EEnvest

Risk reduction for Building Energy Efficiency investments

Recommendations for minimizing technical risks

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Abstract

The EEnvest project aims at supporting investor decision making process by translating building's energy efficiency technical requirements into economic indicators. These indicators are in turn used to evaluate financial risks associated with deep renovation investment and to include non-energy benefits in asset evaluation models.

WP2 focuses on technical risk, developing a structured process able to determine reliability of a renovation project based on technical risk level. This latter is assessed through two independent economic indicators, energy gap and damage, presented to the reader or user as percentage of investment. Additionally, technical risk reduction actions are being investigated, classified, and implemented as correction factors in the technical risk calculation process, and later reported to the final users, as mitigation measures.

The calculation methodology as developed in WP2 permits to determine technical risk through two outputs (indicators), whose combination can describe the probabilistic trend of several occurrences linked to the renovation scenario set case by case. The EEnvest technical risk calculation runs thanks to a technical risks database, created ad hoc in WP2. The database collects several occurrences data that serve as technical risk benchmark, described through probability and impact. The technical risk calculation process extracts the amount risk related to the selected energy renovation measures from the technical risk database, and re-sizes the risk based on inputs of the building renovation project. Project input features are building geometry (dimension, shape, etc.), planned energy performance (Primary Energy, Heating, cooling demands, etc.), including boundary condition (building site, etc.) and verification protocols.

The two technical risk indicators, energy gap and damage, will be integrated in the EEnvest web-based investment evaluation platform.

At the end, within WP2 will be identified some mitigation measures, as positive action for the de-risking of the renovation process of existing commercial buildings.

Document information

Author	Giulia Paoletti, Eurac
Contributors	Federico Garzia, Diego Tamburrini, Riccardo Gazzin, Eurac
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List of abbreviations and acronyms

This list must be as short as possible as abbreviations and acronyms hamper an easy understanding of deliverables by reviewers.

EE	Energy Efficiency
RES	Renewable Energy Source
LCC	Life Cycle Cost
ROI	Return On Investment
HVAC	Heating, Ventilation and Air Conditioning
MC	Monte Carlo calculation
S/V	Compact building shape (Surface / Volume)
U-value	Thermal transmittance of the building elements.
WWR	Window-Wall Ratio

INTRODUCTION

EEnvest - Risk reduction for building energy efficiency investments - project aims to develop, a web-based investment evaluation platform for building owners and private investors, which validates the investment security level of an energy renovation project for commercial building, through a solid and structured assessment method. EEnvest web-based investment platform will determine different risk levels, analysing a series of economic indicators coming from technical and financial risks evaluation models.

The level of guarantee of the investment will be evaluated through eight economic indicators, divided between technical (energy gap and damage from WP2), economic (payback time, maturity, internal rate of return, net present value on investment and debt-service coverage ratio from WP3) and multi-benefit group (thermal comfort, visual comfort, perceived physical and mental health, air quality productivity, from WP4).

Among them, two are specific indicators for the technical risk assessment of the renovation projects identified within WP2. One is the energy gap, which is the energy performance deviation between planned and measured energy consumption, and the other one is the building damage, defined as possible inconvenience due to component malfunctioning, failures, or breakages.

Chapter one is overview of general recommendation to adopt for de-risking the renovation process of commercial buildings.

Chapter two presents an overview on specific recommendation identified as mitigation measures most common found in the deep investigation on literature review, monitored buildings and in the interviews to the buildings professional. Interesting results and similar recommendations to avoid or reduce the certain technical risk of each renovation measure in terms of energy performance gap and damage deviation indicators were found. The

mitigation measures presented are useful, reliable and can be implemented case by case.

Chapter three reports the mitigation measures implemented (as correction factors) in the EEnvest technical risk assessment for building energy renovation process of commercial buildings. Once the cause-effect technical risks have been identified for each renovation measure (D2.1) a deep investigation on mitigation measures were conducted (chapter 4). At the end, these measures were translated in different types of correction factors and divided according to the:

- *building features*, architectural and environmental characteristic of each building, including dimension, building shape and complexity, climate contest and building site characteristics.
- *renovation scenario* (solution sets) specific to the renovation strategy proposed and related to the renovation measures adopted and their dependency one on the other.
- *procedures and verification processes,* such as certification protocols, or monitoring and verification programmes. These mitigation measures are optional.

Correction factors affect the technical risk trend modifying the impact and/or the probability of each negative occurrences.

Each building Pilot follows an energy renovation strategy tailored on the energy improvements and building needs. Planned solution sets have relative technical risks and mitigation measures. The de-risking action is based on the implementation of some mitigation measures and recommendations (optional actions) able to reduce the risk threats associated with the implemented renovation measures. If adopted at the beginning of the renovation project they can limit the occurrences of negative events.

Chapter four reports the EEnvest correction factors database of the whole building: envelope and technical system. In this chapter are reported in numeric value the correction factors, that modify the impact and the probability of negative occurrences, for both indicators, energy gap and damage.

EXECUTIVE SUMMARY

This report presents part of the work under WP2 - Technical risk evaluation framework. The goal of this report is to present the recommendations able to reduce the technical risks in the renovation of the buildings. The recommendations found are the most common, standardized procedures already tested and used in the building sector to address the final quality of the construction project. The actions here collected check and verify the renovation project development in all the phases, from the design to the operation.

The focus of the EEnvest project are commercial office buildings and, according to this target, all information collected to describe the technical risk trend in term of economic deviation due to energy efficiency, malfunctioning, or failures relates to these kinds of building structure and use.

The methodology presented in this report will be replicated for all passive and active buildings elements, providing:

- WP3 with relevant input to elaborate the financial risk model.
- WP4 with a set of renovation measures for which to determine the impact of multi-benefits on commercial asset value.
- WP5 with relevant input on which to establish the EEnvest platform design.

1. RECOMMENDATION FOR DE-RISKING THE RENOVATION PROCESS OF COMMERCIAL BUILDINGS

An important pillar developed in EEnvest project are the recommendations for de-risking the renovation process of commercial buildings to reinforce and support the technical risks calculation method and the new financing instrument. This report gives to EEnvest users (owners and building professionals) and private financiers (investors) a better understanding on technical de-risking action in economic terms.

Deliverable D2.1 presented the technical risk definition and evaluation methodology, here an overview on most relevant recommendations is reported, from effective standardized protocols to good practices considered as vehicle to drive the de-risk perception of the investment.

Office-commercial buildings are complex structures, to design, build and manage, both for technical issues and the different activities contained. A successful investment in renovation of this building typology depends on several issues.

Planning phase

Planning a solid renovation investment strategy for these buildings needs a deep knowledge on the state of the art of the building, from the architectural point of view and technical systems, energy consumption (thermal and electric) and other needs. Such information can be collected on building site, involving the owner and the facility manager, the building maintenance, and the tenants. An energy audit, on the building state of the art, is necessary and should be done by an energy expert with experience on this kind of building. Planning phase is one of the most important to build a solid and robust renovation strategy.

Identification of objectives

The final objectives of the renovation strategy should be identified at the beginning of the renovation intervention, in the planning phase. This stage requires the identification of qualitative and quantitative indicators that the renovation process should achieve, in architectural (aesthetics and functionally features), technical and economic terms. A multidisciplinary team of different building professionals, energy experts, facility manager and investments, is necessary to identify the final objectives.

Positive communication between stakeholders – Problem solving

It is recommended to have a facilitator manager, with positive influence and high empathy on the whole working team. She/he should be highly skilled on problem solving technics and have a good knowledge on buildings and renovation processes. She/he should be able to manage and favour positive collaboration and sharing of process information across the team.

Verification processes

It is recommended to plan the verification process of the energy performance indicators against objectives fixed at the beginning of the renovation process. This assessment should be approved, shared and common to all the working team.

Working team roles and rules

To obtain positive results, it is necessary to identify the roles and rules corresponding to each stakeholder involved. Each component needs to have a clear vision of the renovation phases process and relative inputs (data collection) and outputs (targets to achieve), to plan the activities, the calculation tools, the instruments, and the verification process.

Decision making process

The decision-making process should be done shared among the working team, and not performed by a single person. A loop decision process, based on interaction between different stakeholders with different experiences on the identification of the energy renovation measures, permits to choose the best solution set in a wide range of possibilities and in a short time.

Choose the right working team (experiences, reference, certifications...)

The experience of the building professionals, facility manager or investor is a necessary pillar to pursue positive results. Such matter can be evaluated requiring the reference on past experiences and/or possible certifications. For example, a basic energy expert is a building professional on energy performance usually authorized and certified by a national or local trusted organization. A level above, with a rise level of complexity, there are other kind of certification protocols used to determinate the building energy performance, as Passive House, CasaClima, or LEED. To identify the energy expert, it should be necessary to know the difference between these kinds of protocols, and later identify the certification process and the related expert. If not possible, a good recommendation is to choose an energy expert with previous experience on commercial office buildings.

