4RinEU

Reliable models for deep renovation

D4.1

WP4

Risk Assessment Guidance

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Foreword

Despite the low energy performances of the European building stock, the yearly renovation rate and the choice to perform a building deep renovation is strongly affected by uncertainties in terms of costs and benefits in the life cycle.

The project 4RinEU faces these challenges, offering technology solutions and strategies to encourage the existing building stock transformation, fostering the use of renewable energies, and providing reliable business models to support a deep renovation.

4RinEU project minimizes failures in design and implementation, manages different stages of the deep renovation process - from the preliminary audit up to the end-of-life - and provides information on energy, comfort, users' impact, and investment performance.

The 4RinEU deep renovation strategy is based on 3 pillars:

- *technologies* - driven by robustness - to decrease net primary energy use (60 to 70% compared to pre-renovation), allowing a reduction of life cycle costs over 30 years (15% compared to a typical renovation).
- *methodologies* - driven by usability - to support the design and implementation of the technologies, encouraging all stakeholders' involvement and ensuring the reduction of the renovation time.
- *business models* - driven by reliability - to enhance the level of confidence of deep renovation investors, increasing the EU building stock transformation rate.

4RinEU technologies, tools and procedures are expected to generate significant impacts: energy savings, reduction of renovation time, improvement of occupants IEQ conditions, optimization of RES use, acceleration of EU residential building renovation rate. This will bring a revitalization of the EU construction sectors, making renovation easier, quicker and more sustainable.

4RinEU is a project funded by the European Commission under the Horizon 2020 Programme and runs from 2016 to 2020 (extended to 2021).

The 4RinEU consortium is pleased to present this report which is one of the deliverables from the project work.

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Contents

Executive Summary

In this report, risk management in deep renovation projects using the technologies and methods developed in 4RinEU is described. The report is prepared for professional owners or managers of dwellings but can hopefully also be of use for building surveyors, designers and contractors as well as less professional building owners. It is assumed that the readers' organizations already integrate risk management in their business operations and have not attempted to cover risk management in building management.

In order to reach sustainability goals for building owners, Europe and the world, deep renovation of low-performing buildings is a necessity. Building renovation is in many respects a more complex process than the building of new buildings, and the risks and uncertainties in this process can delay or prevent renovation projects. The authors would like to stress that in building management, doing nothing may over time be one of the riskiest behaviours of all, with building deterioration, negative health impact on building users, loss of market value, increasing costs of operation and negative impact of owner's reputation as possible outcome. Identifying the uncertainties, managing the risks and overcoming the barriers is needed to make a more sustainable building stock while helping the building owner and manager to sleep well at night.

In this report we define risk as "the effect of uncertainty on objectives". Objectives related to health and safety, environment and economy are given priority, while it is emphasized that the reader needs to adapt her risk management to her own objectives.

A long range of risks described in the literature is discussed in chapter 3, underlining that technologies and procedures for building renovation need to be robust.

A key message is that thoroughly assessing the condition of potential renovation objects early in the decision-making process is an important step in selecting suitable technologies for deep renovation. Such an assessment will help to identify limitations and cost-driving elements as well as the potential.

Examples of limitations and enablers to look for in the technical assessment:

- Asbestos, PCBs or other materials that need special procedures for removal or remediation.

- Decay and other moisture damage, potentially detrimental to the building's stability or the health of inhabitants or users.
- The actual construction and materials may deviate from assumptions. This is important when e.g. prefabricated facades are planned to be fixed to existing construction.
- The sizes of components in hydronic heating systems are important for utilization of local heating sources.
- Ducts, shafts or other spaces that can be utilized for new ventilation ducts or pipes. In some cases, existing ducts can even be re-used.
- Potential improvements in e.g. ease of access, fire safety, security or quality of outdoor spaces that can be combined with deep renovation to further increase building value.

In addition to the technical condition of the building, thorough knowledge about the building context: physical, environmental, societal and legal, makes it possible to select deep renovation methods where risks are identified, described and reduced to acceptable levels.

Examples of limitations and enablers to look for in the contextual assessment:

- Building regulations or cultural value of façade can preclude façade renovation.
- Trees, buildings (possibly not yet erected) or local weather may seriously reduce the energy production from photovoltaic panels or solar thermal collectors.
- Bad local air quality can limit the potential of using natural ventilation, or seriously increase the maintenance need for photovoltaic panels or solar collectors.
- Smoking areas, exhaust from nearby buildings or traffic situation can be important for the right location of air intake.
- Public access to areas near the building may limit where instrumentation, PV panels or air intakes should be placed.
- Local energy systems (electrical or district heating) may enable export of surplus heat or electrical power from renewables.
- Legal restrictions may limit the utilisation of local produced power on building or neighbourhood scale.
- Protection of user's privacy may limit collection or use of data on energy consumption, indoor air quality or user behaviour.

4RinEU has attempted to develop robust methods and technologies for deep renovation. In chapter 4 guidance to risk management in projects is given, using these methods and technologies.

- It is more important to produce power when it is in demand than to maximize kWh production. Use the Early ReNo tool with correct input in the early decision-making to increase the profitability of renewable energy sources by optimal sizing and placement of renewables.

- Users who do not behave as expected can cause the energy usage and indoor climate to be quite different from expectations both before and after renovation. Using the Sensible Data Handler can aid to a better understanding of user behaviour and better interaction between user and building systems

- Using prefabricated multifunctional façade elements can reduce risks and costs of relocating dwellers for a long time. It is important to
    - Ensure a thorough planning considering all inputs from the survey and from all involved planners, prior to moving to the construction site
    - Make detailed plans for transport and installation
    - Prepare for delays in transport, damage and unfavourable weather
    - Verify proper installation, e.g. by testing air leakage.

- Using the plug and play energy hub may provide a solution for integrating locally produced hot water and district hot water to heat building and domestic hot water which is simple and with low risk.

- Proper dimensioning, installation and smart control of ceiling fans can increase thermal comfort in hot conditions with minimal energy or installation effort.

As an appendix, we have prepared a mapping of important technical, environmental and societal risks that are of importance for selecting different deep renovation technologies. This is primarily intended to be used together with the 4RinEU rating tool.

1 Introduction

1.1 Purpose and scope of this document

The purpose of deliverable 4.1 is to provide guidance for evaluation of the robustness and flexibility of the technology concepts developed and used for building refurbishment, as defined by the 4RinEU projects. These technology concepts are prefabricated multifunctional facades, plug-and-play energy hub, use of local renewable energy sources and the use of the Early Reno tool, smart ceiling fans and Sensible data handler.

New technologies are always connected with a certain amount of risks, both in the context of malfunction and unforeseen adaption problems. Even if the concept itself is considered safe, the challenges with application to different types of existing building constructions will be addressed. The aim is to identify and avoid undesirable solutions and suggest possible measures that can reduce the likelihood or magnitude of unwanted effects.

1.2 Introduction to risk assessment in 4RinEU

A **Risk** can be defined as 'the effect of uncertainty on objectives'. This definition emphasizes that uncertainties imply positive opportunities as well as perils. In daily language, as well as in this document, we mainly focus on the aspect of risk as some possible event that can cause unwanted effects. Since the event is possible it will have a **likelihood** or **probability** that can be large or small, and it will have a **consequence –** that could be small and large – on some more or less important objective.

Assuming that all organizations (and individuals) have objectives, and that there are risks connected to all objectives, some kind of **risk management** should be present in any organization. It is commonly advised (see e.g. COSO 2019) that risk management should be:

- **Integrated** in the management of core activity
- **Adapted** to the actual organization (strategic objectives, priorities, resources, sector, etc.)
- **Objective**, i.e. focusing on realities rather than perception
- **Prospective** rather than retrospective

The 4RinEU project group aims to ease **some** of the processes involved in good practise risk management, namely the processes most directly connected to deep renovation technologies. General recommendations for risk management are not given here, but can be found, e.g., in (COSO, 2019; ISO, 2018).

Risk assessment can be defined in several ways and in textbook examples it often includes quantification of probabilities and consequences. While this may be feasible in some well-characterised situations, it is mostly beyond the ambition level of 4RinEU. Furthermore, the management – including reduction – of risks is often more relevant to stakeholders than quantification. Ayse and Nordal (2015) suggested a classification of possible events with differing uncertainties, which is illustrated in Figure 1. According to the authors, the different kinds of uncertainty need to be treated in a different way. The "black swans" are per definition unforeseeable, while "Grey swans" can be foreseen as events, but neither probability nor consequences are known. Such events pose big problems for defined risk analysis and are probably best treated by general robustness. The blue arrows represent the main field of work for risk analysis.

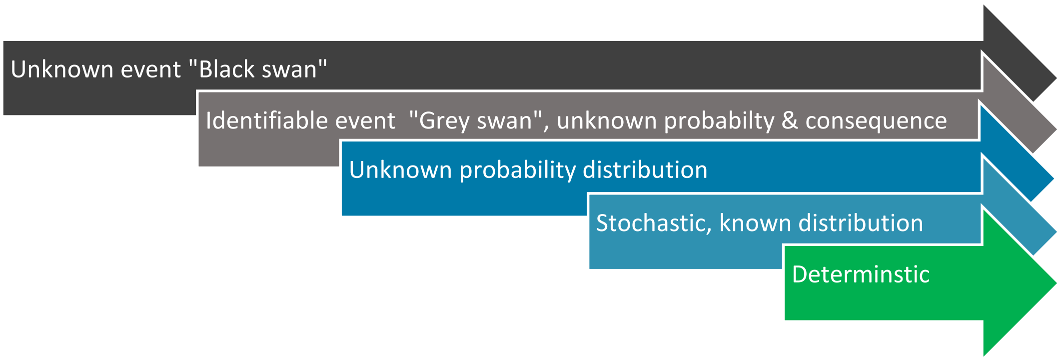

Figure 1. Classification of events according to degree of uncertainty. Illustration of hierarchy suggested by Ayse and Nordal (2015).

