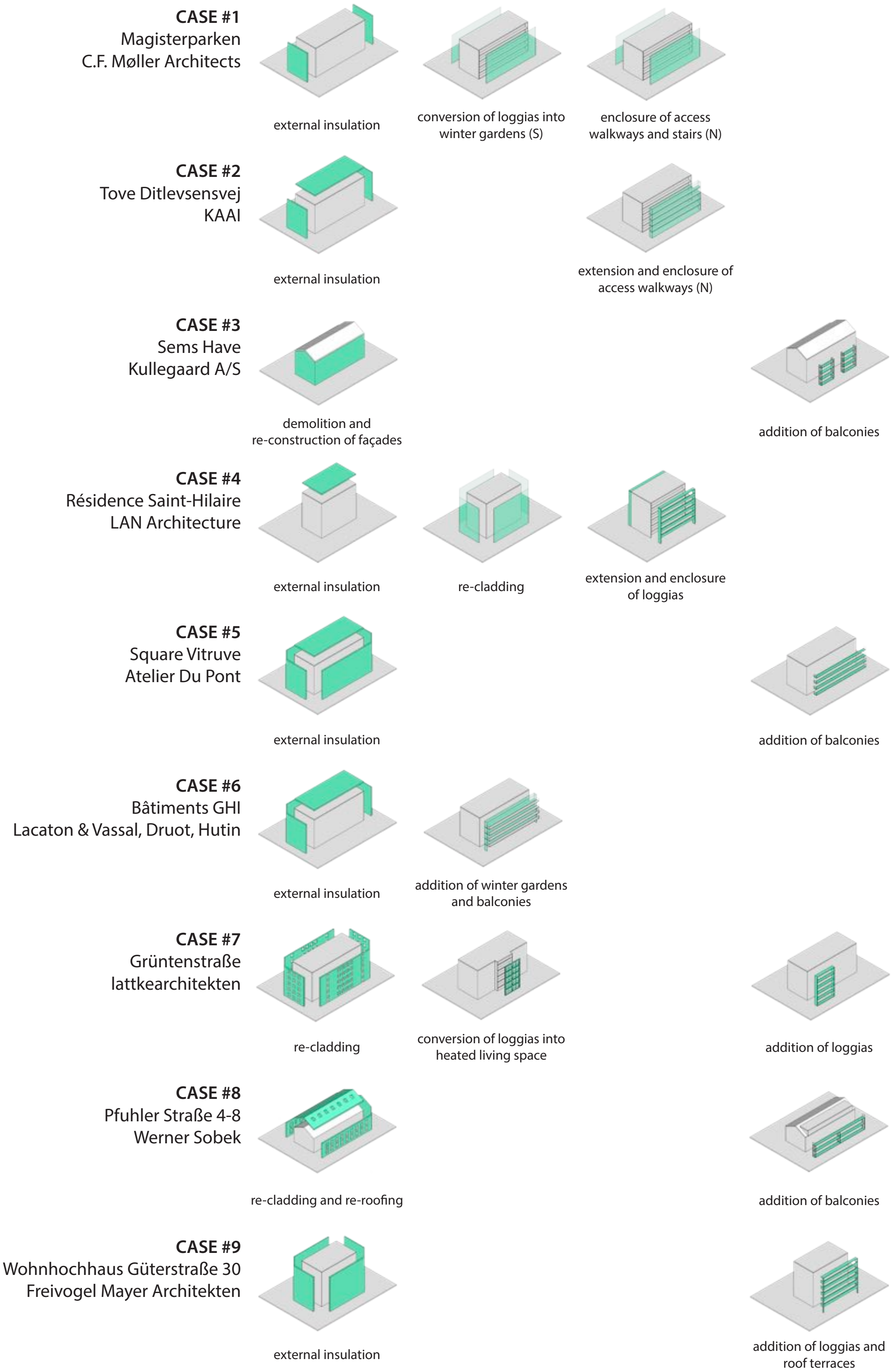
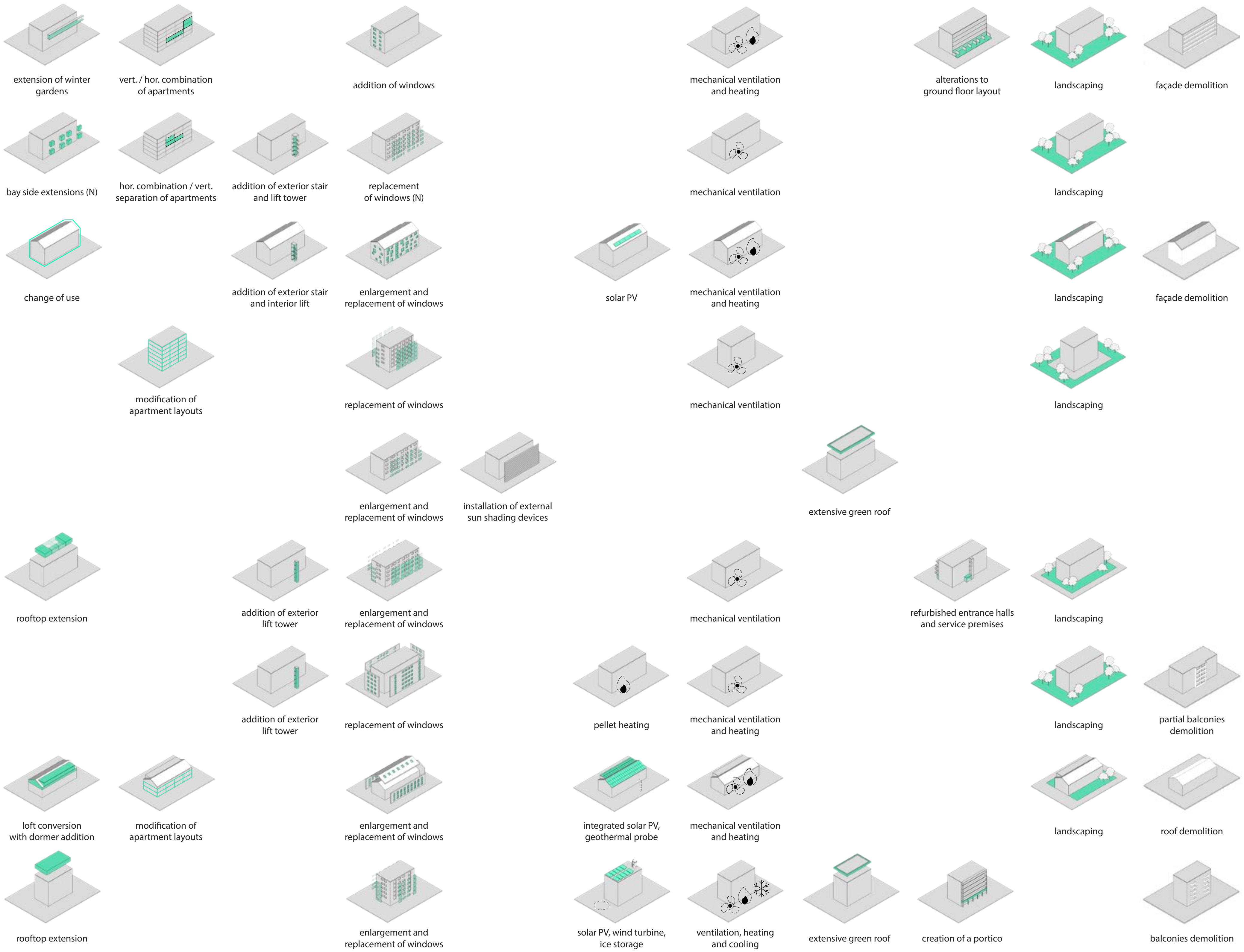