Renovation scenario, cost optimality and LCC

The main drivers for renovation action are (i) improve indoor environmental quality and functionality (ii) reduce energy consumption, (iii) optimize building operation and relative maintenance costs, (iv) improve overall sustainability level reducing environmental, social, and economic impact.[1] The renovation scenario will be identified considering the cost-optimal level (as identified in EPBD recast) between energy performance level, that affects the energy cost of building service life, and the life cycle costs, that affect the maintenance costs during the economic building lifecycle. A wide range of energy renovation measures for commercial building, is collected in the “Guidelines on retrofitting of shopping malls” of EU FP7 CommONEnergy project ((Common Energy Consortium 2017)

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[1] FP7 COMMONENERGY project

2. EENVEST TECHNICAL RISK MITIGATION MEASURES

The recommendations for minimizing the technical risk are mitigation measures as policies, procedures, structured and programmed verification processes aimed at reducing the impact or the probability of a negative events that can occur. Mitigation measures can prevent the technical problems, strengthen the buildings renovation investment and the achievement of the project objective and limit the economic deviation.

Within EEnvest WP2, the mitigation measures were identified for each renovation intervention and building element and divided in relation to their influence and application between “prevention”, “detection” and “recovery” action. Prevention action is a simple and effective mitigation measure, but often not feasible. For example, to avoid an increase of building energy consumption due to an excessive air infiltration, a well-sealed building would be required. This measure is extremely difficult to be implemented. In this case, the Blower Door Test is a “detection” action to measure the building airtightness and able to mitigate the consequences, while a “recovery” action, able to modify and return to the hypothetic condition, is a reduction of air leakages. Within EEnvest technical risk assessment, the prevention and detection action implemented from the first phases of the project development are considered mitigation measures able to limit the negative occurrences and the connected technical risk. Otherwise, detection actions used to find a real failure, malfunctioning or breakage is considered as a deviation cost on planned investment, because it means to test and verify the functionality, security, and state of the art of building elements after the renovation process end, when a negative occurrence would generate additional cost for the recovery. In EEnvest technical risk database, the recovery costs are estimated as damage indicators, however the detection action are not included as they are difficult to estimate depending on several issues and buildings features.

Mitigation measures were identified during the literature review and successively through the interviews to building experts (chapter 5). The information collected have been catalogued and harmonized by energy performance simulation, considering boundary conditions such as climate.

Recommendations for minimizing the technical risks are mitigation measures elaborated for EEnvest users (from the investors to the tenants, including building constructors and design teams), that can be adopted in the renovation of existing buildings to increase the level of guarantee of planned targets because their adoption reduces the preidentified issues limiting the investment deviation in terms of energy performance gap and damages as failures and breakings. These percentages of increase or reduction of technical risks are called, in the EEnvest technical risk calculation methodology, correction factors and are connected to the renovation measures and related strategy proposed by the platform users (D2.1).

The mitigation measures can be adopted during the project decision making phase.

The most important preventive actions identified in EEnvest project, were grouped as follows:

Standardized Protocols:

- CasaClima, Passive House: verification design and construction process.
- Leadership in Energy and Environmental Design (LEED)[2]: verification design, construction of the energy performance of the building and monitoring of the energy consumption and RES system.

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[2] https://www.usgbc.org/leed

- International Performance Measurement and Verification Protocol (IPMVP)[3],: verification of the energy consumption and the RES system production through monitoring.

Processes:

- Integrated Design Process (IDP)[4]
- Blower door test
- Thermography
- ETICS guarantee/system[5]

Programme and tools:

- Maintenance program - Construction
- Maintenance program - Thermal plant
- Maintenance program - Electric plant

2.1 PROTOCOLS USED IN THE DESIGN, CONSTRUCTION, OPERATION PHASES

Reducing risks in the renovation process of an existing building is always an important topic for investors, owners, and tenants. The final quality of the renovation process depends on several aspects, and the quality of the design, construction, and use (management) of the building. Furthermore, indoor comfort, energy saving, and payback time of the investments are strictly connected.

The energy performance of a building is usually estimated by energy simulation process, where, at this renovation time, there are several uncertainties parameters knowledge. As considered by Bucking et al. (2014) are between 8 and 26 the variables responsible for significant changes in net-energy consumption. The energy efficiency (EE) deviation between planned and real one depends on several issue, calculation methods and tools (building energy modelling software can contain fundamental errors embedded in the equations used by the program leading contained inaccuracies in the predictions), difference in the parameters value (as indoor temperature) together with the occupants and use of the buildings (occupancy behaviour varies significantly, occupancy behavioural parameters are not well known especially at design stage, occupancy is quite different from the planned one), and the relative technological systems regulation (Wu et al. 2020).

The S-Curve of Bunn & Burman (2015) introduces a way of visualising the energy performance gap, considering the EE deviation as a result of taken decision and implemented actions as causes of reduced performance. A limited understanding on the energy performance during the early phase of design decisions (poor boundary definition and design assumptions, rather than verified performance in practice, poor definition of performance objectives in design briefs, conflict between energy and IEQ objectives) as a direct impact on energy performance with negative effects (van Dronkelaar et al., 2016) (Wu et al. 2020).

According to Karim et al. (2007) in the renovation of existing building there is a huge uncertainty of design information that, combined with a limited know-how from the design team, architects, engineers, and energy service company (ESCOs), produces poor quality retrofitting design project and a lacking energy performance model (Hwang, B.-G., Zhao, X., See, Y. L., & Zhong,

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[3] https://evo-world.org/en/products-services-mainmenu-en/protocols/ipmvp

[4] http://iisbe.org/down/gbc2005/Other_presentations/IDP_overview.pdf

[5] https://www.ea-etics.eu/etics/system-loyality/

Y. 2015). As summarized by (Lee et al., 2020) the technical risks of a low quality design process influences negatively the quality achievement of the renovation process, and depends on three risks categories (i) design experience risk (uncertainty in energy saving and lack of knowledge by consultant), (ii) the performance risk (lack of knowledge and skill in retrofit, increased unnecessary cost, lack of competence, communication and coordination) and (iii) material innovation risk (uncertainty cost or final performance, lack of standardization material).

To avoid these technical risks an implementation of verification processes, already tested and ready to use in the building sector, is necessary to support and address the renovation process from the early stage of the design development. At this regard, the use of an Integrated Design Process (IDP), a multidisciplinary collaborative process, is a mitigation measure able to increase the results achievement (Paoletti et al., 2013). Unfortunately, IDP requires specific skilled experts to organize a collaborative, iterative and participatory decision-making process. Standardized, robust and replicable processes are the energy certification protocols, that to be implemented need a specific expert in charge to support the renovation project and to address the final energy performance target predefined with the owner. At this regard, in the building sector several *standardized protocols* have been developed to verify the project implementation, from the design to the construction and process implementation, to achieve a high level of quality construction, that permits to verify during the different phase of the project development some pre-defined requirements, usually related to building energy performance and indoor comfort.

Several protocols in EEnvest platform are considered as mitigation measures because their implementation is a quality guarantee of the renovation process able to reduce the energy performance gap in term of impact and probability. For this reason, the use of Passive House certification, developed by the Passive Institute of Dresden, and the CasaClima certification, developed by the Energy Agency of the Province of Bolzano, triggers the correction factors. These protocols are similar and to implement one of them means to have a specific expert on building energy performance, who can support the design team to achieve the energy performance requirements. Furthermore, an external controller will verify (i) the project from the design to the final construction of the building, (ii) the right operation of the adopted solution sets – energy renovation measures – and (iii) the results of mandatories tests, as Blower Door Test (BDT) and thermography, respectively used to verify the air leakage rate and to detect heat flow (presence of thermal bridge or air infiltration), mandatory for these standardized protocols.

In parallel also the verification and monitoring protocols are considered mitigation measures, since de-risking action to monitor and rule the energy flows, guarantees to meet the planned energy consumption, RES production and energy savings and reduce the energy performance deviation. At this regard, two are the standardized protocols inserted as correction factor, the Leadership in Energy and Environmental Design certification (LEED)[6] and the International Performance Measurement and Verification Protocol (IPMVP)[7].

2.2 VERIFICATION PROCESSES

In the building sectors there exists several processes able to support the building experts to check the quality of the construction works at different phases of the renovation project. These procedures are usually standardized by European Standards, that describe the testing procedure step by step.