Instead of quantification, we focus on developing a manageable hazard identification process, presuming that stakeholders generally are capable of managing known risks, even if the associated probabilities, and quantitative prediction are unknown. This hazard identification process is built upon three underlying procedures: identifying undesired events, identifying undesirable effects, and assessing which events cause which effects.

An example of an undesired event is a stone hitting a window, and undesired effects of such an event can be that the glass breaks, the room gets cold or that someone gets cut by the broken glass.

After the initial risk assessment, the stakeholder needs to evaluate if the risk should be **avoided, mitigated, transferred / shared or accepted**. After mitigation (reducing likelihood and / or consequence), a revised assessment is performed.

In the window example, avoiding having a window would only be the preferred choice in rather extreme situations, it would be better to mitigate the risk by reducing the likelihood of the event (e.g., by making friends with stone-throwing local youths) or reducing the consequences – perhaps by installing some kind of safety glass – so no one will get seriously hurt. Sharing the risk through, e.g., insurance is probably not worthwhile in this case, so after some mitigation the risk is accepted.

Literature studies on risks relevant for deep renovation projects and deep renovation technologies are reported in Chapter 3 Literature survey. During the design and development of the 4RinEU technology packages, several loops of risk assessments / mitigation have already been performed in order to contribute to robust and cost-effective deep renovation packages, with the intention of reducing or eliminating the risks described in the literature.

In Chapter 4 the management of known remaining risks is described for the successful application of each technology. A thorough process of hazard identification typically results in a long list of things that possibly could go wrong. Hopefully most of the risks on such a list can be managed quite easily, as they are small or only relevant in particular cases.

It is important to understand that all stakeholders face different risks all the time, and that "doing nothing" may involve quite high risks. However, risks of active and "new" alternatives (renovation) are often being perceived as more threatening than the passive alternative of doing nothing (Hauge, Löfström, & Mellegård, 2014; Hauge, Thomsen, & Löfström, 2013). This may form a significant barrier against building renovation.

As a means of counteracting this tendency to underestimate risks with familiar practice, we suggest that the techniques for assessing and handling risks related to renovation specifically include "business as usual" as an alternative.

1.3 Methods

This chapter describes the steps taken to develop the final guideline for risk assessment, and NOT the method for risk assessment.

A limited literature survey on known risks is performed by "snowballing" from selected papers on barriers against energy-motivated building refurbishment, facade renovation, retrofitting of renewable energy sources, mechanical ventilation, "energy hub", cooling devices and causes of building defects.

The experience of some of the experts participating in the project were collected by structured workshops.

Each of the energy saving technologies included in the technology packages has been subject to a generic risk assessment process, resulting in technologies where identified vulnerabilities are mitigated by describing their limitations in use.

In order to make the risk assessment guidance relevant for practitioners, risk management procedures used by participants in the pilot projects were collected and reviewed.

A checklist of important risk factors and their possible implications for choice and adaptation of deep renovation packages were synthesized from the results of literature survey and expert opinions and is intended to be used together with the rating tool (D 4.2) of this project.

2 Literature survey

2.1 Structuring of objectives

As 'the effect of uncertainty on objectives' is one way to define risk, it may be useful to prepare a structured list of objectives as a starting point for assessing the risk associated with renovation vs. non-renovation and comparing alternatives. The term 'sustainability' was coined to describe the need to balance present needs with the needs of future generations in the evaluation of change. Sustainability is normally assessed by criteria within the three domains of Social, Environmental and Economical sustainability, and this is reflected in the current European standard for sustainability assessment of construction works [EN 15643-series].

1. Sustainability categories within the three main categories, as defined by EN 15634-series of standards.

Social categories	Environmental	Economic
• Accessibility • Adaptability • Health and comfort • Loadings on the neighbourhood • Maintenance • Safety/security • Sourcing of materials and services • Stakeholder involvement	• Environmental impacts • Resource use • Other environmental	• Cost • Financial value • (Market value/capital cost) • (Stability) • (Economic risk) • (External cost) • (Consequential aspects)

Cultural aspects are sometimes included as a fourth domain and are especially important for historical buildings. A review of energy retrofits of traditional and historical buildings (Webb, 2017) discussed some of the particular challenges with these buildings, but highlighted that making these buildings more comfortable and energy-efficient may also contribute to their preservation for the future.

A recent study (Kamari, Corrao, & Kirkegaard, 2017) claims that sustainability assessment of building renovation processes often misses important aspects, and after literature study prepared a list of 142 aspects grouped in the categories functionality, feasibility and accountability. This high number of aspects may be perceived as somewhat overpowering and this framework may be useful mostly as a guide for ensuring that important aspects are not lost in discussions and highlighting the functional qualities of the building as fundamental for its value.

Within the 4RinEU project performance on five areas have been targeted: Energy, Environment, Comfort, Building site management, Economy. These areas form an important subset of sustainability aspects and are emphasized in the literature review. Deliverable 3.5 (Thunshelle, Denizou, Hauge, & Thomsen, 2018) emphasizes that the needs of building users are potentially important as drivers of building refurbishment.

2.2 Economical risks as barriers against deep building renovation

Building renovation is commonly perceived as an activity with higher risks than construction of new buildings (Reyers & Mansfield, 2001) and uncertain profitability of investments in improving environmental qualities in building projects may constitute a major barrier preventing a greener building sector. Uncertainties in actual investment costs, energy performance and market value may restrict the investors willingness to set ambitious targets for new buildings, and it could be argued that the uncertainties are even higher when deciding on deeply renovating an existing building. In a questionnaire study among 35 respondents, "unexpected costs" was ranked as most serious risk when renovating historical buildings (Mallawarachchi, Hansamali, Perera, & Karunasena, 2018) as it had the highest probability of all considered risks, as well as a high impact.

Hauge and co-workers (Hauge et al., 2014; Hauge et al., 2013) identified fear of higher monthly costs as an important obstacle in cooperative housing upgrades, and stressed the importance of including accumulated maintenance needs when comparing alternatives: while the suggested upgrade would lead to higher monthly costs, the upgrade would also take care of maintenance issues that soon would need attending to, anyway.

For professional house owners, the priorities and decision processes are somewhat different, but the importance of including accumulated maintenance needs in the assessment may be as valid for these as for the tenant owners in cooperative housing.

Researchers have found that there is a willingness to pay (WTP) higher prices or rents for energy-efficient dwellings in Ireland (Hyland, Lyons, & Lyons, 2013), United Kingdom (N. Liu, Zhao, & Ge, 2018), USA (Im, Seo, Cetin, & Singh, 2017) and Sweden (Zalejska-Jonsson, 2014). However, (N. Liu et al., 2018) noted that the willingness to pay a premium was smaller in times of economic recession, and the WTP may only be sufficient to pay for minor upgrades (Collins & Curtis, 2018). In other markets, e.g., Australia (Chan & Tony, 2016) the WTP for increased energy efficiency may be lower. The willingness (or ability) to pay may be lower and investment risks higher in shrinking than growing cities, see (Weinsziehr, Grossmann, Groger, & Bruckner, 2017) for a discussion. In a shrinking city or neighbourhood, a landlord may face the dilemma that increased rent may not cover refurbishment costs, while unrefurbished dwellings may become too unattractive to have tenants at all. (2015) noted that energy efficiency measures had higher relative influence on market value in areas with lower than higher property prices.

Also, uncertainty of investment costs is an important barrier against investments. (McDonald & Siegel, 1986; Menassa & Ortiz-Vega, 2013). A more detailed discussion on the risk factors affecting costs are included in the sections on the included renovation technologies.

Attempts have been made to incorporate uncertainties in LCC analysis by the use of probabilistic methods, and one of these studies (Di Giuseppe, Massi, & D'Orazio, 2017) highlights the importance of basic financial parameters like discount rate and inflation, while also stressing the multitude of influencing factors. Their results further illustrate the general point that smaller samples have higher relative variability, i.e., that diversification reduces overall risks. (Copiello, Gabrielli, & Bonifaci, 2017) demonstrated that within their assumptions, the discount rate was the most important factor.

(Zheng, Yu, Wang, & Tao, 2019) described how probabilistic methods could be used to further describe the economic risks when investment, energy saving and energy price all are uncertain, but assuming known probability distribution. In their example, they found that excluding thermal insulation of roof, external wall and the retrofit measures with the highest investment costs per saved energy unit reduced the value-at-risk from 97,6 % to 0,07 %.

Uncertainties in future energy costs is to an increasing degree related to short term variable electricity costs due to variable production from renewable sources and demand peaks. Thus, it is likely that energy flexibility (ability to shift energy loads) will have some financial value in the future energy market. Increasing, or at least preserving, the energy flexibility, can reduce the risk of energy market changes decreasing the profitability of investment.

Deliverable 3.4 of the 4RinEU project (Barchi & Dallapiccola, In prep.) provides a discussion of grid interaction and district-scale deep renovation.

2.3 Generic risks of energy performance gap

Several authors have observed that energy savings after implementation of energy saving measures are often lower than predicted. Concepts such as rebound effects (Galvin, 2014)

– energy use after renovation is higher than expected – and prebound effects (Sunikka-Blank & Galvin, 2012) – energy use before renovation is lower than assumed – have been coined to describe energy performance gaps due to behavioural changes.

(Calì, Osterhage, Streblow, & Müller, 2016) studied refurbishment of German apartments and found that the causes of discrepancy between estimated and actual energy savings in four categories, of which two are mainly related to behaviour and two to technical issues. Users may commonly increase indoor temperature and ventilation to more comfortable levels after refurbishment. On the other hand, users or operators may use the building and its installation in an inefficient way without gaining in comfort – often attributed to lacking understanding or lack of user friendliness in user / equipment interface.

Figure 2 Four different types of reasons for actuals savings being smaller than expected. Adapted from Cali & al 2016.