Figure 66: Case studies. Summary table of retrofit measures



extension of winter gardens
vert. / hor. combination of apartments
addition of windows
mechanical ventilation and heating
alterations to ground floor layout
landscaping
façade demolition
bay side extensions (N)
hor. combination / vert. separation of apartments
addition of exterior stair and lift tower
replacement of windows (N)
mechanical ventilation
landscaping
change of use
addition of exterior stair and interior lift
enlargement and replacement of windows
solar PV
mechanical ventilation and heating
landscaping
façade demolition
modification of apartment layouts
replacement of windows
mechanical ventilation
landscaping
enlargement and replacement of windows
installation of external sun shading devices
extensive green roof
rooftop extension
addition of exterior lift tower
enlargement and replacement of windows
mechanical ventilation
refurbished entrance halls and service premises
landscaping
addition of exterior lift tower
replacement of windows
pellet heating
mechanical ventilation and heating
landscaping
partial balconies demolition
loft conversion with dormer addition
modification of apartment layouts
enlargement and replacement of windows
integrated solar PV, geothermal probe
mechanical ventilation and heating
landscaping
roof demolition
rooftop extension
enlargement and replacement of windows
solar PV, wind turbine, ice storage
ventilation, heating and cooling
extensive green roof
creation of a portico
balconies demolition

For example, the project by Atelier Du Pont in Paris (F) adds cantilevered walkways with fixed louvered screens to the parts of the buildings where sunlight conditions were more critical.

In addition to the measures on the building envelope, **technical building systems and renewable energy technologies** represent further major fields of intervention.

On the one side, installing or replacing existing plant and equipment improve the building performance by reducing the overall energy demand. Besides heating systems, mechanical ventilation systems (with or without heat recovery) are widely used to ensure indoor air quality and prevent mold and condensation, which may be caused by very airtight envelopes.

On the other side, renewable energy sources supply the building with clean energy, produced on-site. Solar photovoltaic represents the most employed technology, with particular attention being paid to its architectural integration in the built environment.

Among the case studies, the project by Freivogel Mayer Architekten in Pforzheim (D) relies on an innovative energy concept which combines power from photovoltaic panels and a wind turbine, with hidden solar façade absorbers and an underground ice storage to reach a combustion free HVAC system.

As none of the projects described had building energy performance as the only goal, there are a number of further **interventions on living and circulation spaces** that can be mentioned among the retrofit measures implemented.

In this regard, many projects come with the extension of floor area and internal alterations to the apartments. This allowed to introduce new dwelling types (e.g. attic and duplex apartments, penthouses) or modify apartment layouts (e.g. enlarging small rooms, creating open plan kitchen and living areas, adding mezzanine floors), thus meeting the needs of inhabitants for modern day living.

If necessary, exterior stairs and/or lift towers have been added to improve access to upper floors and ensure barrier free access to the elderly and other individuals with limited mobility.

Finally, changes to ground floor plans (e.g. with the creation of ‘own front door’ units) and upgrades to private or common outdoor amenity space have often been included, so as to improve the integration of the building with its surroundings. Even though no case study takes into explicit consideration the role that open space can play in influencing the microclimate (i.e. urban heat island effect), a couple of projects adopted green roofs as a measure to simultaneously increase the thermal performance of the roof and reduce the water run-off.

Research limitations and perspectives

A few concluding remarks about the retrofit measures and projects presented are now in order.

First, the provisions contained in building energy codes and labels are not the only provisions that a retrofitting project should comply with. Local building and planning regulations, above all, can sometimes hinder the implementation of certain retrofit measures.

Compared to vacant sites, built-up sites often present limited possibilities for action: due to the overlapping and interlocking of height limits, street setbacks, floor to area ratio, shadowing, etc. even the most basic retrofit measures can face obstacles to their implementation. A typical example is the case of altered distances to neighbouring properties as a result of wall insulation.

In this regard, all but one of the case studies consists in free standing blocks and towers, with open space on the four sides. It is apparent that this type of buildings and neighbourhoods, so common in the suburbs of many European cities, easily lend themselves to the retrofit measures illustrated in Figure 66. Further investigations would be needed to assess their transferability to the compact urban fabric.

Second, despite being multi-family buildings, all the case studies were under single ownership. Retrofitting projects in single-owned buildings are much easier to accomplish compared to similar projects in buildings where the apartments are separately owned, and this for two main reasons: faster decision-making process, and access to dedicated funds, especially when it comes to social housing.