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[6] https://www.usgbc.org/leed

[7] https://evo-world.org/en/products-services-mainmenu-en/protocols/ipmvp

Within EEnvest project the correction factors implemented to reduce the technical risk of the renovation project are:

(i) *Blower Door Test* (BDT), it is a testing procedure to measure the air leakage in the building, according to the European Standards EN13829 and EN ISO 9972.
(ii) *Thermography*, it is a non-destructive testing based on infrared testing technology used to detect the distribution to the surface temperature according to ISO 18251.
(iii) *External Thermal Insulation Composite System* (ETICS)[8], a set of specification and configuration of system components, such as installation manuals and national regulation.

In EEnvest platform such processes are considered de-risking action, as they reduce the deviation between planned and achieved results when implemented. BDT and thermography identify the air-leakage or lack of insulation, improve the energy efficiency of the building and the indoor quality, while ETICS improves the final quality of the building construction, also enhances the energy efficiency of the whole building and its lifetime.

2.3 PROGRAMME AND TOOLS

Building maintenance

Building maintenance includes all the interventions regularly carried out on all buildings elements, from technical systems (thermal, electric, and hydraulic plants) to the building structure, to guarantee a high level of operation, in terms of energy efficiency, functionality and security. A building ordinary maintenance program is a complete planning of cleaning, inspecting, and repairing task scheduled on monthly or annual basis, and divided between minimum checklist identified and strictly regulated by European and national laws, and optional additional ones.

During the interviews conducted to different stakeholders (Chapter 5), from building experts to manufacturers, it comes out that in parallel to a good project development and construction phase, to execute an ordinary maintenance to the building components is the best way to reduce failures and guarantee the right reliability and durability of the components as well as their service life. The maintenance program is not often considered during the decision process and the selection of the solution sets, because it does not affect the initial investment. On the other side, it has an impact on the whole building service life, thus an overview on the minimum annual efforts (action and relative cots) coming from each building components is necessary from the early stages of the design project. During the design phase the renovation measures should go through a cost-benefit analysis, that also includes the costs and the minimum efforts to address the ordinary maintenance. Successively, roles and responsibilities should be identified to avoid some barriers, as (i) facility managers lacking skill set to operate the building as intended, (ii) operators not involved early in the process, sequences of operation not aligned with design intent, and information not accessible, interpretable and actionable (iii) faults occurred and remained invisible, (iv) manual control is usually very complex and difficult to understand (Wu et al. 2020).

There are different kind of maintenance, to the building envelope, to the building system (thermal, hydraulic, electric, PV and fire protection system, etc.), and a manager should be identified accordingly.

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[8] https://www.ea-etics.eu/etics/about-etics/

To adopt a maintenance program allows to reduce the technical risk in terms of (i) energy performance gap, as consumption deviations, and (ii) technical damages, as failures in the operation of technical system, breakages, and service life of the building elements.

2.4 PLANNING IMPLEMENTATION OF THE MITIGATION MEASURES

The mitigation measures to be useful and effective should be integrated in specific moment of the renovation project. At this regard, the mitigation measures are more effective if adopted since the beginning of the project planning or early in the design phase, when it is possible to reduce the technical risks and foresee effects presented in D2.1 chapter 3.2.

Table 1 describes the best moment in term of efficacy and invested efforts, when it is necessary start to implement each de-risking preventive action that in economic terms means less investment deviation respect to the planned renovation project, both for limiting the energy performance gaps, malfunctioning, failures, and breakages.

Table 1. Overview of some EEnvest mitigation measures with the identification of their integration in the project timeline.

INTEGRATION OF THE MITIGATION MEASURES		PLANNING PHASE	DESIGN PHASE	CONSTRUCTION PHASE	OPERATION PHASE
		Collection of the building data, identification of needs and functional improvement. Collection of the building code and minimum renovation requirements (functional, structural, and energy performance…) Estimation of the economic investment	Design project development. Involvement of different stakeholders. - Preliminary design - Definitive design - Executive design		
PROTOCOLS	CasaClima Passive House	Estimation of the cost investment	Verification of the design project through an external building professional	Verification of the construction works though different testing in the building site	
	Leadership in Energy and Environmental Design (LEED)	Estimation of the cost investment	Verification of the design project through an external building professional	Verification of the construction works though different testing in the building site	Verification of the energy performance of the building and the RES system through monitoring process
	International Performance Measurement and Verification Protocol (IPMVP)	Estimation of the cost investment	Design of the monitoring system and its management verification of the energy performance of the building and the RES system through monitoring process		Verification of the energy performance of the building and the RES system through monitoring process

PROCESSES	IDP	Integration of different stakeholders with different experiences and knowledge, involved from the early phases of the project development to identify the project objectives (final requirements). Final objectives must be shared and common to all workign team, that together will elaborate the best solution set based on cost optimality and prefixed indicators.	Continuos support and positive collaboration between the working team (based on different stakeholders) to identify the best solution set, in terms of economic, funcional and legislative point of view.	Collaboration and support during the building construction	Educate the bulding tenants and users in a correct use of building and related techncial systems (as regulation of the lighting system). Building users have a direct impact on enegy savings and indoor quality. High level of indoor environment quality (IEQ) in buildings has a major impact on occupant health, comfort and work performance.[9]
	Blower Door Test (BDT)	Estimation of the cost investment	More attention should be taken in the construction details, es. to limit the air leaks	Testing phase	
	Thermography	Estimation of the cost investment	More attention should be taken in the construction details, es. to limit the thermal losses.	Testing phase	
	External Thermal Insulation Composite System (ETICS)	Estimation of the cost investment	Minimum requirements of the construction company		
PROGRAMME AND TOOLS	Building maintenance - Construction - Thermal plant - Electric plant	Estimation of the cost investment	In the identification of the renovation strategy should be evaluated also the cost analysis of the solution sets identified also considered the maintenance costs.		

Furthermore, in addition to these general mitigation measures, each technical system and building element has its own specification that should be valuated case by case (chapter 4). For example, the energy efficiency of the biomass boiler is achieved if the used fuel complies with the solid biofuel quality defined by UNI EN ISO 17225. On the other way, low quality of the final fuel can reduce the energy efficiency of the boiler and cause several faults, as inappropriate combustion, ignition failure, or auger malfunctioning.

In EEnvest platform, the main mitigation measures are collected for each building elements and the user can choose if the minimum specification should be adopted for each technical system.

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[9] https://www.rehva.eu/indoor-environmental-quality-and-healthy-buildings

Next chapter reports the results obtained in WP2, presents the technical risks and the mitigation for each building element.

3. EENVEST CORRECTION FACTORS IN TECHNICAL RISK ASSESSMENT FOR BUILDING ENERGY RENOVATION PROCESS

EEnvest correction factors are applied to modify the assessed technical risk level in terms of impact and probability (related to the energy efficiency measures implemented in the renovation of commercial office buildings). They are numerical factors used to modify a predefined baseline-value of technical risks occurrences (either impact or probability).

Several types of correction factors are included in EEnvest technical risk evaluation methodology and database, according to the building features, renovation strategy solution sets, climatic context, verification processes and procedures implemented.

Case by case the correction factors values change in relation to the pilot boundary conditions of the project. The correction factors modify the technical risk indicators (impact or probability) in economic terms. They have been divided in different groups, in relation to the:

1) *Building features,* architectural and environmental characteristics of each building, including dimension, building shape and complexity, climate condition (e.g., heating degree days), and building site characteristics as building exposure to external events (sun, wind, sea, etc.). These correction factors are strictly connected to the “current state” of the building, its features and building site, for these reasons the variability of such correction factors are very low and does not depend on energy renovation strategy and difficult to change through mitigation action. As an example, building proximity to the sea is a correction factor that negatively affects both indicators, because this characteristic (i) can affect the windy context, increasing the heating losses due to the increase of air infiltration (energy gap indicator) and (ii) the brackish air reduces the long life of the building elements (damage indicator).
2) *Renovation scenario* (solution sets) related to the renovation strategy. These correction factors depend on the combination of the renovation measures adopted and their dependency on one another. Different renovation strategies affect in different way the achievement of project results, being correction factors activated differently depending on the specific strategy. For example, comparing an energy renovation strategy that includes the substitution of the windows and the insulation of the wall with only one of these measures, results in the first combination having reduced technical problems, as there is lower technical risk of negative occurrences, connected to air and water infiltration.
3) *Procedures and verification processes,* such as certification protocols, standardized procedures and monitoring programmes implemented to verify in different phases of the renovation process the results achievement. These mitigation measures are optional actions able to reduce the risk threats associated with the implemented renovation measures. If adopted at the beginning of the renovation project, they can limit the occurrences of negative events.

The last category of correction factors is considered the most interesting and useful mitigation measure by all the building stakeholders involved in the interviews (chapter 5), as they are deemed to avoid technical risk issues and to guarantee the pre-defined and planned results. This kind of mitigation measures can be implemented in a renovation project, being structured procedures, standardized processes and replicable actions that permit to check, verify, and validate the results, through measurement or specific operations.