2.4 Health, safety and environmental risks in renovation processes

Health and safety of construction workers is an important concern in all building processes, and it is assumed that proper risk management procedures are implemented by all contractors. Some studies point out that renovation may have higher and different risks than new-builds. Dusts from demolition and renovation work may contain a range of harmful agents (Hameed, Yasser, & Khoder, 2004), due to moisture damage in construction (Johanning, Auger, Morey, Yang, & Olmsted, 2014), (Hasegawa, Schleibinger, Nong, & Lusztyk, 2009) or harmful building materials such as asbestos (Latif et al., 2011) or lead-containing paints (Jacobs, 1998).

During renovation work, there is also a higher risk that a more vulnerable population will be exposed. The importance of the different vulnerability between healthy workers and the general population is reflected in much stricter guidelines for indoor air quality than for occupational exposure (Balaras et al., 2000).

(Ronk, Dennerlein, Hoffman, & Perry, 2011) observed a (non-significant) tendency of less compliance with best safety practice in renovation than new construction projects.

The scientific literature on specific environmental risks in renovation of residential buildings seems relatively scarce. In general, construction site environmental management systems aim to reduce the noise and disturbance, emissions to air, water and soil and reducing waste (Barrantes, Piedra-Marin, Brenes, & Cordero, 2019); (Rahman & Esa, 2014)

The use of prefabricated elements has been promoted as a means to reduce environmental impacts (Borja, César, Cunha, & Kiperstok, 2018), and this is probably even more relevant in renovation projects, where the space available for e.g. waste treatment often is very limited. The environmental risks in renovation projects overlaps the environmental in the end-of-life of the building, particularly the aspects related to the treatment of used building materials / waste. Guidelines are given in Hiniesto, Olmo, and Romera (In prep.).

2.5 Procurement and financial schemes risks

Currently there are several financing schemes, from the traditional ones where the owners (public or private) has a own budget (also through a bank loan) to the most alternative ones like Public private partnership (PPP), Energy performance Contract (EPC) and crowdfunding (CF) that involve private partners to finance building initiative (new or renovation one).

Each financing scheme has a different procurement and developing process. Nevertheless, from the early phases of the renovation process, it is very important to identify objectives, working team, reasonability and verification processes to test the real results achieved. This is due to the different management features connected with each financing scheme.

At European level there are several regulations on public procurement and public tenders, public private partnership and energy performance contracts, in particular:

- Directive 2014/24/EU on public procurement
- Directive 2014/25/EU on procurement by entities operating in the water, energy, transport and postal service sector

- Directive 2014/23/EU on the award of concession contract
- Directive 2004/18/EC of 31 March 2004 on the coordination of procedures for the award of public works contracts, public supply contracts and public service contracts.
- Directive 2006/32/EC of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC

Public Private partnership (PPP)

Public Private partnership (PPP) is "a long-term contract" between public and private parts, designed to deliver a public infrastructure project and service (Figure 3). Under this contract, the private partner bears significant risks and management responsibilities. The public authority makes performance-based payments to the private partner for the provision of the service or grants the private partner a right to generate revenues from the provision of the service. In a PPP, the private finance is usually involved. When properly prepared, PPP projects can provide significant benefits to the public sector as well as to the project users. (Source: EIB, https://www.eib.org/epec/)

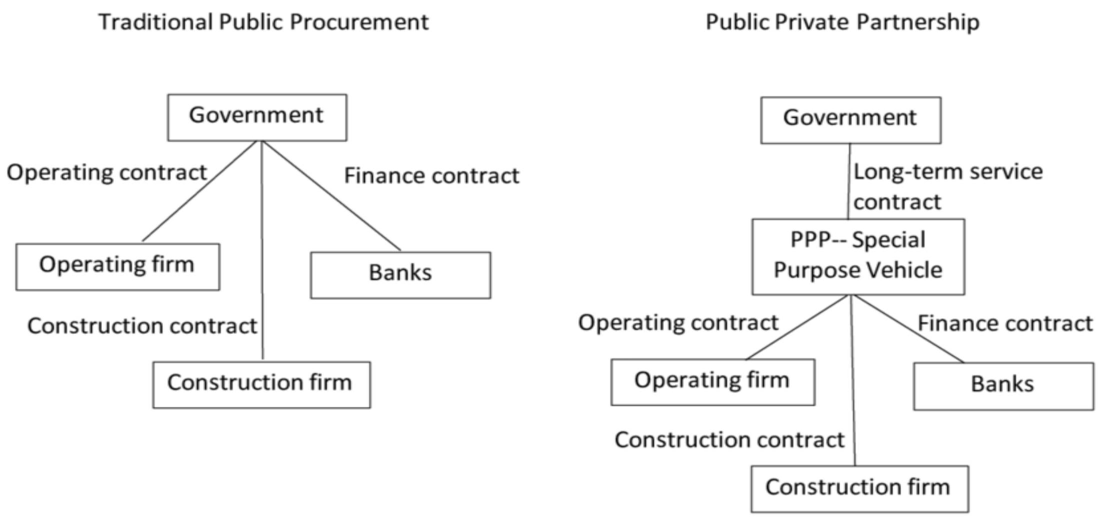

Figure 3: Scheme of PPP(Jin & Rial, 2018)

PPP contracts are more complex than a traditional process (public procurement), because they require a detailed project development, from the construction to the management phase, including maintenance and services costs. Risks will be identified, classified and estimated, in parallel mitigation measures will be identified, and risks that affect negatively the business plan have to be shared between public and private partner

Figure 4 shows the risk distribution between public and private part under different procurement schemes.

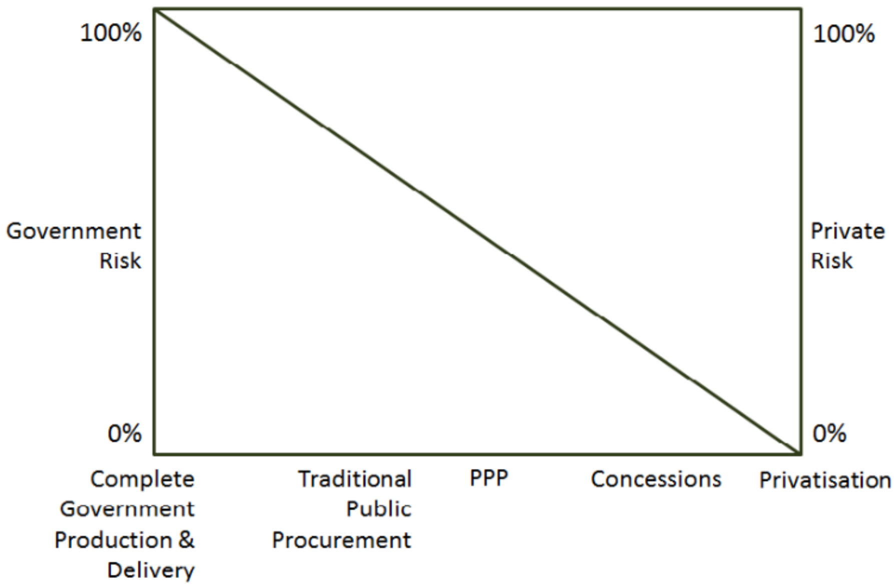

Figure 4: different combinations of public and private partnerships, classified according to risk and type (OECD, 2012)

PPP guidelines elaborated by the European Investment Bank (EIB) are available at the following link: https://www.eib.org/epec/g2g/index.htm.

Energy Performance Contracts (EPCs)

EPCs are part of the PPP contracts. EPCs consist of financial instruments based on energy services and projects, that increase the energy savings during each renovation process.
EPCs have usually a duration of at least 10 years (notably when related only to part of the energy system equipment) but they also may run up to 20 years and more in deep renovation process, when there is a need of significant refurbishment on the building structure itself.(EUROSTAT, 2015).

EPC guidelines elaborated by European Commission are available at https://ec.europa.eu/eurostat/documents/1015035/7959867/Eurostat-Guidance-Note-Recording-Energy-Perform-Contracts-Gov-Accounts.pdf/.

Risks connected to each financing scheme could be several and due to different reasons. Some of the possibilities are listed here and are further explained in T*able 2*:

- Political risks, government instability or change in building regulation code, ...
- Financial risks, poor business plan or energy savings not achieved, …
- Economic risks, costs increase, …
- Design risks, undetailed projects or poor project information, …
- Installation risks, bad installations, high maintenance costs, …
- Technology risks, wrong solutions systems or sizing, breakages, …
- Operation risks, changes in the building use or number of people, …

Measures and verification risks, modelling errors, improper M&V design, …

T*able 2. PPP and EPC risks: part 1: political, financial, economic and design risks. Source: (Ke, Wang, Chan, & Lam, 2010; Lee, Lam, & Lee, 2015)*

Risks	Causes	Consequences	Solution
Political	Unfeasibility of changes in the agreement		
Political	Government's reliability	Influence economic events	
Political	Change in law or in the building code	Building's project changes ➔ Construction costs increase ➔ Reduction of profits (for the ESCO)	Specify which laws and regulations that are fulfilled by the contract, and how to deal with any changes.
Financial	Bankruptcy (in PPP)	Building's workings unfinished	Bank guaranty
Financial	Payment default (in PPP)	Energy savings are not achieved (in particular in EPC)	Guarantee in energy savings
Economic	Energy source tariff change	Fuel cost increase: it affects negatively the financing contract	Estimate change in energy cost during the years of exploitation prior to contract. Distribute energy cost risk in contract. Consider long term energy contract if possible.
Economic	Interest rate increase	Interest rate volatility	Consider fixed interest financing.
Economic	Construction costs increases		
Economic	Reduction of profits (for the ESCO)		
Design	Project changes during the construction phase	Building's project changes ➔ Construction costs increase ➔ Profit reductions (for the ESCO)	Include a clause in the contract for project changes
Design	Inappropriate design , renovation measures or technology choices (as system size)	Economic unfeasibility for the ESCO.ESCO renounces to the contract	Include a clause in the contract with the penalization when renouncing the contract

Table 3 PPP and EPC risks: part 2: installation, technology, operation and verification risks. Source: (Ke et al., 2010; Lee et al., 2015)

Risks	Causes	Consequences	Solution
Installation	Delay in the construction phase (also due to external issues,such as weather)	Extension of the working time ➔ costs increase	
Technology	Change of the technology system	Reduction in the energy savings	
Operation	Poor maintenance	Fast degradation è Reduction in the energy savings - Energy consumption increase	Specify minimum maintenance in contract and penalizations to the ESCO for a bad maintenance
Operation	Due to user behaviours or external condition as weather	è Energy consumption increase - Reduction in the energy savings	Distribute risks in contract; separate between weather and user behavior.
Measures and verification (particularly in EPC)	Imprecise/inaccurate metering	Measurement errors	Include control and calibration (if needed) of meters in maintenance scheme.