But social housing represents only a small part of the total present stock - about 12% at the EU level - and building ownership is highly fragmented. Under these conditions, policy certainty and sustainable funding mechanisms, together with awareness-raising initiatives to sensitise and attract homeowners, are crucial for overcoming existing barriers. The fact that the annual renovation rate is only 0.4-1.2% sends a clear signal that stronger policy packages are needed to boost confidence in the market and increase the uptake of retrofits.

Third, supposing a step change in renovation rates, the retrofits of today will be the buildings of tomorrow, and shallow retrofit measures or poor designs are likely to lead to ‘lock-in’ effects for many years to come. And this not only with reference to the energy efficiency potential of existing buildings, but also to housing and urban quality. Every engagement with a building that does not take this into account is a missed opportunity to combine low-carbon transition with wider regeneration purposes.

From this point of view, the projects illustrated in the thesis can definitely be considered as ‘shining examples’, best practices which benefitted of some favourable conditions: forward-looking clients, experienced design teams, adequate budgets, supportive residents, just to mention a few. It goes without saying that there are plenty of cases in which the application of the same codes and labels led to much less remarkable results.

The outcomes of the research, in general, and the table of retrofit measures, in particular, could be used as a support tool for both policy makers and designers interested in the challenges and opportunities of urban retrofitting.

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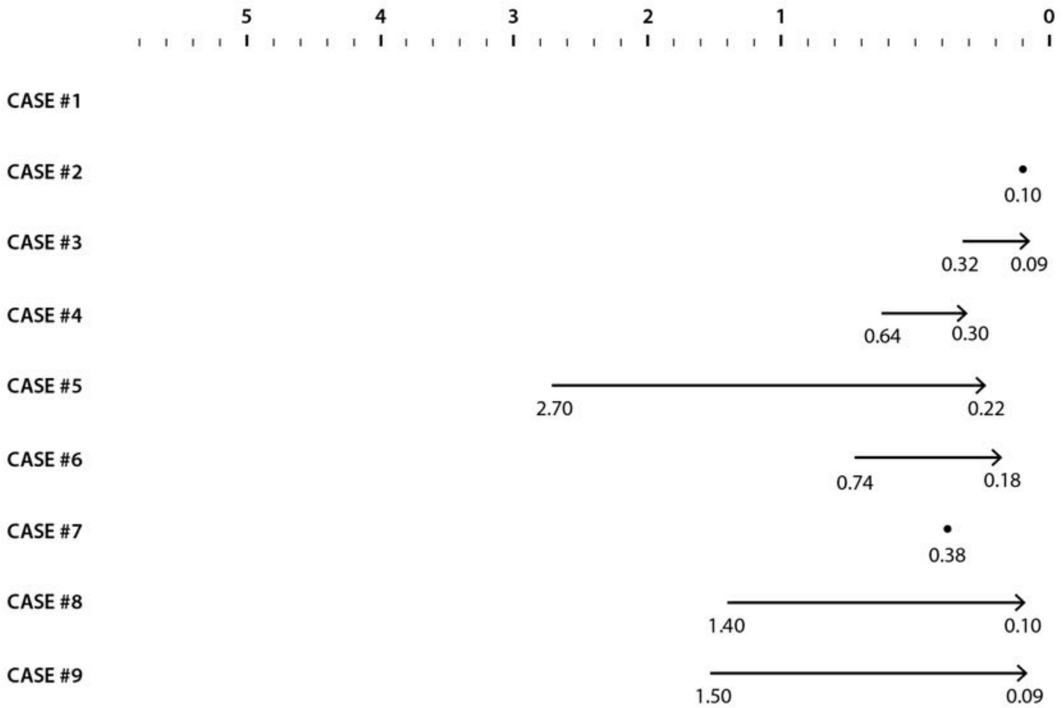
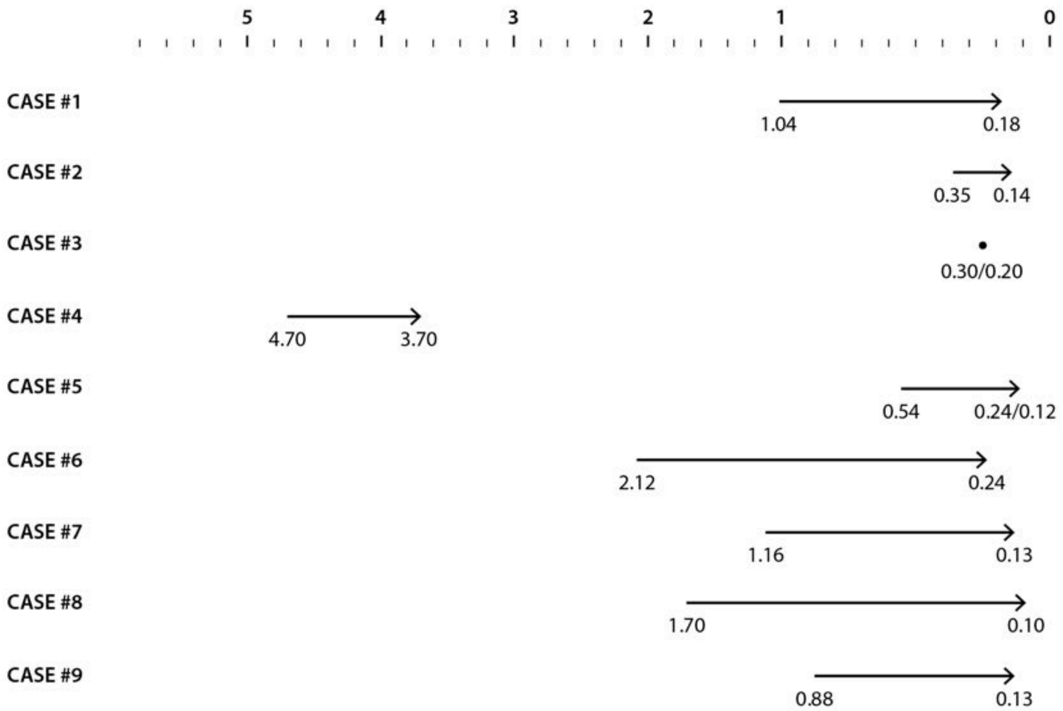
Appendix A