As illustrated in D2.1, EEnvest technical risk assessment estimates the deviation level of two indicators, (i) energy gap, with the variability of thermal and electric energy efficiency between predicted and consumed, and (ii) damage, with an economic increase to the investment, with different level of impact, in relation to malfunctioning, failures or breakages.

4. EENVEST DATABASE: TECHNICAL RISK AND CORRECTION FACTORS

This chapter presents the EEnvest database as developed in WP2. The data presented are the technical risks and the correction factors (mitigation measures) of each building element analyzed and already published in the D2.1 chapter 3.2 on "i*dentification on technical risks for each building elements"*.

It is notable that all information found has been retrieved from the data collection done within WP2 through a deep work of (i) literature review, (ii) interviews with building experts, manufacturers, suppliers, and installers of insulation materials, components, and technical system, and (iii) energy performance parametric simulations.

The technical risk data is split in two indicators: energy performance gap and damages. Data for the energy performance gap indicator were found in the literature review, data for damage indicator was collected by the interviews. The interviews resulted in a valuable way to classify the technical damages, by distinguishing the individual cause-effect occurrence and identifying the different level of risk in term of impact and probability.

In the EEnvest technical risk database, negative occurrences (final effect of several causes) are specified for each indicator and completed by their own variable percentage of impact and probability that they will occur and mitigation measures that can reduce them.

The list below reports the building elements currently analysed and collected in the EEnvest database.

BUILDING ENVELOPE ELEMENTS

Roof:
- Flat roof
- Pitched roof

Floor:
- Next to the ground (outside)
- Next to air (outside)
- Floor next to unheated area (e.g., Garage)

Walls (all typologies):
- External wall:
  - External Cladding
  - Prefabricated facade
  - Internal Insulation
  - Window facade system:
    - Curtain wall
    - Double skin
- Wall next to unheated area:
  - New insulation
- Wall next to ground:
  - New insulation

Windows
Shading system
External doors

BUILDING SERVICES AND RES SYSTEMS

Heading system

Heating system
- A. Heat pump:
    - Air/air HP
    - Air/water HP
    - Geothermal HP
- B. District Heating
    - District Heating Substation
    - Customer’s internal heating system
- C. Gas Condensing Boiler
- D. Biomass boilers

Emission system
- Radiant floor
- Radiant ceiling
- Radiators

Distribution system
Regulation System
DHW generation dedicated
Cooling system
Mechanical ventilation system
Lighting system
*Building energy management system (BEMS)**

RES

Photovoltaic system
*Solar thermal system**
*Other on-site electrical power generation systems from RES (e.g., wind etc.)**

OTHER INSTALLATIONS AND EQUIPMENTS

*Building automation, measuring, management systems**
*IT installations**
*Fire and security systems**
*Commissioning**
*Elevators**
*Note: * these building elements are not currently developed.*

4.1 BUILDING ENVELOPE ELEMENTS

ENERGY PERFORMANCE GAP INDICATOR

The negative occurrences defined for the building envelope elements concerning the energy performance gap indicator are mainly caused by (i) air infiltration and (ii) thermal bridges.

1.Air infiltration

Within WP2 several literature sources on building energy performance deviation due to air infiltration have been collected. Available recommendations that can be adopted to limit these problems were reported.

Table 2. Overview on energy performance deviation due to the air infiltration.

AIR INFILTRATION		
ENERGY PERFORMANCE GAP	RECOMMENDATIONS	SOURCE
Infiltration accounts for 25%–50% of the heating load in both residential and commercial buildings		*A comparison of measured and simulated air pressure conditions of a detached house in a cold climate*. (Juha Jokisalo, Targo Kalamees, Jarek Kurnitski, Lari Eskola, Kai Jokiranta, Juha Vinha 2008)
Exhaust air losses in larger industrial buildings may represent 60% of the heating load		*Fuel consumption in industrial buildings.* (Kirkwood Ronald C. 1977)
Ventilation heat loss had been only up to 20% of the total heat loss from a typical house in the United Kingdom.		*Natural ventilation in well-insulated houses.* (D. J. Nevrala, D. W. Eheridg 1977)
Attributed 40% of the heating/cooling load in houses to infiltration.		Residential air infiltration. (Caffey GE 1979)
One-third of the heating and cooling loads in a building are due to infiltration		Persily A (1982) Understanding Air Infiltration in Homes, Report PU/CEES No. 129. Princeton University Center for Energy and Environmental Studies, Princeton, NJ.
15% of the heat load commercial buildings		National Institute of Standards and Technology (1996) NIST estimates nationwide energy impact of air leakage in U.S. buildings. Journal of Research of the NIST 101(3): 413.
The average air leakage for the buildings is 20% tighter than the average for the 228 buildings included in a similar 2011 analysis.	LEED or requirement of an effective air barrier.	(Emmerich and Persily 2014)
Referred to residential buildings, estimates the distribution of air infiltration dispersed by building components as percentage of energy gap incidence		(Younes, Abishdid, and Bitsuamlak 2012)
The results indicate that, nationwide, air infiltration is responsible for about 18% of the total annual heating load of the office building stock, but only 2% of the cooling load in US office buildings.		(Emmerich, Persily, and VanBronkhorst n.d.)
Estimates the percentage distribution of infiltration air leakage by building components as follows: Walls: 18%–50%, with an average of 35%.		Component leakage testing in residential buildings (Dickerhoff, Grimsrud, and Lipschutz 1982)
Ceiling details: 3%–30%, with an average of 18%. This leakage undermines the purpose		

of insulation in attics, residential houses, and ceiling insulation in buildings.	Harrje DT and Born GJ (1982) Cataloging air leakage components in houses. In: Proceedings of the American Council for an Energy-Efficient Economy, 1982 Summer Study, Santa Cruz, CA, American Council for an Energy-Efficient Economy, Washington, DC.
Forced-air and/or cooling systems: 3%–28%, with an average of 18%. This category represents air leaks in conditioning/heating air paths and ducts.	
Windows and doors: 6%–22%, with an average of 15%. The infiltration air leakage in windows is a matter of the window type rather than age (Weidt et al., 1979). It is important to note that this percentage represents infiltration through seals and cracks in doors and windows, not due to the opening of doors by passing individuals, for instance.	
Fireplace: 0%–30%, with an average of 12%. As for doors and windows, this percentage represents the air leakage through a ‘cold fireplace’, not a running fireplace with open dampers, plugs, caps, or such.	
Vents in conditioned spaces: 2%–12% with an average of 5%. This refers to undamped or improperly damped small exhaust vents in a conditioned space.	
A plot of the air leakage at 75 Pa vs. the reported number of stories of the building and shows a tendency toward more consistent tightness for taller buildings.	Airtightness of Commercial Buildings in the U.S.(Steven J Emmerich and Persily n.d.)
A plot of the air leakage at 75 Pa vs. the year of construction of the building for buildings built more recently than 1955. While common expectation is that newer commercial buildings must be tighter than older ones, the data simply give no indication that this is true.	(Steve J Emmerich and Persily n.d.)
Although the data show considerable scatter, they do indicate a general trend toward somewhat tighter constructions in the colder climates. The average air leakage was 33 m3 /h·m2 for buildings in locations with less than 2000 heating degree-days compared to 18 m3 /h·m2 for building in locations with more than 2000 heating degree-days.	

Literature data identified an increase in heating demand due to air infiltration in the building envelope. These values are around 30% for residential buildings and around 15-20% for commercial and office buildings. Within WP2 a value of 20% for commercial buildings was adopted.

This heating demand increase is referred to the whole building, therefore it was subdivided in the different elements that compose the building, to find the impact of air infiltration for the different elements in percentage. The resulting values are:

- Wall: 18%-50%, with an average of 35%.

- Roof: 3%-30%, with an average of 18%.

- Windows and doors: 6%-22%, with an average of 15%.

By having a range of impact, it was possible to identify three values: low, medium, and high impact for the different elements of the building envelope. These percentages of increase in heating demand were input into the datasheet and linked to the initial heating demand value "as planned", to calculate the increase in energy demand caused by air infiltration. This process will be explained in the following paragraphs.

As reported in Emmerich and Persily (2014) the energy performance gap due to air infiltration can be reduced if an effective air barrier is adopted. Reduced air infiltration values have been found in commercial building certified with LEED. This is probably because of a higher accuracy required to reach the LEED standard, both in the design and in the construction phase. With regards to this, the use of certification protocols as LEED, Passive House, CasaClima, or standardized procedures as Blower Door Test, were considered as mitigation measures and good recommendations to be adopted to de-risk the renovation process. Specific correction factors, estimated *ad hoc*, have been implemented in the EEnvest technical risk calculation process.