2.6 Facade renovation

2.6.1 Assessment criteria

A previous EU-sponsored project (Häkkinen et al., 2012) identified 15 **sustainability aspects** of particular interest for refurbishment concepts for external walls. They can conveniently be used as a checklist to ensure that the hazard identification process covers all relevant aspects. Prefabricated elements have been studied extensively in the projects TES Energy façade, SmartTES and E2Rebuild (CORDIS, 2014).

However, these do not cover the risks related to integrated elements like PV or thermal solar collectors or integrated ventilation ducts.

Table 4. Assessment criteria for facade renovation (Häkkinen, Peuhkuri & al. 2012)

SUSREF Assessment criteria
Durability

Impact on energy demand for heating
Impact on energy demand for cooling
Impact on renewable energy use potential
Impact on daylight
Environmental impact of manufacture and maintenance
Indoor air quality and acoustics
Structural stability
Fire safety
Aesthetic quality
Effect on cultural heritage
Life cycle costs
Need for care and maintenance
Disturbance to the tenants and to the site
Buildability

2.6.2 Moisture risks

Moisture is a major cause of building damage and bad indoor air quality. An analysis of 2423 process induced building defects in Norwegian buildings indicated that most of the defects were related to moisture. Improper design, inaccurate craftsmanship and inappropriate materials were common. It was emphasized that the vast majority of defects could have been avoided by using well-established knowledge. (Lisø, Kvande, & Thue, 2006). Lisø (2006) emphasized climate *change* as a factor that should be included in the management of building-related risks, as at least some regions may experience harder rain spells and more frequent periods of wind-driven rain.

Little, Ferraro, and Arregi (2015) discuss the use of building physical assessment using the Glaser method and numerical simulation methods, and point out that the use of numerical HAM simulations aided by software like WUFI has major advantages over the Glaser methods, and is suitable in situations where liquid water transport or air convection through holes or cracks are of importance. In massive stone walls, liquid water transport is a major mechanism and internal insulation is a major risk, such that internal insulation is generally discouraged.

Even if interstitial condensation is not a problem, internal insulation decreases the external surface temperature, and in cold climates frost damage may lead to extensive problems and high maintenance costs (Biseniece et al., 2017).

External renovation, on the other hand, has the potential of remediating the risk of internal condensation due to insufficient thermal insulation, improving the protection of the existing wall against driving rain, and reducing air infiltration and exfiltration. Where applicable, external insulation and weather-proofing is the most suitable method for reducing heat transport and moisture risk. However, it is necessary to assess whether diffusion or convection of moisture from internal air can accumulate and cause problems. Likewise, moisture entering form the outside can cause mould problems, decay of wood or reduced insulation efficiency in the newly insulated wall.

Especially in climates where driving rain is a problem, a ventilated cladding and a two-step barrier against rain and wind is highly recommended to eliminate the transport of liquid water into the insulation layers.

Externally insulated walls still may experience moisture problems. Typical challenges are water leakage at the wall / roof junction or around windows, and insufficient moisture protection during the renovation process – including transport and storage of materials.

These challenges may cause problems also when prefabricated elements are used (Kalamees, Pihelo, & Kuusk, 2017; Pihelo, Kalamees, & Kuusk, 2018). A thorough treatment of the building physical considerations for timber-frame prefabricated elements for building renovation is given in (Homb, Time, et al., 2014).

2.6.3 Fire risks

The facade has long been recognized as a pathway for the spread of fire between individual apartments or fire-cells (Yokoi, 1960), and considerable attention has been given to the fire-related properties of facade elements containing flammable materials like EPS (Hofmann, Kaudelka, & Hauswaldt, 2018). Fires spreading from waste containers to facade have been identified as a relatively common cause of fire, and it has been questioned whether existing test methods (ISO, 2002a, 2002b) provide sufficient safety. Newer test methods have been developed (Martensson, 2016). According to (Kotthoff, Hauswaldt, Riese, & Riemesch-Speer, 2016), facades with flammable thermal insulation are the main problem. However, vertical gaps in the construction, e.g., between ventilated cladding and wind barrier, are potential routes for the spreading of fires. The spreading of fires from facade to roofs or attics is a major concern (SINTEF 520.310 2019).

Integrated elements such as ventilation ducts and photovoltaic panels may introduce new fire-related risks.

Integrating ventilation ducts spanning more than singular fire-cells may require installation of fire dampers according to national regulation. Test methods for fire-resistance exist (CEN, 2014, 2015).

A thorough treatment of fire safety considerations when using timber-frame external elements for renovation is given in (Loebus, Werther, Friquin, & Tulamo, 2014).

2.6.4 Structural integrity risks

The multifunctional timber facade elements are usually designed as non-loadbearing, self-supporting type of facade cladding. In this first case, only the vertical dead loads will be led through the elements to a support. The support consists of brackets fixed to the building or a new foundation built in front of the existing structure. The intermediate fixations bear the horizontal loads from wind suction and geometrical imperfection, while vertical loads are only taken by the bottom support.

In a second option, the vertical loads will be taken by the supports at each floor. In this way, the dead loads do not accumulate within the elements until the bottom support. But consequently, the existing structure must be able to bear these loads.

Another option is using the elements as load bearing structure for extensions to the existing building. In this case, the vertical forces do not only arise from the weight of the elements but also from loads of additional new floor areas or from new roof surfaces.

The new façade elements for retrofit can also be subject to loads from stabilizing the existing structure. This might be the case when the existing walls are not stable enough anymore due to aging or decay, additional new loads from building extensions, or changed building codes which might require higher resistance after the renovation than originally foreseen. Even strengthening the building's structure with the new elements in order to resist seismic loads is possible (Fotopoulou et al., 2018; Reggio, Restuccia, & Ferro, 2018).

Risks concerning structural integrity can be separated between risks that are depending on the retrofit façade system and risks that are independently.

Independent risks are change of requirements due to new building codes or change of the building's category due to the renovation action. In this case the building might be subject to a structural redesign and strengthening, although this does not arise from the fixation of the elements themselves. This possibility must be evaluated by the planning team in the basic evaluation phase at the very beginning of the project and has to be kept in mind afterwards, since some architectonical decisions later might still influence this risk.

The other risks directly arise from the elements themselves. The existing structure might not be suitable for every of the different structural concepts which have been described above. Especially, leading vertical forces through the existing structure does usually present a problem to the lower structure of the building. This is depending on the building's height and the existing construction type. Another common risk arises from two-layered walls, where one or even both layers are not capable of carrying horizontal loads. Therefore, efforts must be undertaken anchoring the elements to the ceilings. This correct anchoring position into load bearing parts of the existing structure must be carefully assessed during the survey.

The same principle applies regarding the transport of loads through the existing structure. Just because it can be proven that tension forces are able to be anchored to one part of the building (e.g. a brick wall), this part might not be sufficiently connected to the rest of the building. Therefore, the risk of creating structural failure during the load transport through the structure applies. In the example, a part of the brick wall might just fall off, with the tension anchor still perfectly working.

Structural design of the façade also must take account of the possibility that one element might fail, for example due to fire. In this exceptional load case, it must be assured that progressing failure of the façade is prevented and the elements above the location of the failure will not fall down. This does not necessarily mean that the supports must be strong enough at every floor to carry all the façade. Appropriate design like avoiding joints between the elements being all vertically in one line and adopting appropriate fire safety design will prevent this risk.

Special attention has to be paid to the survey of the building's existing foundation and to the comparison between loads prior to retrofitting and afterwards. If the result is that the existing foundation is not stable enough, it will be difficult to compensate this deficiency. In this case there is a risk of additional costs arising from additional working time on site in a position difficult to access. If new foundations are necessary, the risk of insufficiently stable ground conditions might follow. However, there are possibilities to choose from a range of different solutions before having to add new foundations. It is positive that the timber elements are light weight compared to most existing structures. This holds even if integrating building service components, since most of them are lighter than blown-in cellulose fibre, which is preferably used as insulation material.

2.6.5 Noise

External insulation and weatherproofing will normally reduce transmission from outside to the indoors, thus improving acoustic quality of the dwellings.

2.7 Heat-recovery ventilation in renovation

2.7.1 Assessment criteria

Mechanical heat-recovery ventilation is recognized as an energy-efficient way of providing new dwellings with fresh outdoor air and remove moist and polluted indoor air, particularly in cold and hot climates, where the energy demand for heating and cooling is large. Primary assessment criteria for mechanical ventilation are thus effects on heating demand, cooling demand and electrical power for fans, and the effect on air quality – including moisture damage risk. Secondary effects that need to be assessed are effect on noise, fire safety, health and safety for users, maintenance needs, aesthetic and cultural heritage values, and environmental impacts.

2.7.2 Fan power

Retrofitting heat-recovery ventilation units often leads to compromises in design of the system, as space is limited. Small dimensions and sharp bends in ducts may increase necessary fan power, often leading to noise problems as well.

2.7.3 Air quality

Mechanical ventilation will normally increase the supply of outdoor air, and accordingly reduces pollutants with internal sources. Filtration of the supply air will reduce the number of particulates in the indoor air. Particulate outdoor pollution is a major health risk, estimated to cause a yearly loss of 83 million disability-adjusted life years globally and almost 5 % of all deaths in Europe (Global Health Data exchange 2019). Thus, the health benefit from filtration can be important. However, gaseous pollution is normally not removed in ventilation, and indoor concentrations of pollutants such as ozone or nitrogen oxides may increase.