Case studies. U-values of building envelope components before and after retrofit

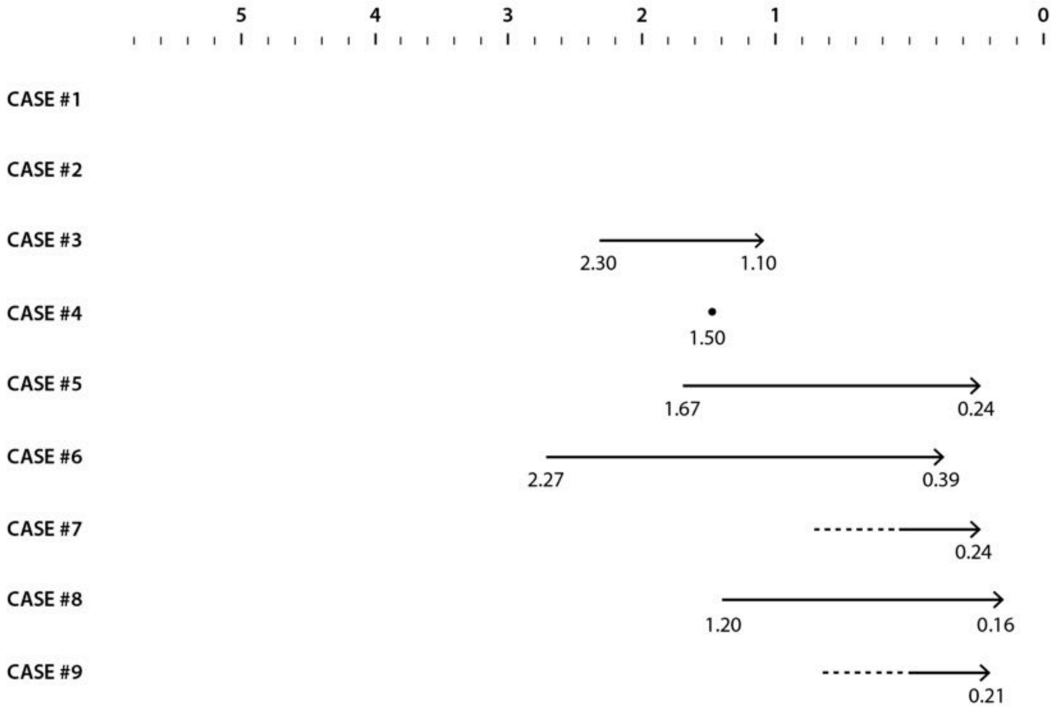
Roof U-values



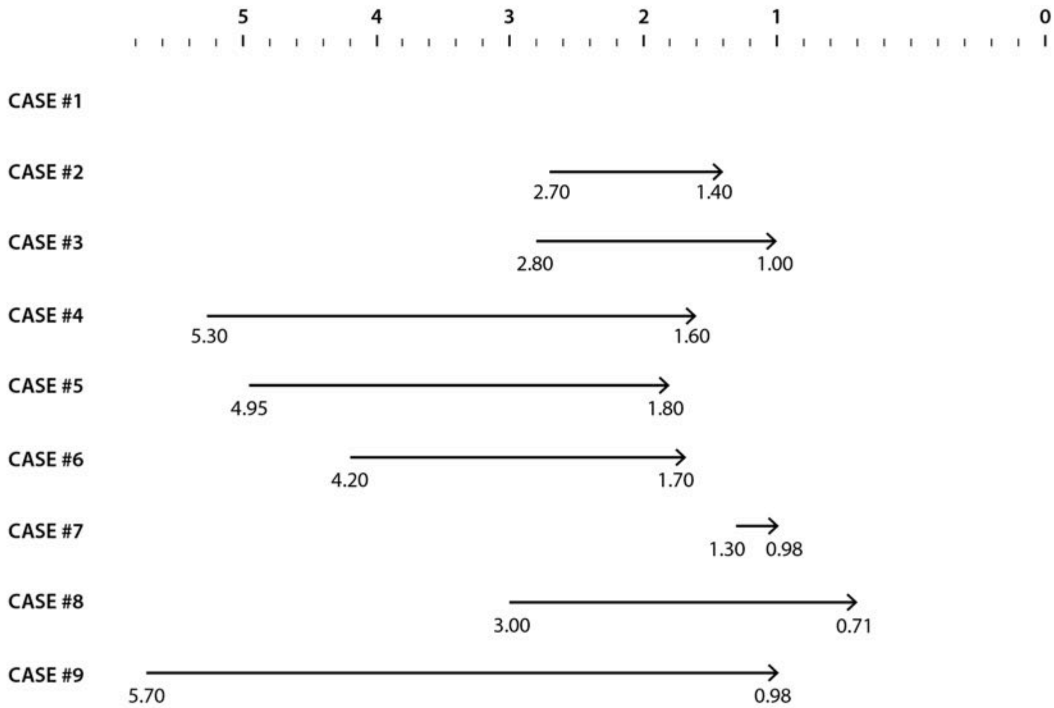
Walls U-values



Ground floor U-values



Windows U-values



Appendix B

Case studies. Section diagrams of typical apartment units before and after retrofit

KEY

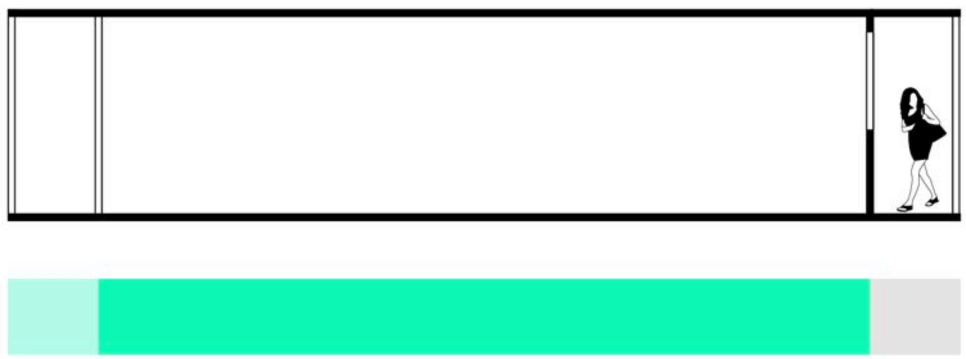
- Private heated space
- Private enclosed space
- Private open space
- Common heated space
- Common enclosed space
- Common open space