2. Thermal bridge

A second main cause of energy gaps in the building envelope is due to thermal bridges. Thermal bridges can occur between different components of the envelope in the corners (roof-wall connections, ceiling-wall connections) and coplanar (e.g., window-wall). However, in the case of office buildings with curtain wall façades or prefabricated elements, thermal bridges often occur between individual elements of e.g., the façade, such as between joints of prefabricated panels or in anchoring systems.

It is very complicated to estimate an energy gap value in these cases, because there are many discontinuities or very different situations among buildings, in terms of geometry, exposure, climate, types of intervention etc.

Table 3. Overview on energy performance deviation due to the thermal bridge

AIR INFILTRATION		
ENERGY PERFORMANCE GAP	RECOMMENDATIONS	SOURCE
Point thermal bridge effects in cladding systems can constitute a significant part of buildings' thermal balance. Neglecting their presence can lead to significant underestimation of actual heat flows which can account for 5% to almost 20% of total heat flows through the building envelope, depending mostly on the thermal transmittance of the load bearing wall and the ventilation characteristics of the air cavity.		Theodoros G. Theodosiou∗, Aikaterini G. Tsikaloudaki, Karolos J. Kontoleon, Dimitrios K. Bikas Thermal bridging analysis on cladding systems for building facades (Theodosiou et al. 2015)
Under steady state conditions, the weakest parts of the building envelope, by means of thermal losses, are the windows on the main facades of the building; more specifically, according to the data presented in Table2, 62–64 % of heat flows through the envelope are attributed to windows, 20–18 % to walls and 6–10 % to linear thermal bridges, for the cases of present and more demanding thermal insulation requirements, respectively.		
Table 3. Unventilated additional percentage on total heat flows (%U-value W/K): L bracket 10-18 % T bracket 12-16 %		

Table 3. Ventilated additional percentage on total heat flows (%U-value W/K): L bracket 9-13 % T bracket 8-12 %	
Table 3. No cavity additional percentage on total heat flows (%U-value W/K): L bracket 13-16 % T bracket 15-18 %	

In literature, U-value increase percentages have been found, usually referring to simple wall cladding caused by installation defects or heat losses not foreseen in the design phase. These values have also been used for roofs and floors next to the air.

Other U-values were found for prefabricated facades with anchoring systems with and without ventilation cavities. These percentages were included in the PHPP calculation to verify the increase in transmittance per square meter for each element and consequently calculate the increase in heating demand caused by thermal bridges.

CORRECTION FACTORS

The correction factors are divided into three groups, as:

(i) ***Building feature***, architectural and environmental characteristics of each building directly connected to the building and its features.

  - Climate conditions of the context in which the building is located. Three climate zones are considered in EEnvest technical risk assessment: Nordic, Continental and Mediterranean. The energy performance deviation has been carried out through energy performance simulation, estimating the increase in energy losses due to thermal bridges, and air infiltration.
  - Building exposure. Two levels of wind exposures were considered: high for a suburban context and low for an urban context, where the building is more protected from the context.
  - Proximity to the sea, for the damage indicator, is a negative factor, because the brackish in the air reduce the service life of the building elements, attacking and corroding the materials, accelerating the degradation and deterioration. It has been estimated that there is a share of 20% reduction in the probability of damage occurring if the envelope components are not in contact with sea air.

(ii) ***Protocols*** (p*rocedures and verification processes)* as the mitigation measure connected to the decision-making process respectively to energy gap and damage indicator.

  - Certification protocols such as CasaClima, Passive House Certification, LEED, or verification process as Blower Door Test are considering de-risking action. This because they check the design project and verify (on the building site) the final quality of the building renovation, measuring some indicators, as air infiltration or monitoring the energy consumption. To simplify the technical risk calculation and reduce the correction factors, different certification procedures as CasaClima, Passive House Certification, LEED have been put together, in one correction factor, that modify the impact of 80% and the probability of 20%, the energy gap deviation due to the air infiltration and thermal bridges, excluding some cases with internal insulation.
  - The presence of a maintenance program reduces the probability of risks, both in air infiltration and thermal bridges, occurring in the different elements of the building envelope by 50%.

(iii) ***Renovation scenario*** related to the renovation strategy and the combination of the renovation measures adopted and their dependency one to the other.

4.1.1 Roof

Flat roofs and pitched roofs are the two roof typologies identified according to their shape, functional and structural characteristics, and to their different behaviour in water run-off. In relation to the position of the insulation system used, between outside (located in the external layer) or inside, there are different level of technical problems and negative occurrences: for example, air and water infiltration issues are absent in the case of internal insulation.

The roof occurrences identified for both elements are similar for both the indicators:

- Energy performance gaps due to air infiltration and presence of thermal bridge.
- Damage (as investment deviation of unplanned works) due to water infiltration.

Energy gap

As for roofs with external insulation (flat or pitched one), the main causes of energy gaps are:

- air infiltration, (i) due to installation issues for complex architectonic structures, presence of corners (overlay sheath or tape laying), bad insulation laying, wall-roof connection or (ii) due to the presence of several components as windows, chimney, lift, border or parapet connection, and other technical system or (iii) lack of discontinuity due to the plant systems crossing, such as cables or RES installation.
- thermal bridge, (i) due to installation issues for complex architectonic structures, presence of corners, wall-roof connection, and bad insulation laying, (ii) due to the presence of several components as windows, chimney, lift, border or parapet connection, and other technical system or (iii) lack of discontinuity due to the plant systems crossing, such as cables or RES installation.

In case of roof with internal insulation**,** the energy gaps are mainly due to thermal bridges maybe caused by (i) technical issues and (ii) bad installation. In building with high level of complexity, along the wall-ceiling connection, in the corners, or in the discontinuity of the structure for the presence of other elements, as connections, roof-windows, or plant systems crossing, such as cables or RES installation.

Correction factors

Table 4. Overview of the roof correction factors related to the building features adopted for energy gap indicator.

BUILDING FEATURE		ENERGY PERFORMANCE GAP				
		AIR INFILTRATION		THERMAL BRIDGE		
		Building exposure (wind)		Climate conditions		
		High	Low	Nordic	Continental	Mediterranean
Roof: (Flat and pitched)	External insulation	1	0.8	1	0.91	1.1
	Internal insulation	-	-	-	-	-

Table 5. Overview of the roof correction factors related to the adopted protocols for energy gap indicator.

PROTOCOLS (PROCEDURES AND VERIFICATION PROCESSES)	ENERGY PERFORMANCE GAP	
	AIR INFILTRATION	THERMAL BRIDGE

		CasaClima, Passive House certification, LEED Blower Door Test		Maintenance program - Construction		CasaClima, Passive House certification, LEED Blower Door Test,		Maintenance program - Construction	
		Impact (No = 1) Yes	Probability (No = 1) Yes	Impact	Probability (No = 1) Yes	I Impact (No = 1) Yes	Probability (No = 1) Yes	Impact	Probability (No = 1) Yes
Roof: (Flat and pitched)	External insulation	0.2	0.8	-	0.5	0.2	0.8	-	0.5
	Internal insulation	-	0.8	-	0.5	-	0.8	-	0.5

Table 6. Overview of roof correction factors related to the scenarios and combination of renovation measures adopted for energy gap indicator.

SCENARIOS - COMBINATION OF MEASURES		ENERGY PERFORMANCE GAP			
		AIR INFILTRATION		THERMAL BRIDGE	
		New windows on roof		New windows on roof	
		Impact (No=1) Yes	Prob. (No=1) Yes	Impact (No=1) Yes	Prob. (No=1) Yes
Roof: (Flat and pitched)	External insulation	0.7	0.95	0.7	0.5
	Internal insulation	-	-		

Damage

The interviews provided valuable data to classify the technical damages, distinguishing the individual causes of each occurrence, and identifying different risk levels in term of damage impact and probability.

The most common problems of the roofs, flat or pitched one, are connected to the water infiltration, considered one of the most invasive negative occurrences in the renovation process of such element. Such problems occur in a pitched roof more frequently 10% more of flat one. On the other site, the flat roofs result a characterized element of office buildings. From three interviews with builders and building maintenance companies, it results that problems of air infiltration are often accompanied by water infiltration. Hence, main causes of roof damage are:

- water infiltration due to installation issues (bad insulation laying, overlay sheath or tape laying), roof complexity (corners) or connection with other elements (windows, chimney, lift, other technical system installed or there integrated);
- problems due to the water condensation, often for indoor insulation.

The main mitigation measure for the damage indicator is a periodic maintenance of the roof that includes the cleaning of drains and the condition check of the external layer. From the interviews done results that the hydraulic system is usually insufficient for the current climate conditions, in particular the size and the number of gutters should be increased for adapting to the actual rainfall intensity measured in the last years. For this reason, more and more often is necessary to clean these elements from the leaves.