The ventilation system may also be a significant source of pollutants (Bluyssen et al., 2003). In systems with leakages or rotary heat exchangers, there is a risk that pollutants (typically odours) may be transmitted between rooms connected to the same ventilation unit.

In order to reduce risks of bad supply air quality, the air intake should be placed to minimize pollution. High-quality products should be used, and cleanliness ensured during installation. If different dwelling units are supplied from a common rotary heat exchanger, gas filters (active carbon) should be used.

2.7.4 Thermal comfort

Integrated ventilation ducts in external building elements, or co-locating them with uninsulated heating pipes, may lead to heating or cooling of the supply air, with negative effects on thermal comfort. If extract air is cooled, there is a risk of condensation. (Homb, Uvsløkk, Grynning, & Time, 2014) recommended at least 50 mm of mineral wool (or other insulation products with similar U value) on the outside of ventilation ducts to safeguard against these problems. The exact need for insulation depends on climate.

2.7.5 Noise

Retrofitting mechanical ventilation can increase risk of annoying noise, either from fans, or because of noise transmission between dwelling units. Noise from fans and exhaust can be annoying to neighbours and surroundings as well as within the building. Duct attenuators (silencers) and antivibration support for fans are normally necessary. Homb, Uvsløkk, et al. (2014) strongly recommend individual ducts from the ventilation unit to different dwelling units and performing a calculation of sound pressure levels in apartments closest to the ventilation unit. Noise from fans and exhaust can be annoying to neighbours and surroundings as well as within the building.

2.7.6 Exfiltration heat losses

The introduction of mechanical supply and extract ("balanced") ventilation will change the pressure differences between indoor and ambient air, while stack (natural) ventilation or mechanical extract ventilation will create negative indoor – outdoor pressure differences. The effect of this is larger wind-driven exfiltration rates through air leakages, resulting in heat losses, and potentially also condensation problems. Thus, it is important to assess air tightness of the building when balanced ventilation is considered.

2.8 Natural ventilation in renovation

When there is no or little need to heat or cool the outdoor air, using pressure differences due to wind or gravity effects can be an attractive option for ventilation. Utilizing the exposed thermal mass of the building, increasing ventilation periodically can reduce cooling and heating demand.

2.8.1 Assessment criteria

The primary assessment criteria when considering natural ventilation are thermal comfort, energy demand for heating, cooling and fans, and indoor air quality. Effects on noise, safety and security are potentially important secondary criteria.

2.8.2 Thermal comfort and heating / cooling demand

Most climates are quite variable both in terms of temperatures and wind speed and direction. Duration diagrams for pressure differences can be constructed based on weather data, and for many locations the 90 % range of pressure differences spans two orders of magnitude. Differences on a local scale can be also large, e.g., due to urban canyons and heat island effects. This variability affects the actual ventilation efficacy and thermal effects.

The thermal acceptability of natural ventilation will also vary with different geometry of windows, floorplans and usage. In a warmer than neutral thermal body state, elevated air speeds are often well tolerated, while annoyance with draft is common at low air speed in neutral or cooler thermal state (Parkinson, Parkinson, & de Dear, 2019).

2.8.3 Air quality

Normally, natural ventilation does not allow efficient filtration of the supply air. Thus, if outdoor air quality does not fulfil health-based criteria due to particle pollution, mechanical ventilation with filtration of the supply air is a better alternative. The quality of the supply may also be affected by local sources such as smoking or cooking.

2.8.4 Security and safety

Fall from windows is a significant cause of injury and death (K. E. Stone, Lanphear, Pomerantz, & Khoury, 2000) and open windows are well-known points of entry for criminals. Safety and security must therefore be regarded if window airing is a part of the ventilation strategy.

2.9 Energy supply and distribution in renovation

2.9.1 Assessment criteria

No published papers listing all relevant criteria for retrofits to the energy supply were identified.

Hydronic systems like the plug and play energy hub (PPEH) involve water borne heating systems, domestic hot water (DHW) delivery and energy metering. Primary assessment criteria for heat distribution are primary energy use, environmental impact and thermal comfort.

Secondary risks connected to DHW systems include leakage and water damage, risk of *Legionella* infection because of microbial activities and biofilm formation (Shaheen, Scott, & Ashbolt, 2019), and risk of burns / scolding due to high water temperatures (M. Stone, Ahmed, & Evans, 2000; Zou et al., 2015).

2.9.2 Risk of substandard function

Optimal utilization of different available heating sources (e.g., solar collectors, heat pumps and district hot water), possibly including use of heat storage in water tanks, building structures or ground, is a non-trivial design and operation challenge. The technical details are beyond the scope of this report.

2.10 Ceiling fan

2.10.1 Assessment criteria

No published papers claiming to list all relevant criteria for (smart) ceiling fans were identified. The main purpose of the ceiling fan is to increase thermal comfort by a cooling air current. This effect is documented in several papers (Pasut, Arens, Zhang, & Zhai, 2014; Schiavon & Melikov, 2008), and energy saving effects and design principles are described (Babich, Cook, Loveday, Rawal, & Shukla, 2017a, 2017b; Hoyt, Arens, & Zhang, 2014).

Since the fans are electrical appliances with moving parts, some mechanical and electrical risks are conceivable.

2.10.2 Mechanical risk

Apparently, ceiling fans are not uncommon as a cause of head injury, in particular among children in hot climates (Furyk, Franklin, & Costello, 2013; Hoz, Dolachee, Abdali, & Kasuya, 2019; Potts, 1999). Most reported cases seem to be caused by children being hit by fan wings in normal operation, but fans or fan parts falling from the fan are also possible.

2.10.3 Electrical risk

Electrical ceiling fans probably have risks similar to other electrical home appliances, and no information of specific risks was found in the literature. Directives to ensure consumer safety apply, and products complying with these can be regarded as low risk.

2.10.4 Comfort risks

Known risks arising from air movement include sense of draught or eye irritation. (Pasut et al., 2014) did not detect any complaints of dry eyes in a laboratory experiment. Different individual preferences for air movement and thermal conditions can create problems when more than one user is present, and different control approaches for fans in open-plan offices have been suggested to minimize such problems (S. Liu, Yin, Schiavon, Ho, & Ling, 2018).

The use of a ceiling fan will reduce the vertical temperature gradient in the room. This will increase the air temperature in the occupied zone as well as the heat transport through the roof due to air movement and lower temperatures at the ceiling – room boundary. In sun-exposed roofs with little thermal insulation, such effects may counteract the improved thermal comfort generated by the air current from the ceiling fan.

Appliances may generate undesired noise, and several negative physical and mental effects are associated with noise. A google search on "ceiling fan noise" yielded more than 43 000 hits, indicating that noise from ceiling fans may be experienced as annoying.

Standards and regulations for noise from technical building systems should be followed. E.g., the Norwegian NS 8175 standard requires the A-weighted sound pressure ($L_{A,p}$) to be below 30 dB, with 20 dB as the limit for buildings with excellent acoustic environment.

2.10.5 Risk of substandard function

Improper installation, for example with too little space between ceiling and fan, may yield lower air currents than intended (Babich et al., 2017b).

2.11 Local solar energy

2.11.1 Assessment criteria

The primary assessment criterion for BIPVs is normally the value of the produced electricity. (Yang, 2015) reviewed barriers against and risks of BIPV, and pointed out that mechanical rigidity, primary weather impact protection, energy economy, fire protection and noise protection are important functional requirements that need to be fulfilled by the integrated elements, in addition to the requirements related to energy production. Safety during transport, building and operation is also important.

2.11.2 Economic impact / value

(Lovati et al., 2019) pointed out that the selection of economic performance criteria may have a large impact on selection / optimization of RES and argued that using net present value (NPV) for optimization has large benefits over IRR, PT or LCOE. When estimating the cash flows, analysing high-resolution time series is important, as the value of electrical power varies with local demand and tariffs. Legal restrictions on the sale of electrical power may reduce the value of the electricity produced.

PVs have been shown to need quite frequent maintenance to avoid reduced performance.

2.11.3 Fire risks

Fire-fighting in photovoltaic systems has raised concerns about risk of electrical shocks for firefighters (Flicker et al., 2018), and combustibles in PV panels contributing to heat and smoke in a fire, particularly when integrated in a facade (Chow, Han, & Ni, 2017). An assessment of human health risks from the selected priority chemicals lead (Pb), cadmium (Cd) and selenium (Se), concluded that in the considered fire scenarios, human health risks from exposures were small (Sinha, Heath, Wade, & Komoto, 2018.) However, the fire-protective properties of the integrated construction need to be assessed in individual cases.

2.11.4 Health and safety risks

In normal operation, PV systems will be safe, but like any other objects fixed to the exterior of a building, there are risks of injury if parts are broken or fall down, typically in extreme weather situations or unexpected physical impact. The mechanical rigidity of the system and its anchoring must be sufficient to withstand weather or physical impact. Local regulations and recommendations will apply. To reduce the risk of injury from falling glass, safety glass may be required for PV panels integrated in walls.

3 Risk management guidance using 4RinEU technologies

During ownership of a building or building portfolio, risk management should be an integrated part of management and decision processes. The complete risk picture of property investments falls well beyond the scope of this guideline. It is assumed that the owner has a reasonably clear picture of their vulnerability pertaining to interest / discount rates, rent, property value, political changes etc. as a foundation for their decision processes.

We recommend a life-cycle risk perspective when making decisions on whether to renovate or not, and what renovation package to select. Further, we stress the importance of including the risks of business as usual in the assessment. Depending on local conditions this may include accelerating accumulation of maintenance needs, reduced willingness to pay by tenants, liabilities due to substandard building conditions, reputation in addition to energy and other operating costs.