Scale 1:100

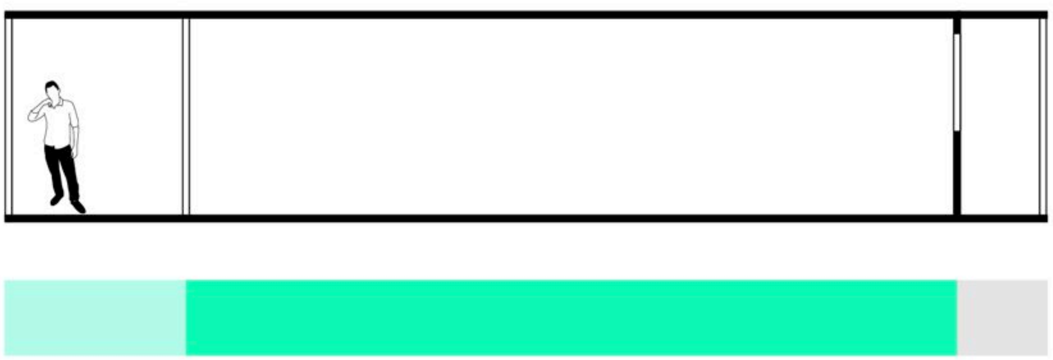
CASE #1 - Magisterparken

Floor 1-13 | Before retrofit

Floor 2-11 | After retrofit

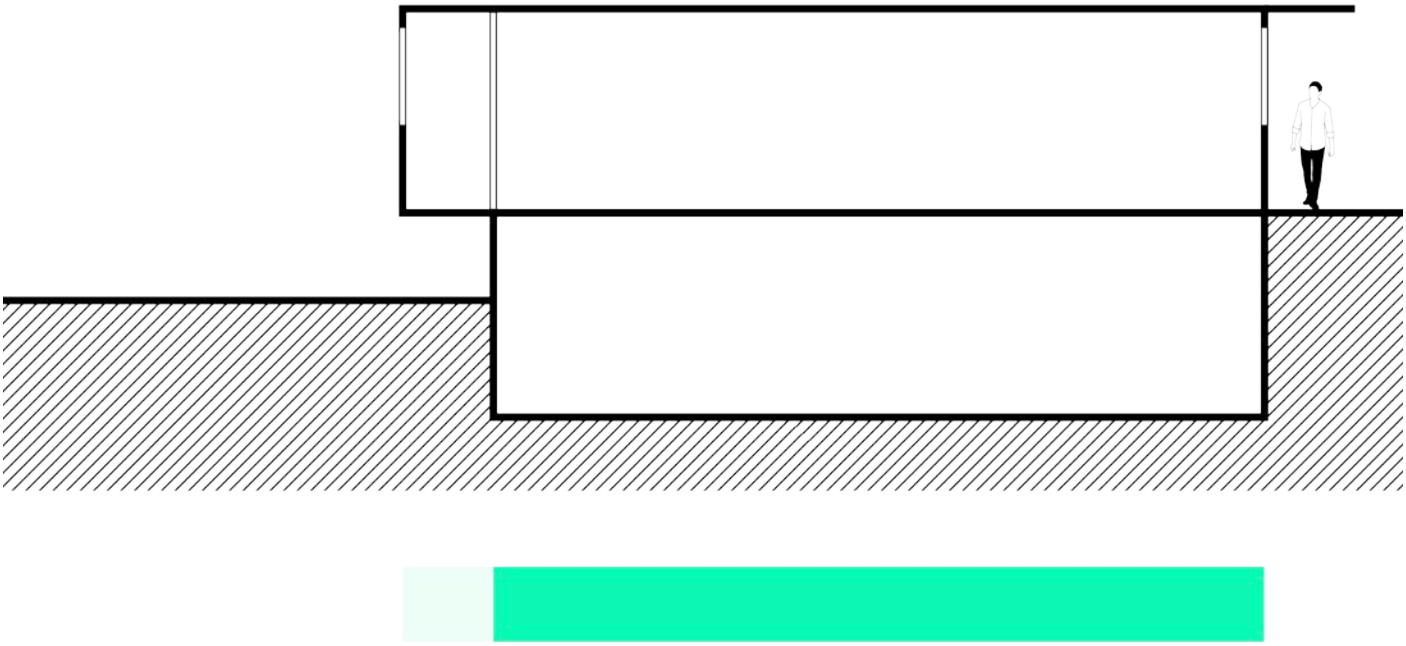


Floor 12-13 | After retrofit

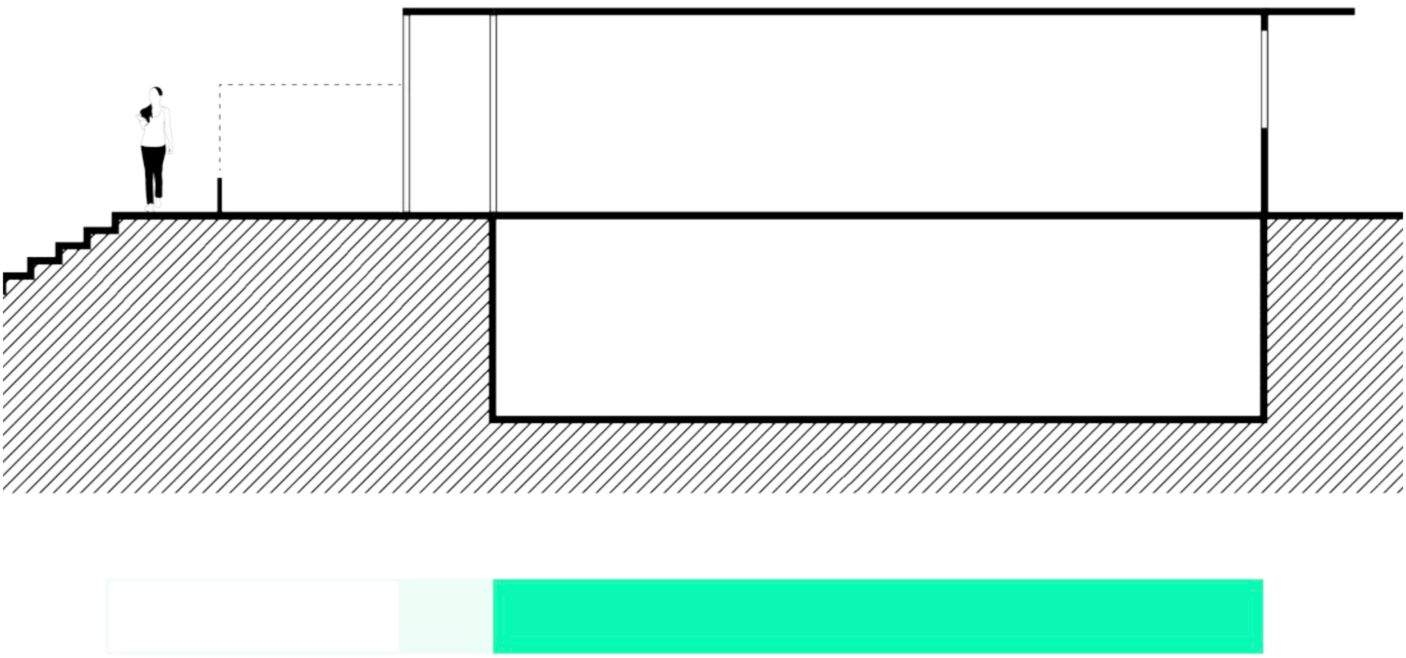