A maintenance program, which guarantees a periodic check of the roof condition, reduces the abovementioned problems, and increases the lifetime of such elements.

Correction factors

Table 7 Overview of roof correction factors related to the building features adopted for the damage indicator.* 1 indicate no reduction factor applied.

BUILDING FEATURE		DAMAGE	
		Service life (static issues and water infiltration)	Condensation
		Close to the sea	Close to the sea
		Probability (Yes = 1) No	Probability (Yes = 1) No
Roof: (Flat and pitched)	External insulation	0.8	0.8
	Internal insulation	0.8	0.8

In Table 7 water infiltration and condensation problems have been identified as the main cause of damage in roof element.

Table 8. Overview of roof correction factors related to the adopted protocols for the damage indicator

PROTOCOLS (PROCEDURES AND VERIFICATION PROCESSES)		DAMAGE			
		CasaClima, PHPP, LEED, Blower Door Test		Maintenance program - Construction	
		Impact	Probability (No = 1) Yes	Impact (No = 1) Yes	Probability (No = 1) Yes
Roof: (Flat and pitched)	External insulation	-	0.8	-	0.5
	Internal insulation	-	0.8	-	0.5

Table 8 shows the correction factors for the values to be applied to the damages. The presence of protocols and certifications would reduce the probability of damage occurring due to water infiltration by 20%. This probability is reduced even more, up to 50%, in the presence of a maintenance program with a damage impact reduction of 50% as well.

Table 9 Overview of roof correction factors of related the scenarios and combination of renovation measures adopted for the damage indicator.

SCENARIOS - COMBINATION OF MEASURES		DAMAGE	
		New roof on windows element	
		Impact = 1	Prob. (No=1) Yes
Roof: (Flat and pitched)	External insulation	-	0.9
	Internal insulation	-	-

In damages correction factors related to the scenario composition, the impact is fixed to 1 because in case of “water infiltration” (as first cause of technical issue) the final impact of this problem makes the same damages in terms of reparations and costs.

4.1.2 Floor

Three are the main floor types considered:

- Floor next to ground, e.g., foundation, floor in contact with the ground;
- Floor next to external space, e.g., pilot house floor;

- Floor next to unheated area, such as garages or cellars.

The methodology used to identify the technical risks is based on the identification of the negative occurrences that affect the energy efficiency or cause damages to the building element.

Energy gap

Causes of energy performance gaps, between what was foreseen in the design phase and after the implementation of the retrofit, are air infiltration and thermal bridges. In the case the energy performance gap indicator deviation can be due to heating losses for *air infiltration* and *thermal bridge* for the presence of other building elements, walls, building structure (pilasters or corners), and with the connection elements, that cross the floor, as lift, stair, passage of pipes, ducts, and systems (general leakages). These kind of discontinuities increases the possibility to have these problems along the panels laying and relative connections.

A parametric simulation implemented in the Passive House Planning Package (PHPP)[10] tool was used to estimate the energy performance deviation of the floors. A building model with high energy efficiency standards (i.e. minimum energy performance transmittance of the building envelope) was selected and analysed in three climate conditions: Nordic (Stockholm -SE), Continental (Paris -FR), and Mediterranean (Rome -IT). The parametric analysis was performed, increasing with percentages the U-value of the floor and the results obtained were the impact on the heating demand in kWh/m^2 (NFA). The impact quantification for the energy gap indicator is the variation between the baseline (the model of the hypothesis) and the heating demand resulting from the U-value floor increase. Furthermore, the final deviation will be evaluated also considering the correction factors, that can modify the impact and the probability of each occurrence.

Correction factors

Table 10. Overview of floor correction factors related to the building features adopted for energy gap indicator.

BUILDING FEATURE		ENERGY PERFORMANCE GAP				
		AIR INFILTRATION		THERMAL BRIDGE		
		Building exposure (wind)		Climate conditions		
		High	Low	Nordic	Continental	Mediterranean
Floor	Next to the ground (outside)	1	0.8	1	0.83	0.67
	Next to air (outside)	1	0.8	1	0.83	0.67
	Floor next to unheated area (es. Garage)	1	0.8	1	0.83	0.67

Table 11. Overview of floor correction factors related to the adopted protocols for energy gap indicator.

PROTOCOLS (PROCEDURES AND VERIFICATION PROCESSES)	ENERGY PERFORMANCE GAP							
	AIR INFILTRATION				THERMAL BRIDGE			
	CasaClima, Passive House certification, LEED Blower Door Test		Maintenance program - Construction		CasaClima, Passive House certification, LEED Blower Door Test,		Maintenance program - Construction	
	Impact (No = 1) Yes	Probability (No = 1)	Impact	Probability	I Impact (No = 1) Yes	Probability (No = 1)	Impact	Probability

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[10] https://passivehouse.com/04_phpp/04_phpp.htm

			Yes		(No = 1) Yes		Yes		(No = 1) Yes
Floor	Next to the ground (outside)	0.2	0.8	-	0.5	0.2	0.8	-	0.5
	Next to air (outside)	0.2	0.8	-	0.5	0.2	0.8	-	0.5
	Floor next to unheated area (es. Garage)	0.2	0.8	-	0.5	0.2	0.8	-	0.5

Damage

The main cause of damage, which can be found after a floor renovation, is usually water infiltration due to insulation issues (overlay sheath, etc.).

Interviews with maintenance companies have confirmed as the main cause of damage the rising of water, also in floors next to ground. Water infiltration is related to discontinuity due to the presence of other building elements, as stairwell, lift shaft or along the floor borders, along the connection with other elements, as walls.

The damage probability range of these kind of problems (water infiltration) varies between 2% and 3%, with an economic impact of 3.50 €/m^2 for the floor next to air and to unheated area, while for floors next to ground the average impact is estimated of 8.00 €/m^2 due to the difficulty of repairing foundation slabs. These impact values are identified by interviews.

Correction factors

Table 12 Overview of floor correction factors related to the building features adopted for the damage indicator.

BUILDING FEATURE		DAMAGE	
		Service life (static issues and water infiltration)	Condensation
		Close to the sea	Close to the sea
		Probability (Yes = 1) No	Probability (Yes = 1) No
Floor	Next to the ground (outside)	0.8	-
	Next to air (outside)	0.8	0.8
	Floor next to unheated area (es. Garage)	0.8	-

Table 13. Overview of floor correction factors related to the adopted protocols for the damage indicator.

PROTOCOLS (PROCEDURES AND VERIFICATION PROCESSES)		DAMAGE			
		CasaClima, PHPP, LEED Blower Door Test,		Maintenance program - Construction	
		Impact	Probability (No = 1) Yes	Impact (No = 1) Yes	Probability (No = 1) Yes
Floor	Next to the ground (outside)	-	0.8	-	0.5
	Next to air (outside)	-	0.8	-	0.5
	Floor next to unheated area (es. Garage)	-	0.8	-	0.5

4.1.3 Wall

The types of wall studied for technical risk assessment are:

- The ***external cladding*** refers to all those interventions of rebuilding or new application of the insulation layer on the external surface of the building to be renovated and subsequent external finishing or cladding applied on the insulation layer.
- ***Ventilated facades*** with respect to external cladding, by means of a system of mullions and transoms or different anchoring systems (usually in steel), allow for separating the external cladding from the insulation layer, to make the air cavity ventilated and avoid overheating of the facade. Additional thermal bridges that may occur in the anchoring systems have been studied separately.
- ***Prefabricated façades***, usually composed of modules which are installed by means of substructures or point anchorage systems, present different risks compared to normal external cladding due to the increased discontinuity between elements and between panel joints.
- ***Other types of façades*** such as *double skin façades* have been studied in a similar way to ventilated façades regarding the thermal bridges of the glazing frames, but with further reduced impacts because they are prefabricated façades with installation by very specialised companies and with consequent reduction of errors during façade installation on site.
- ***Façade with internal insulation.*** Another studied type concerns insulations made at the inner side due to the fact that many buildings cannot be retrofitted with insulation on the exterior for reasons such as historic preservation, cost, zoning or space restrictions, or aesthetics.

The last types of retrofit concern the installation of insulation in walls that are facing the ground and unheated rooms.