3.1 Preliminary assessment in early decision phase

The "early decision phase" referred to in this section corresponds generally to phases [0] Base case analysis, [1] procurement and [2] planning in 4RinEU 3.6 (González et al., In prep)

The 4RinEU Rating Tool is designed as a guide to selecting renovation packages with acceptable risks for archetypical buildings. It is advisable to consult existing information on actual energy usage, maintenance costs, indoor climate and other technical documentation already at this stage to uncover any large discrepancies from the assumptions in the 4RinEU Tool. Bear in mind that prebound effects due to e.g. energy poverty, may cause the buildings to seem more energy-efficient than they are from a pure technical perspective, and actual savings to be lower than calculated savings.

Assessing the possibilities and limitations of local renewable energy solutions in this phase will reduce the risk of unrealistic targets and suboptimal solutions. The Early ReNo tool was developed for this purpose.

(Thunshelle et al., 2018) points out that the significance of the dwelling to the inhabitants goes well beyond energy costs and indoor environment and recommends involving residents in the planning from an early stage.

The financial risks can be reduced by carefully selecting financing scheme. Available financial instruments are reviewed in 4RinEU D 4.5 (Klinski & Høilund-Kaupang, In prep).

Table 5 and Table 6 contain *examples* of economical, societal and legal aspects that should be considered in a preliminary risk assessment before deciding to proceed with a renovation package.

The actual risk in individual projects needs more detailed assessment depending on the selected renovation package and prioritized targets / aspects. Deliverable 5.2 of the 4RinEU (Pinotti &al, In prep) describes the identification of particularly important aspects and formulation of project targets for the three pilots in the projects.

This is typically an activity in the early design phase. Tools and guidelines are given in sections 3.5 - 3.6 on the different renovation technologies.

Table 5 Preliminary checklist of financial project risk

Financial risks	
Funding	Ability to secure loans? Solvency of clients and subcontractors
Value	Will renovation increase property value? Booming or declining area?
Rent	Ability and willingness to pay rent

Table 6 Preliminary checklist of societal project risk

Societal risks	
Legal context	Will the necessary permits be given? Consider central and local regulations, listing of historical buildings or sites. Consider both building permits, and necessary permits for building process (e.g. blocking of streets.)

	Any legal rights by other stakeholders that may delay or block process?
Users	Communication issues, can owners and tenants be addressed efficiently? (E.g. Do they have access to electronic communication, will they understand and trust the information, will they respond? Who can efficiently represent users that can't or wouldn't be involved?) Behavioural issues; can necessary cooperation with users be assumed, any risks of irrational or violent behaviour? Vulnerability issues; any users not tolerant of the anticipated stressors in the process?
Ownership	Ownership issues Decision making issues (NB joint ownership, housing associations)

3.2 Risk management in the design phase

The design phase should be considered one of the most important steps of each renovation process. Early in the design phase the final objectives of the renovation process must be identified; final energy performance targets, indoor comfort, aesthetics features, investment costs, in order to identify the right solution sets of the renovation strategy. The renovation concept should overcome the problems and the lacks identified in the assessment and diagnosis of the buildings (energy audit) and in the evaluation of the needs as identified by the owners and/or occupants (survey process). Under this condition, the design team develops deep renovation packages with very low technical and environmental risks, and large benefits considering energy, environment, and indoor environmental quality.

It is recommended to involve different building experts in order to choose the best solution sets in a wide number of possibilities, using a multidisciplinary approach selection. In particular, when prefabrication of components is considered, it is recommendable to involve the manufacturer and the contractor, that can support in an active way the design process and details definition, enhance the efficiency and quality of the design, and reduce technical risks. Early involvement of contractor / element supplier was rated positive in the 4RinEU Oslo Pilot (Holøs, Lukina, Hauge, & Thunshelle, 2019). Nibbelink, Sutrisna, and Zaman (2017) also claimed that early contractor involvement reduced risks in refurbishment projects.

The designer is normally liable for any design failures, but the building owner will normally bear the risk of any deviations from the design basis.

The building owner (without specific technical knowledge) should require that (1) the designers are explicit and specific about the risks that arise from incomplete knowledge on the building's construction and condition, and (2) these risks should be evaluated at an early stage.

It is normally sufficient to sort risks in three categories by expert evaluation of the design team:

1. High concern, take precautions
2. Medium concern, monitor and take precautions if necessary
3. Low concern

To ensure sufficient and correct information about the object undergoing deep renovation is probably the most important precaution at this stage. More specific guidance on this is given in the sections of different renovation technologies.

3.3 Risk management from contracting to commissioning

An important aspect of building contracts is the distribution and management of risks. It is believed that a fair distribution of risks (including "positive risks") is important to reduce overall risks, and several suggestions on how to achieve this have been proposed, see, e.g., (Bunni, 2009). In the Oslo 4RinEU pilot, an open-book participatory contract model was selected (Holøs et al., 2019). Furthermore, a pre-implementation workshop involving building owner, design team, contractor and user representatives was organized in order to identify several project-specific risks. In the same way, to reduce the risks connected to the maintenance phase, guidelines to properly operate and maintain the elements, equipment and operating protocols predefined can be elaborated.

At European level exist several different building contracts (as identified by Directive 2014/24/EU) and they can change between (i) design contests, a contract enabling to acquire architecture and engineering or data processing, a plan or design selected by a jury after being put out to competition with or without the award of prizes, (ii) works contract mainly based on building or civil engineering works and (iii) service contract based on design and execution of works. The choice of the contract typology depends on specific needs and final objectives that we aim to achieve with the building process adopted –building design or construction works. However, in both kind of contracts, it is necessary to identify the targets and the requirements of the final works or services contracts, such as meaningful reduction of energy demand, enhancement of indoor environmental quality, construction time/impact. For this reason, within the works/service tender should be identified the KPIs and their (maximum/minimum) values, the calculation method (software and tool) the verification process and the responsible people of each step (identification of the building professional experts and/or constructors) for all the project phases. Only in this way, through a deeply planning, it will be possible to reduce the risks connected at each project phase deviation.

Risks connected to each financing scheme are previously introduced in Chapter 2 Literature survey. Below, Figure 5 compares the traditional process (completely financed by public authorities, also with bank loans) and a public-private partnership (PPP) process, one of the most common finance scheme based on variable participation of public and private investments.

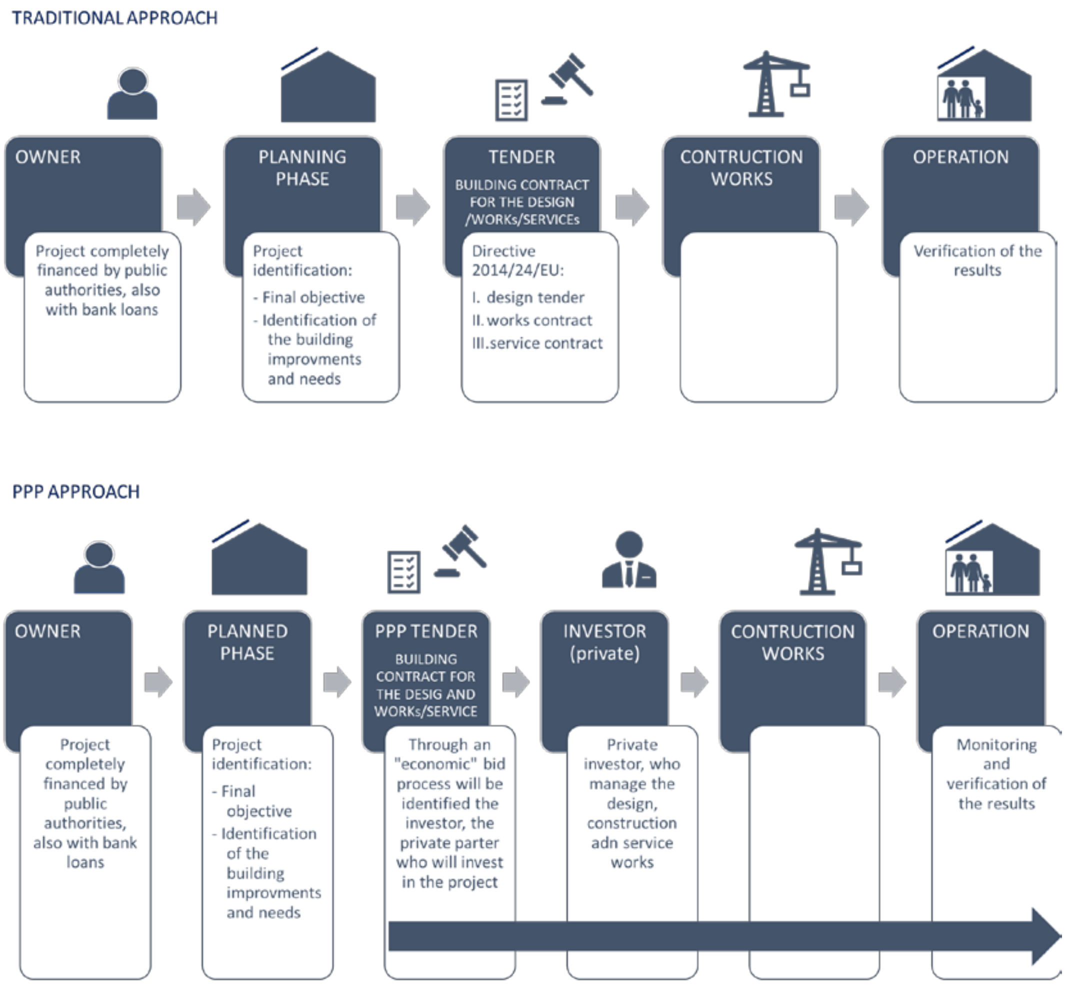

Figure 5. Phases of tradition process and PPP ©GPaoletti EURAC research

Detecting, remediating or reducing the effects of any failures are main tasks within the commissioning phase. In particular, the functionality of any new technical installations, including their control systems, should be tested and their function documented in a systematic way. It is recommended to include operation and maintenance personnel in the commissioning process to ensure transfer of the necessary competence. When users are expected to operate new systems, or use their dwelling differently, some training activity beyond delivering a manual is usually necessary. The commissioning phase should be actively used to ensure that both users and operation personnel have the skills and understanding necessary to ensure correct operation.