CASE #1 - Magisterparken

Ground floor | Before retrofit

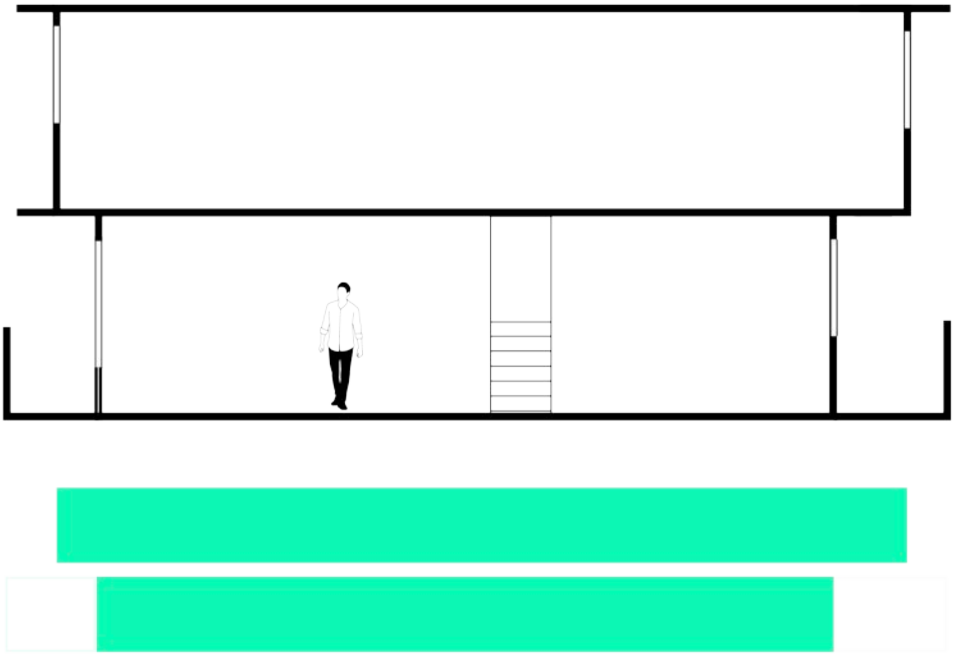


Ground floor | After retrofit

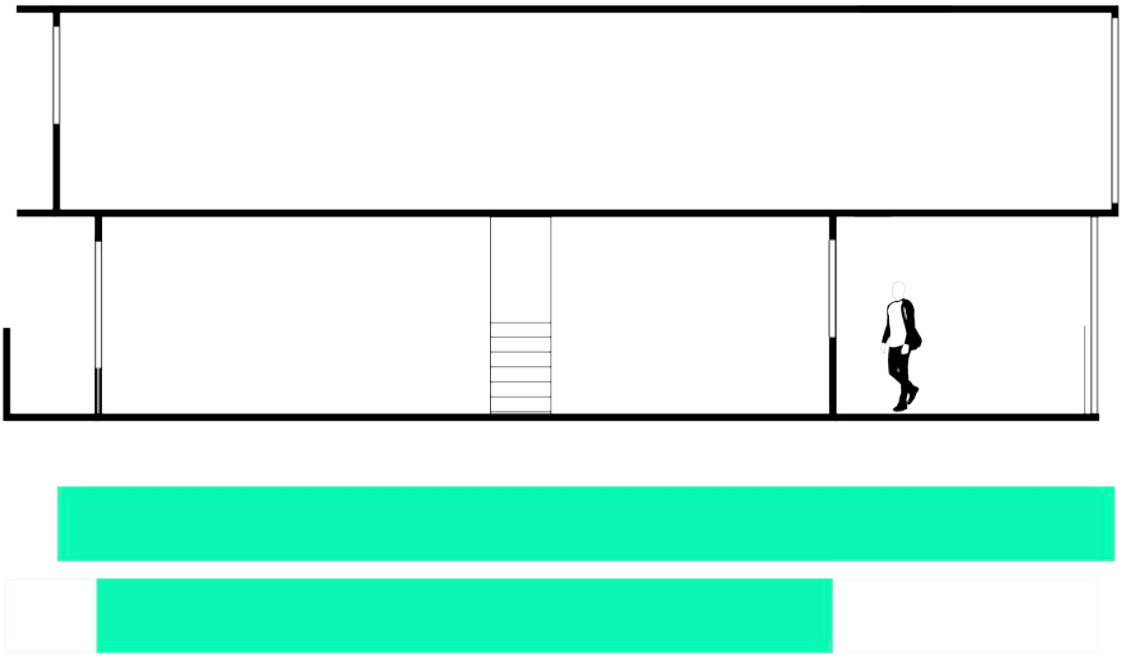


CASE #2 - Tove Ditlevsensvej

Floor 2-3 | Before retrofit