Energy gap

The main causes of energy gaps can be found in two macro areas, air infiltration and thermal bridge, due to:

- Air infiltration
    - Connection with other elements: borders/angles, balconies – terraces interfaces, corners openings (windows or doors) and systems, general leakages near the connections
    - Manufacturing issues or bad insulation installation (plaster cracks, bad airtightness tape laying - breakages overlay sheath)
    - In *prefabricated façade*, connection with other modules, between modules and traditional parts and interfaces with systems (BIPV, ducts, etc): bad modules installation, airgap, not perfect vertical and horizontal alignment and sealing
    - In *window façade system* (curtain wall), modules interferences with anchoring, fixing systems and connection with other elements, air exchanger or integrated elements (shading systems), weakness, bad curtain wall installation (not perfect overlay, bed alignment, etc.)
    - In *window façade system* (curtain wall), manufacturing issues and general leakages in the curtain wall seals and joints (breakages, defects, deflection of frame, etc.)
- Thermal bridge:

  - Connections of elements or borders/corners, balconies, terraces interfaces, weakness around connections with the wall and with other materials.
  - Openings (windows or doors) and systems (ducts, pipes, cables, electrical boxes, etc.), weakness, bad insulation installation and general leakages
  - Fixing (anchoring) systems, general leakages in the connection between elements
  - In window façade system (curtain wall), borders and connections, bad curtain wall installation (not perfect overlay, bed alignment, etc.)
  - In window façade system (curtain wall), leakages in the curtain wall seals, joints, anchoring, shading systems, and connection with other elements (wall, floor, etc)

As for the roofs, for the external cladding the value of 20% overheating caused by air infiltration into the envelope was used. The percentages of overheating referred to the walls in the literature (Dickerhoff et al. 1982) and are 18%, 35% and 50% for low, medium, and high impacts. Calculating these percentages on the total infiltration of 20% resulted in 3.6%, 7% and 10%, which are the percentages of overheating due to wall air infiltration. These results were also considered for a cladding made of prefabricated panels.

For air infiltration values in curtain walls or double skin facades, reference is made to data from interviews with a 5-20% impact in thermal consumption due to the presence or absence of the windscreen. Impacts further vary according to climate.

In ventilated facades a significant thermal bridge is found in the anchoring systems. Not considering the presence of these systems in a calculation of the thermal load of the building can underestimate from 5% to almost 20% (Theodosiou et al. 2015) of the total heat flow through the building envelope, a variation that depends on the transmittance of the structural wall and the characteristics of the ventilated façade and its air gap. The heat fluxes are subsequently expressed in this study as point heat bridges per unit area obtaining additional U-values to be added to the wall. The values obtained are distinguished by the presence of "L" and "T" brackets and by the presence or absence of thermal break insulation in the anchoring elements.

According to these data, the EEnvest design and calculation of thermal bridges in ventilated facades were 5%, 10% and 15% for low, medium, and high impacts. These increases, considered as underperformance due to thermal bridging, were added to the wall U-values of the reference PHPP model in Stockholm. Once the wall U-value was increased, the delta of the heating demand compared to the reference delta was calculated, which was then divided by the square metres of external walls of the building. In this way, the heating demand delta values per square metre were calculated for low, medium, and high impacts.

The same article (Theodosiou et al. 2015) indicates U-value increases for anchoring systems as those of the ventilated façade, but with the presence of unventilated air cavities this time. These values have been taken for the double skin façade. These values (10%, 15% and 20% for low, medium, and high impact), as for the ventilated façade, were taken from the PHPP of the reference building in Stockholm to obtain the delta of the U-value and the delta of the heating demand per square metre.

Finally, from the reference paper (Theodosiou et al. 2015), for the thermal bridge values of the prefabricated façade, considering anchoring systems as those of the ventilated façade with the exclusion of the presence of the air gap, those referring to the absence of air gaps between the layers were taken.

Correction factor

Table 14. Overview of the wall correction factors related to the building features adopted for energy gap indicator.

BUILDING FEATURE		ENERGY PERFORMANCE GAP				
		AIR INFILTRATION		THERMAL BRIDGE		
		Building exposure (wind)		Climate conditions		
		High	Low	Nordic	Continental	Mediterranean
External wall	External Cladding	1	0.8	1	0.98	0.86
	Ventilated	1	0.8	1	0.98	0.86
	Prefabricated facade	1	0.8	1	0.98	0.86
	Internal Insulation	-	-	-	-	-
	Window facade system: Curtain wall or Double skin	1	0.8	1	0.98	0.86
Wall next to unheated area	New insulation	-	-	1	0.98	0.86
Wall next to ground	New insulation	-	-	1	0.98	0.86

Table 15 Overview of the wall correction factors related to the adopted protocols for energy gap indicator.

PROTOCOLS (PROCEDURES AND VERIFICATION PROCESSES)		ENERGY PERFORMANCE GAP							
		AIR INFILTRATION				THERMAL BRIDGE			
		CasaClima, Passive House certification, LEED Blower Door Test		Maintenance program - Construction		CasaClima, Passive House certification, LEED Blower Door Test,		Maintenance program - Construction	
		Impact (No = 1) Yes	Probability (No = 1) Yes	Impact	Probability (No = 1) Yes	I Impact (No = 1) Yes	Probability (No = 1) Yes	Impact	Probability (No = 1) Yes
External wall	External Cladding	0.2	0.8	-	0.5	0.2	0.8	-	0.5
	Ventilated	0.2	0.8	-	0.5	0.2	0.8	-	0.5
	Prefabricated facade	0.2	0.8	-	0.5	0.2	0.8	-	0.5
	Internal Insulation	0.2	-	-	-	0.2	0.8	-	-
	Window facade system: Curtain wall or Double skin	0.2	0.8	-	0.5	0.2	0.8	-	0.5
Wall next to unheated area	New insulation	0.2	0.8	-	0.5	0.2	0.8	-	0.5
Wall next to ground	New insulation	0.2	0.8	-	0.5	0.2	0.8	-	0.5

Table 16 Overview of the wall correction factors related to the scenarios and combination of renovation measures adopted for energy gap indicator.

SCENARIOS COMBINATION OF MEASURES	ENERGY PERFORMANCE GAP				
	AIR INFILTRATION		THERMAL BRIDGE		
	New windows on wall element		New windows on wall element		External shading system
	Impact (No=1)	Prob. (No=1)	Impact (No=1)	Prob. (No=1)	Impact (No=1)

		Yes	Yes	Yes	Yes	Yes
External wall	External Cladding	0.7	0.95	0.5	0.95	0.9
	Ventilated	0.7	0.95	0.5	0.95	0.9
	Prefabricated facade	0.7	0.95	0.5	0.95	0.9
	Internal Insulation	-	-	-	-	0.9
	Window facade system: Curtain wall or Double skin	0.7	0.95	0.5	0.95	0.9
Wall next to unheated area	New insulation	-	-	0.5	0.95	-
Wall next to ground	New insulation	-	-	-	0.95	-

Damage

Damage is mainly caused by:

- Water infiltration due to:
  - bad insulation or waterproof layers installation, e.g., plaster cracks, poor sheath overlay, poor parapet protection, distance between cladding elements, etc.
  - proximity to the borders with openings (windows), balconies-terraces, and systems (of any kind), or due to possible breakages.
- Glass breakages (curtain wall only), weather and exposure conditions (thermal expansion, rigid conditions, wind) especially along weak point (anchoring, fixing, etc.).

Air infiltration usually also leads to water infiltration. This last one can produce significant damages in different types of cladding wetting the internal layers of the wall, causing (not only) the loss of thermal insulating properties of the materials but also internal condensation and breakages.

As far as prefabricated façade systems are concerned, the probability of such damage occurring is reduced because the installation is normally carried out by specialised companies and with elements already tested during the prefabrication phase. Damage and water infiltration may however occur between the joints of the modules, depending on the quality of the finishing work at the points where the panels are connected.

In the case of curtain walls and glass façades, the impact of damage probability is further reduced, as the entire prefabricated façade is installed by extremely specialised companies. Damage to glass is also limited, because defective and damaged elements are replaced directly during façade installation.

Correction factor

Table 17. Overview of the wall correction factors related to the building features adopted for damage indicator.

BUILDING FEATURE		DAMAGE	
		Service life (static issues and water infiltration)	Glass breakages
		Close to the sea	Close to the sea
		Probability (Yes = 1) No	Probability (Yes = 1) No
External wall	External Cladding	0.8	-
	Ventilated	0.8	-

	Prefabricated facade	0.8	-
	Internal Insulation	0.8	-
	Window facade system: Curtain wall or Double skin	0.8	0.8
Wall next to unheated area	New insulation	0.8	-
Wall next to ground	New insulation	0.8	-

Table 18 Overview of the wall correction factors related to the adopted protocols for the damage indicator.