Post-monitoring of key parameters, including user satisfaction, is valuable both as an assessment of performance and as a fault-detecting process. Tools such as the Sensible data handler can ease the involvement of users in monitoring and fault detection as well as their understanding of the building / user interface.

3.4 Risk management after commissioning

Even deep renovation by the highest standards will not remove risks of technical failure, misuse, damage by external forces etc. The management of risk in the use phase (O&M) and at the end of the life-cycle is beyond the scope of this report, but it is pointed out that in the Oslo 4RinEU pilot project, the team responsible for future maintenance of the building was successfully included in the design process and risk-identifying workshop. Finally, it is repeated that risk management should be embedded in the management systems and routines of all involved practitioners and other entities responsible for the property.

3.5 Risk management of prefab multifunctional facade

3.5.1 Objectives: mapping of the risk

When a multifunctional prefabricated façade is considered as part of a deep renovation, we recommend a more detailed study of the objectives that will be affected and risks connected to those objectives. Table 7 suggests a structure for this study. At an early stage, it is often possible to "grey out" some aspects that most likely are irrelevant for that phase – for example it is not necessary to assess daylight in a building when it is demolished. It is also possible to preliminary assign green, red and yellow colours according to positive, negative or negligible effects, and to indicate topics that should be examined particularly closely. Obviously, an energy-motivated deep renovation should have a positive impact on energy demand for heating and cooling in the operation (use) phase, but the impact on daylight in the dwellings is less obvious.

Table 7. Life-cycle perspective on different aspects of refurbishment by multifunctional façade elements. The grey boxes are normally irrelevant or of limited importance. Green shading: most often positive impact, red shading: most often negative impact. Yellow shading: Unknown, to be assessed in actual cases.

Aspect	Existing situation	Renovation	Operation	End of life
1. Durability				
2. Impact on energy demand for heating				
3. Impact on energy demand for cooling				
4. Impact on renewable energy use potential				
5. Impact on daylight				
6. Environmental impact (non-energy)				
7. Indoor air quality and acoustics				
8. Structural stability				
9. Fire safety				
10. Aesthetic quality				
11. Effect on cultural heritage				

12. Cost				
13. Need for care and maintenance				
14. Disturbance to the tenants and to the site				
15. Buildability				

3.5.2 Condition assessment as basis for risk management

In order to identify the risks connected to the different aspects, it is normally necessary to perform a thorough condition assessment of the existing walls and adjoining building elements (foundation, windows and doors, roofs, technical installations and other elements attached to the façade) before it is possible to assess impacts and manage risks.

Such a condition assessment should take the existing construction into account, and the preparation of a checklist will facilitate the condition assessment. After condition assessment and selection of renovation concept, a revised impact matrix should contain fewer unknowns, but some remaining risks / uncertainties can be highlighted. A simplified example is shown in Table 8.

Assessment of moisture risk is important to renovation affecting the climate envelope of the building, and hygrothermal assessment is recommended. More detailed recommendations for hygrothermal simulation are given in Appendix 2.

Table 8. Fictive ***example of early assessment*** *of impact on different aspects of renovating an existing block of flats using prefabricated facade*

Aspect	Existing situation	Renovation	Operation	End of life
1. Durability	Vulnerable render		Robust solution	
2. Impact on energy demand for heating	Poor insulation			
3. Impact on energy demand for cooling	No cooling used		Slight improvement	
4. Impact on renewable energy use potential	No RES		PV included	
5. Impact on daylight	Acceptable		No change	

6. Environmental impact (non-energy)	PCB in caulking	PCB must be safely removed!		
7. Indoor air quality and acoustics	Low AER, moisture damage	Unknow moisture damage?	Mechanical ventilation included	
8. Structural stability	Sufficient carrying capacity			
9. Fire safety				
10. Aesthetic quality	Unappealing, worn exterior		Accepted by owner and inhabitants	
11. Effect on cultural heritage	Not listed or protected. insignificant		Minor importance	
12. Cost	High energy cost	Complicated geometry and building site	Reduced energy and maintenance	Lower cost due to PCB removal
13. Need for care and maintenance	High maintenance cost		More robust than current construction	
14. Disturbance to the tenants and to the site		Acceptable disturbance		
15. Buildability	Demanding geometry	Careful design needed!		

Table 14 and Table 15 in the appendix propose some technical and environmental risks to consider when planning the condition assessment. These can be used to make checklists for the condition assessment.

Relevant standards for the condition assessment should be used if applicable, e.g. NS 3424 (Norway), NEN2767 (the Netherlands), EN 16096 (Cultural heritage).

3.5.3 Risk management

Examples of identified risks elements, outcome and countermeasures for prefabricated multifunctional façade elements are given in the table. See (Holøs et al., 2019) for a detailed analysis of the façade renovation in the Norwegian demo.

Table 9. Selected risks and countermeasures prefabricated multifunctional facades

Event / cause	Possible outcome	Countermeasure
Element not fitting to building	Compromised stability or function	QA of scanning / measuring
Hidden moisture or moisture damage	Decay, mould, other damage	Thorough survey
Inadequate design process	- Low moisture safety - Lacking fire safety - Air leakage	Integrated planning process, including manufacturer and all special planners.
Inadequate planning / site management	Errors in mounting of elements	Make and follow detailed plan for delivery, storage and mounting.
Failure to store elements in dry and protected conditions	Moisture damage, mechanical damage	
Element damaged or delayed in transport	Moisture damage	Prepare for provisional coverage.

3.5.4 General advice to building owner on prefabricated multifunctional facade

- When comparing deep renovation with demolition and new building: include costs of "discontinued operation"(tenant loss, lost revenue). Give attention to the timing of the deep renovation, favourable timing may reduce risks and costs due to unfavourable weather and alternative lodging.
- An integrated planning process is recommended – early inclusion of element manufacturer and builder in the planning process will allow their experience to be exploited and reduce risk of unnecessary redesign.
- Use appropriate collaboration contracts where possible.
- Be sure to include the behaviour of the complete building in the planning process.
- Be consequent in the remediation of thermal bridges.
- For the building process, the best result will be achieved without inhabitants in place.
- If integration of PV or ST in the facade elements is planned: compare section 2.11

3.6 Risk management of Plug & Play Energy hub

3.6.1 Objectives

The main objectives of the Plug & Play Energy Hub are

1. Energy transfer from source to final user (DHW, Heating)
2. Network connection (multiple sources connection network managed by a unique building controller)
3. Energy optimization
4. Certified energy meter
5. Scalable technology

3.6.2 Risk management

Table 10 Selected risks and countermeasures of PPEH

Event / cause	*Possible outcome*	*Countermeasure*
DHW too hot	Scalding	Limit temperatures at "end point"
Legionella spread	Serious infection	Ensure possibility to increase temperature above 65 °C, prevent build-up of biofilm in systems where water can be aerosolized (e.g. showers)
Component damages	Leakage, malfunction	• Choose high-quality component (plate exchanger SWEP, circulation pump) • Follow periodic maintenance scheme from producer • Include alarm function in installation
Flow too low	Insufficient heating	Predictable alarm related to sensors value
Network problems	Unpredictable function	Use standard and robust protocol
Temperature of the source not normal	Unpredictable / suboptimal function	Give specific alarm

3.6.3 General advice to building owner on PPEH

Detailed management of energy loads and sources enables matching loads with the best (cheapest) available energy source, mapping demand and distributing costs.

Design piping and size of pipes to avoid lack of flow

Pay attention to communication (bus) and electrical connection as well as hydronic system.

3.7 Risk management of Comfort ceiling fan smart operation

3.7.1 Condition assessment as basis for risk management

In order to operate efficiently and safely, a ceiling height of 2.55 m or more is needed. Also, since the ceiling fan has small or no benefits with very hot roofs, the thermal insulation of roofs should be checked and, if necessary, improved before fan installation.

3.7.2 Risk management

Table 11 Selected risks and countermeasures, Smart ceiling fan

Event / cause	*Possible outcome*	*Countermeasure*
Fan blade hitting person	Injury (mostly head)	Ensure min. 2.3 m floor-to-blade distance
Unstable installation	Injury	Follow installation instruction. For fan diameter > 1.2 m thorough structural analysis necessary
Too low airspeed in occupied zone	Low thermal comfort	Locate fans as a function of the most likely configuration of the furniture (e.g., sofas, tables) Ensure > 0.25 m free space between blades and ceiling.
Increased room air temperature	Low thermal comfort	Increase roof insulation
Noise from fan motor or blades	Annoyance	Select high quality products with low noise, ensure proper installation

3.7.3 General advice to building owners on ceiling fans

The following points should be considered:

1. Choose a product that is certified and designed for the specific type of building
2. Choose the best location(s)
3. Carefully evaluate the floor-to-blades distance, and the ceiling temperature during the hot season
4. Complete the installation according to seller’s instructions

3.8 Risk management of RES technologies / Early Reno

3.8.1 Objectives: mapping of the risk and assessment criteria

The objective of the Early Reno tool is to achieve correct sizing of the PV/ST plant and to optimise the operation of lighting and ventilation.

3.8.2 Condition assessment as basis for risk management

The technical condition of the building is of relatively minor importance when the Early Reno Tool is used. However, it is very important to secure high-quality input data on such things as geometry of building and surroundings (shading), power and heat load profiles, local climate / weather and local air quality.

The natural ventilation module is particularly suitable for early design phases, as it requires only basic information about a typical room of the building, the building use and an annual climatic record. Furthermore, the tool provides building designers with useful information about the level of ventilation rates needed to offset given rates of internal heat gains.