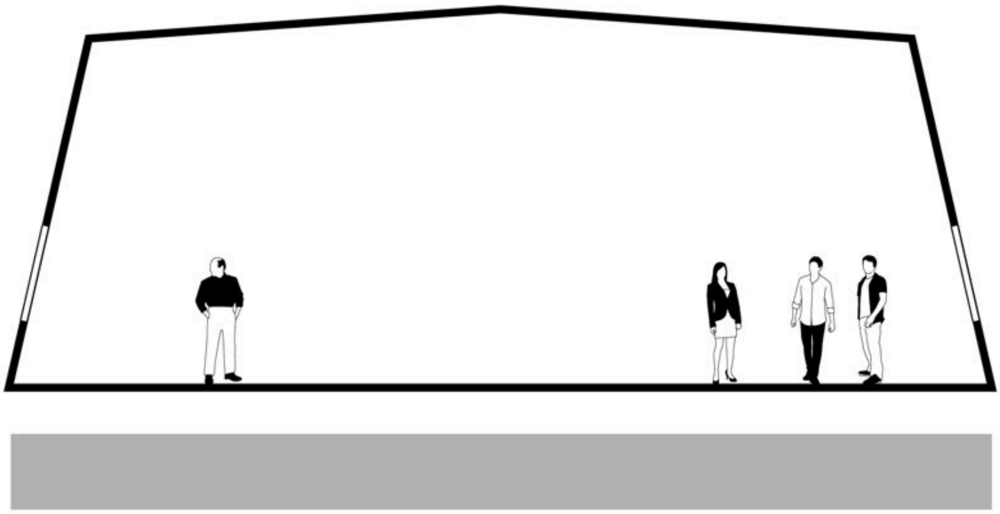


Floor 2-3 | After retrofit

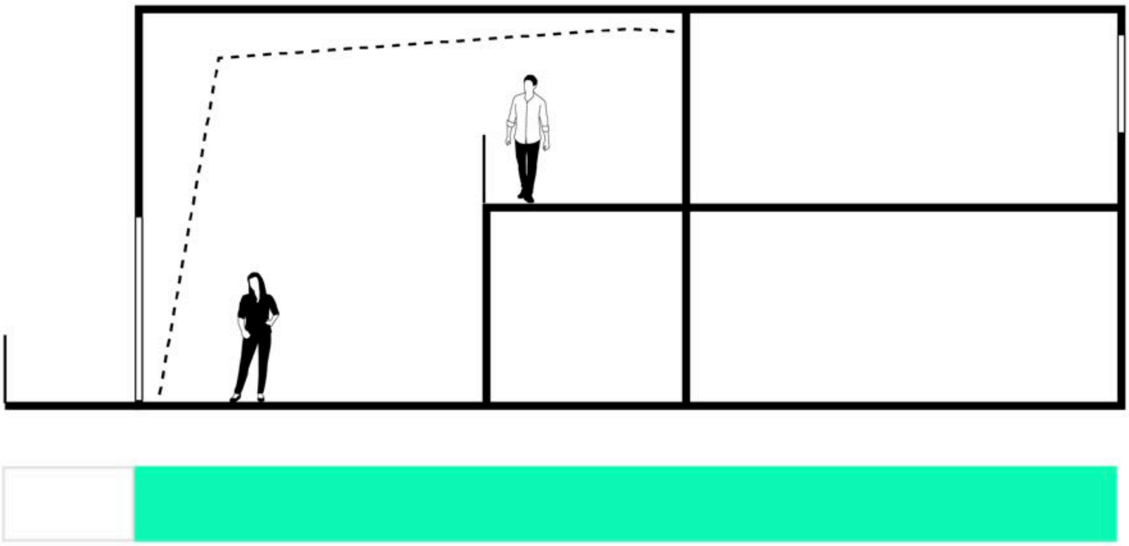


CASE #3 - Sems Have

Upper floor | Before retrofit (Block B)

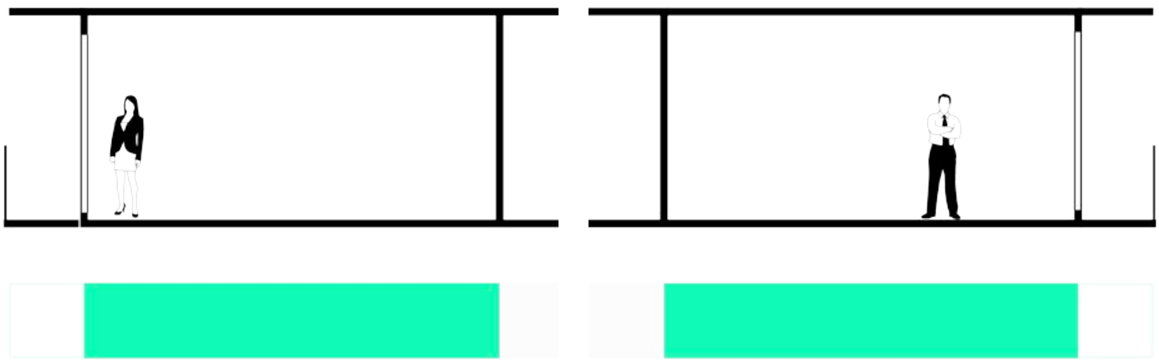


Upper floor | After retrofit (Block B)