Previous research works (Annamaria Belleri, Avantaggiato, Psomas, & Heiselberg, 2018; A. Belleri, Psomas, & Heiselberg, 2015) compared the ventilative cooling potential tool outputs with the predictions of a building energy simulation model of a reference room in two different climates (Rome and Copenhagen) and highlighted the following aspects:

• the outputs are useful to compare the ventilative cooling potential in different climates for different building typologies;

• the outputs also support the decision making by selecting the most efficient ventilative cooling strategy and by providing rough estimation of the airflow rates needed to cool down the building in relation to internal gains, comfort requirements and envelope characteristics;

• the tool enables also to analyse the effect of other energy efficiency measures, like internal gains reduction, solar gains control and envelope performance, on ventilative cooling effectiveness.

3.8.3 Risk management

Table 12 Selected risks and countermeasures of local renewable energy sources.

Event / cause	*Possible outcome*	*Countermeasure*
Wrong installation of the modules	Low energy output Malfunction of the system of not working at all	Use of Early Reno Skilled workers for the installation Quality audit of the system

		Ensure a good project management team for the construction and the commissioning
Wrong sizing of the PV/ST field and of the storage tank	Lower economic value of installation	Use of Early Reno
Inaccurate load profile	Lower economic value of installation	Quality assurance of input data
Unevaluated shadows	Less power and value than expected	Use Early Reno with detailed data
ST plants not connected with the existing HVAC	Lower utilizable heating power	Connect to system

Table 13- Selected risks and countermeasures, Early ReNo tool

Event / cause	*Possible outcome*	*Countermeasure*
Wrong input data	Undependable result	Quality assurance of the data
Lack of valuable input data (no hourly energy profiles)	Undependable result	Default values and references for the data
Designers not committed to using the tool (they could be stuck in the traditional PV/ST sizing approach – against the innovation)	Reduced profitability	Benchmarks to calibrate the results

3.8.4 General advice to building owners on RES design

Integrating ventilative cooling and renewable energy sources can be highly beneficial for a renovation project, but the details related to each individual project may have a large impact on profitability.

In order to get the highest return on investments, it is recommended to put effort in mapping these details and use the Early ReNo tool before design choices with high economic impact are made. The following is important when using the tool:

1. Use the weather file of the real location, if not available it can be calculated from satellite-data databases.
2. When drawing the 3D model, do not neglect possible causes of shading (e.g., near buildings, trees).
3. Check the correctness of the orientation.
4. A correct choice of the inputs is important, an appropriate effort is recommended in this phase to obtain reasonable results.

5. Results should be interpreted as a suggestion for the designers and not as the best possible simulation of the plant operation. In fact, the model used in the optimization algorithm was simplified to maintain reasonable computational times.
6. Use the tool in early design stage only for selecting the ventilative cooling strategy.
7. Choose more detailed calculation method for component sizing and ventilative cooling performance evaluation once the ventilation strategy is defined.

3.9 Risk management of Sensible Building Data Handler

3.9.1 Objectives

The Sensible Building Data Handler may contribute to reduce the energy performance gap by giving a better understanding of user behaviour – thus identifying prebound and rebound effects, as well as enabling the users to interact with the buildings in a more informed way, allowing them to achieve desired comfort with minimum energy use and cost. Furthermore, as a platform for communication between building users / managers, the Sensible Building Data Handler may aid the identification and remediation of building defects, thus reducing consequences of these defects.

3.9.2 Condition assessment as basis for risk management

The physical condition of the building is of limited relevance for the use of the sensible data handler. However, there may be local limitations due to internet access and user willingness or ability to interact with the Sensible Building Data Handler. There may also be legal obstacles in effect.

3.9.3 Risk management

When introducing the Sensible Building Data Handler, risks related to data accuracy, security, privacy and safety issues need to be handled. The users must experience clear and understandable benefits from using the system. At the time of preparation of this document, compelling evidence of the risks and potential of the system is not available.

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Appendixes

1 Lists of technical and environmental risks and their implications for renovation packages

In the following tables, some relevant risks are listed.

Table 14 Some technical project risks that may need special attention in condition assessment, choice or adaptation of renovation technologies.

Technical risks (what to look for)		Particularly relevant for
Structural stability	Is total carrying capacity sufficient to support added weight? Decay causing local weakening? Sufficient support for bolts / screws / other fixtures? Possibilities for supplemental foundation work? Is the project affecting (increasing) wind loads? Project affecting snow loads?	Using prefab multifunctional façade elements
Moisture safety	Airtightness and vapor diffusion resistance within acceptable limits? Signs of rising damp that needs remediation? Need for changing the roof construction to protect upper part of wall?	
Ventilation	Will existing ventilation system be affected by renovation (e.g. blocking of vents?)	

	If renovation includes ventilation system: can clean fresh air be delivered to living space? (Space for air intake, ducts, ventilation unit(s) need for filtration)	
Insulation	Is U-value of existing construction as assumed? Are thermal bridges within acceptable limits? Give special consideration to roof/wall and foundation / wall. Most other will be greatly improved!	Usefulness of ceiling fan
Energy infrastructure	If solar power produced: Sufficient capacity of electrical power lines / system to provide surplus? If higher power peaks: Sufficient capacity of electrical power lines / system / provider to supply? Supply or demand for local / district heating.	Getting permission from the electrical distributing company to connect to the power lines
External elements	Any need for signpost, antennas, powerlines or other elements to be anchored to or penetrate the façade?	

Table 15 Some environmental project risks that may need special attention in condition assessment, choice or adaptation of renovation technologies.

Environmental risks		**Particularly relevant for**
Hidden mould or decay in existing construction	Any hidden mould / moisture damages in the affected construction that need to be remediated during refurbishment? (Decay may also affect structural stability)	
Regulated pollutant sources in existing construction	PCBs (insulating windows, caulking, paint, masonry), Short-chained paraffins, halogenated flame retarders, etc. (insulation material, caulking...) Asbestos (mainly siding and ventilation ducts)	
Local air quality	Can local pollution affect function or durability of refurbishment, or maintenance costs? Particles / dust can affect efficiency of solar collectors / panels, corrosive gases (NH_3, SO_2) from local industry / agriculture can shorten service life of metal components. Local pollution sources that restrict placement of air inlet? (Traffic, kitchen exhaust, smoking areas…) Outdoor air quality acceptable for natural ventilation	Solar heat or power collectors Choice of ventilation system and ventilative cooling strategy Choice of filters for the ventilation systems

Table 16 Examples of societal project risks that may need special attention in condition assessment, choice or adaptation of renovation technologies. Checklists needs adaptation to individual cases

Societal risks		**Particularly relevant for**
Legal	Restriction on façade changes Restrictions on electricity export / usage Restrictions from building codes	Prefab façade elements, Photovoltaics
Economic	Differing priorities between stakeholders Uncertain financing schemes	
User-related	Communication challenges (trust, language, computer / internet access and skills.) Differing priorities Denial of access to appartment	Monitoring

2 Hygrothermal building simulation

Hygro-thermal simulation of building components, as well as energy simulation at building level, is becoming more common due to improved simulation software and the continuously increasing calculating capacity available with computers. This allows analysis of dynamic behaviour of components and boundary conditions instead of a representative static condition. Such analyses are valuable tools for evaluating the suitability of building constructions under realistic boundary conditions.

There are plenty of software tools (e.g. WUFI[1], Delphin[2], COMSOL Multiphysics[3]) able to perform such analyses and they can have different level of detail, referring both to the input parameter that the user can manage and to the output that can be obtained. Usually, neglecting the economic issue, the choice of the software is related to the context of the study that has to be performed and to the expertise of the user doing the analysis.

When using this simulations software, the user has to define several input parameters in order to run the models. The choice of these settings is the most crucial part of the simulation process (probably even more than the choice of the software itself), mainly because of two reasons. Firstly, small changes in the boundary conditions and parameters (duration of the analysed period, climatic conditions choice, material properties used, physical properties taken into account along the simulation, etc.) can of course affect the results in a consistent way. Secondly, it is essential that the building owner, who is going to evaluate the results of the simulations in order to take decisions in the design process, is made aware of the boundary conditions that have been considered to assess a certain output.

In the following, a checklist of crucial information that must be clarified when looking at the results of hygro-thermal and energy simulations is presented.

Duration of the simulation	Both in energy and hygro-thermal dynamic simulations it is very important to understand which period the results are referring to. Moreover, especially for moisture related issues, it should

[1] Fraunhofer IBP

[2] Bauklimatik Dresden

[3] Comsol Inc.

	be clarified if the simulation is long enough to include possible effects of moisture storage and interstitial condensation.
Initial condition	Initial conditions can influence a lot the results of a simulation. For a typical yearly energy simulation of a building, it should be clarified if a preconditioning has been performed (usually 1 month). Concerning hygro-thermal models, the initial water content of the simulated geometry can affect for several months the results, both positively and negatively. Therefore, the choice of initial water content parameters has to be motivated. To assess the construction's ability to dry out, it is useful to perform a simulation with very high initial moisture content in addition to a normal initial moisture.
Boundary climatic conditions	In all the simulations in energy and hygro-thermal field, it is necessary to define the boundary climatic conditions that can be stationary or dynamic depending on the performed study. In particular, when a dynamic condition is used and this information comes from a weather file, it should be guaranteed its source and that it is representative of the climatic condition to be modelled. The same attention should be paid when boundary data come from a monitoring campaign.
Material properties	Very often simulation software provides a material database to be used. Of course, when looking at the results of a simulation, it should be clarified which material has been used and checked that their properties are similar to the real material conditions. For instance, when modelling an insulation layer of an existing building, the thermal conductivity of the material may be completely different depending on the actual condition of the insulation (e.g. deterioration and moisture content). This is a relevant aspect, which may affect simulation results and their comparison with real conditions.
General models used (equations, models, occupants' profiles and behaviour)	It is often necessary, especially in energy simulations, to implement some models and equations in order to set specific inputs, as well as it is needed to define occupancy profiles and behaviour to model the occupants' presence. Therefore, the choices of the used models and equations (usually coming from

	literature and norms) and of the different profiles, which can obviously influence the outputs, should be justified and clarified when looking at the results of a simulation.