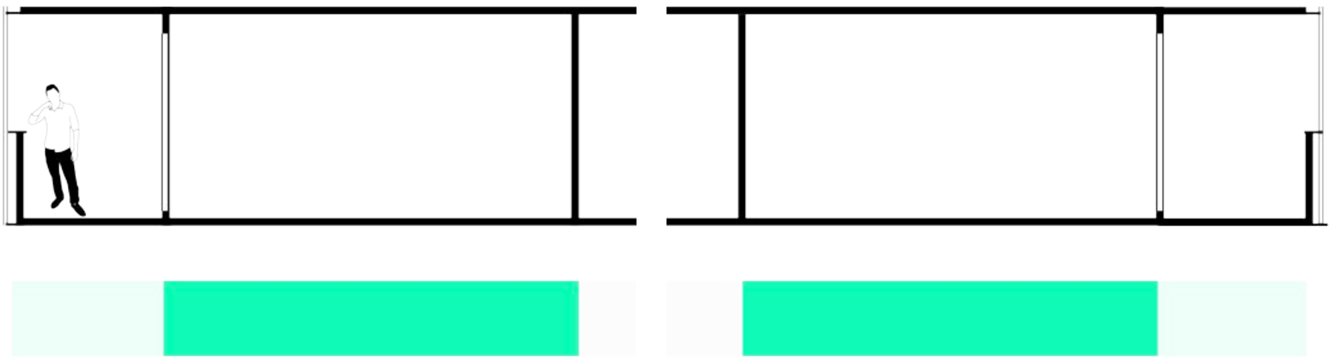


CASE #4 - Résidence Saint-Hilaire

Floor 1-18 | Before retrofit

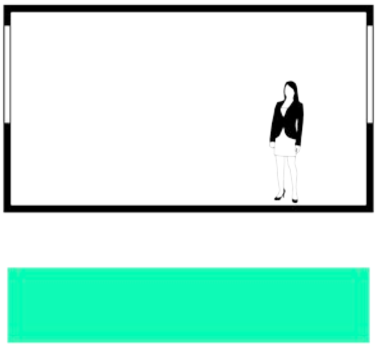


Floor 1-18 | After retrofit



CASE #5 - Square Vitruve

Floor 1-4 | Before retrofit



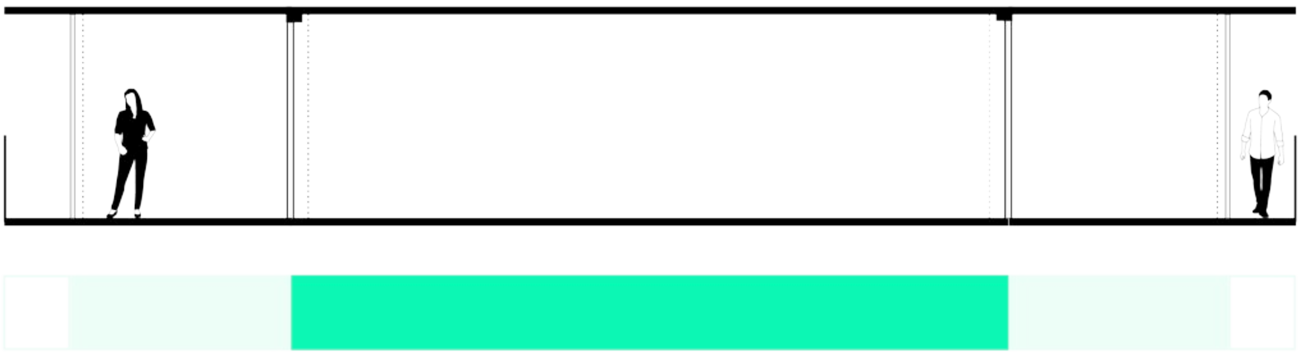
Floor 1-4 | After retrofit

CASE #6 - Bâtiments GHI

Floor 1-15 | Before retrofit (Blocks G, H and I)

Floor 1-15 | After retrofit (Blocks H and I)

Floor 1-15 | After retrofit (Block G)



CASE #7 - Grüntenstraße 30-36

Floor 0-5 | Before retrofit (Type A)

Floor 0-5 | After retrofit (Type A)

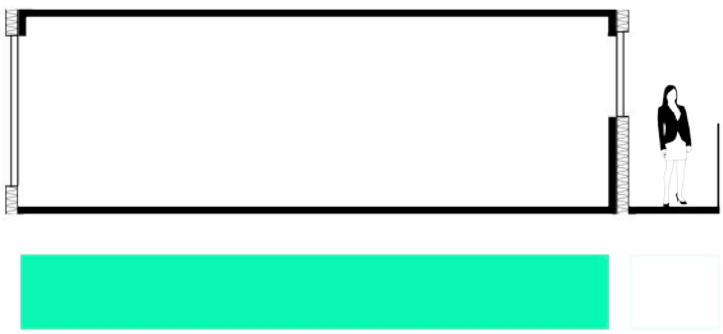
Floor 0-5 | Before retrofit (Type B)

Floor 0-5 | After retrofit (Type B)

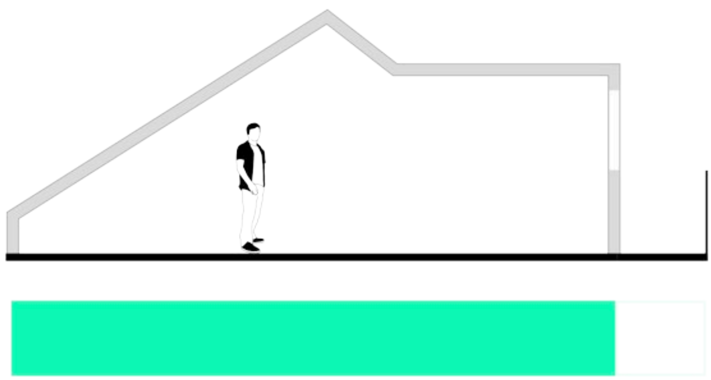
CASE #8 - Pfuhler Straße 4-8

Floor 0-1 | Before retrofit

Floor 0-1 | After retrofit



Floor 2 | After retrofit



CASE #9 - Wohnhochhaus Güterstraße 30

Floor 1-8 | Before retrofit

Floor 1-8 | After retrofit

Floor 9 | After retrofit