PROTOCOLS (PROCEDURES AND VERIFICATION PROCESSES)		**DAMAGE**			
		CasaClima, PHPP, LEED, Blower Door Test		Maintenance program - Construction	
		Impact	Probability (No = 1) Yes	Impact (No = 1) Yes	Probability (No = 1) Yes
External wall	External Cladding	-	0.8	-	0.5
	Ventilated	-	0.8	-	0.5
	Prefabricated facade	-	0.8	-	0.5
	Internal Insulation	-	0.8	-	0.5
	Window facade system: Curtain wall or Double skin	-	0.8	-	0.5
Wall next to unheated area	New insulation	-	0.8	-	0.5
Wall next to ground	New insulation	-	0.8	-	0.5

Table 19 Overview of the wall correction factors related to the scenarios and combination of renovation measures adopted for the damage indicator.

SCENARIOS - COMBINATION OF MEASURES		**DAMAGE**		
		New windows on wall element		
		I Impact = 1	Probability No	Probability Yes
External wall	External Cladding	1	1	0.9
	Ventilated	1	1	0.9
	Prefabricated facade	1	1	0.9
	Internal Insulation	-	-	-
	Window facade system: Curtain wall or Double skin	1	1	0.9
Wall next to unheated area	New insulation	-	-	-
Wall next to ground	New insulation	-	-	-

4.1.4 Windows

The energy gap and damage results have been explained in D1.1.

Energy gap

In the window element analysis, the energy gap as a deviation between planned energy performance and real energy consumption, can be produced by two occurrences: air infiltration and thermal bridge (D1.1. Chapter4.1)

Correction factor

Table 20 Overview of the window correction factors related to the building features adopted for energy gap indicator.

BUILDING FEATURE	ENERGY PERFORMANCE GAP							
	AIR INFILTRATION					THERMAL BRIDGE		
	Climate conditions (impact)			Building exposure (wind)		Climate conditions		
	Nordic	Continental	Mediterranean	High	Low	Nordic	Continental	Mediterranean
Windows	1	0.65	0.37	1	0.8	1	0.71	0.41

Table 21 Overview of the window correction factors related to the adopted protocols for energy gap indicator.

PROTOCOLS (PROCEDURES AND VERIFICATION PROCESSES)	ENERGY PERFORMANCE GAP							
	AIR INFILTRATION				THERMAL BRIDGE			
	CasaClima, Passive House certification, LEED Blower Door Test		Maintenance program - Construction		CasaClima, Passive House certification, LEED Blower Door Test,		Maintenance program - Construction	
	Impact (No = 1) Yes	Probability (No = 1) Yes	Impact	Probability (No = 1) Yes	I Impact (No = 1) Yes	Probability (No = 1) Yes	Impact	Probability (No = 1) Yes
Windows	0.2	0.8	-	0.5	0.2	0.8	-	0.9

Table 22 Overview of the window correction factors related to the scenarios and combination of renovation measures adopted for energy gap indicator.

SCENARIOS - COMBINATION OF MEASURES	ENERGY PERFORMANCE GAP				
	AIR INFILTRATION		THERMAL BRIDGE		
	Wall insulation		Wall insulation		Window shading system between glasses
	Impact (No=1) Yes	Prob. (No=1) Yes	Impact (No=1) Yes	Impact (No=1) Yes	Impact (No=1) Yes
Windows	0.7	0.7	0.7	0.7	0.1

Damage

In terms of damage, the economic deviation is the cost due to repairs, with three level of configurations impact related to: company call fee, workmanship hours and materials. (D1.1. Chapter4.1)

Correction factor

Table 23 Overview of the window correction factors related to the building features adopted for damage indicator.

BUILDING FEATURE	DAMAGE			
	Service life (static issues and water infiltration)	Condensation	Glass breakages	Automatic control system
	Close to the sea	Close to the sea	Close to the sea	Close to the sea
	Probability (Yes = 1) No	Probability (Yes = 1) No	Probability (Yes = 1) No	Probability (Yes = 1) No
Windows	0.8	0.8	0.8	0.8

Table 24 Overview of the window correction factors related to the adopted protocols for damage indicator.

PROTOCOLS (PROCEDURES AND VERIFICATION PROCESSES)	DAMAGE			
	CasaClima, PHPP, LEED Blower Door Test,		Maintenance program - Construction	
	Impact	Probability (No = 1) Yes	Impact (No = 1) Yes	Probability (No = 1) Yes
Windows	-	0.8	-	0.5

Table 25 Overview of the window correction factors related to the scenarios and combination of renovation measures adopted for damage indicator.

SCENARIOS - COMBINATION OF MEASURES	DAMAGE		
	Wall insulation		
	Impact = 1	Probability No	Probability Yes
Windows	1	1	0.9

4.1.5 Shading system

The methodology followed for the shading systems is divided, as for the other elements of the envelope, in the identification of the causes of the energy gaps and their impact, and the damages that can be created in these systems. As far as the energy consumption increases are concerned, they have been divided for the winter season with the consequent consumption increase due to heating, and for the summer season for the consumption caused by cooling.

The main damages are due to malfunctions.

Malfunctions due to poor maintenance and cleaning (dust, lamellas alignment or rotation, manual control problems, mechanical breakages, etc.).

Energy gap

For the winter case, regarding the proper functioning and use of shading systems, several studies have shown that building occupants are usually poor at making appropriate use of daylight by controlling the blinds available to them.

In a study (Motamed 2019) of 26 recently refurbished post-war buildings in Geneva it is shown that the main causes of the performance gap are related to the quality of execution, operation, and user behaviour (both occupant and energy operator).

An eight-month measurement campaign was carried out in two identical office rooms in the LESO solar experimental building in Lausanne, Switzerland (Motamed 2019). It was shown that proper management of shading and lighting by an advanced automated control system mitigated the energy gap by 72% compared to manual use by a standard occupant and by 19% compared to the best-case scenario of using such systems. These automated systems consider the risk of glare and visual comfort within the offices, when this risk is not present the shading systems are opened, which in a manual control usually remain lowered. This greater openness during the day allows greater solar gain during the winter with a positive impact on both heating and electric lighting. This improved performance of the shading systems was considered in the PHPP reference model to assess solar gain in winter periods and quantify overheating due to tampering with the automatic shading system controls.

As for the summer case, energy savings values in summer cooling were taken from monitoring in a South Korean school (Park et al. 2020) after external shading systems had been refurbished. Correct positioning, even for the summer season, can have a high impact in energy savings. These energy saving percentages were carried over into the PHPP reference simulation model by adjusting the incidence of shading in the glazed surfaces of the model. From the model it was possible to calculate impact values for different climates.

Correction factor

Table 26. Overview of the shading system correction factors related to the building features adopted for energy gap indicator.

BUILDING FEATURE		**ENERGY PERFORMANCE GAP**					
		Climate conditions (impact) - Heating demand increase			Climate conditions (impact) - Cooling demand increase		
		Nordic	Continental	Mediterranean	Nordic	Continental	Mediterranean
Shading system	North windows	1	0.89	0.46	1	1.15	1.23
	East windows	1	0.96	0.63	1	1.28	1.69
	South windows	1	0.88	0.60	1	1.47	2.00
	West windows	1	0.99	0.63	1	1.33	1.69
	Roof windows	1	1.24	0.82	-	-	-

Table 27 Overview of the shading system correction factors related to the adopted protocols for energy gap indicator.

PROTOCOLS (PROCEDURES AND VERIFICATION PROCESSES)	**ENERGY PERFORMANCE GAP**			
	CasaClima, Passive House certification, LEED, Blower Door Test		Maintenance program - Construction	
	Impact (No = 1) Yes	Prob. (No = 1) Yes	Impact	Prob. (No = 1) Yes
Shading system	0.2	0.8	-	0.9

Damage

In terms of damage, the economic deviation is the cost due to repairs, with three level of configurations impact related to: company call fee, workmanship hours and materials.

Correction factor

The cost of replacing a shading system usually is caused by poor maintenance. From interviews it was verified that the cost of the motor for the shading system ranges from 150 € to 250 €. The presence of at least one motor for every two windows in the building is also evaluated.

Table 28. Overview of the shading system correction factors related to the building features adopted for damage.

BUILDING FEATURE	**DAMAGE**			
	Close to the sea	Building exposure (wind)		Automatic control by weather station
	Probability (Yes = 1) No	High	Low	Probability (Yes = 1) No
Shading system	0.8	1	0.8	0.9

Table 29 Overview of the shading system correction factors related to the adopted protocols for damage indicator.

PROTOCOLS (PROCEDURES AND VERIFICATION PROCESSES)	**DAMAGE**			
	CasaClima, PHPP, LEED, Blower Door Test		Maintenance program - Construction	
	Impact	Probability (No = 1) Yes	Impact (No = 1) Yes	Probability (No = 1) Yes
Shading system	-	0.8	-	0.5

4.1.6 External door

Energy gap

Increased air infiltration from entrance doors caused an increase in the heating load of all the window models under the baseline operating conditions (Hyung Jun An et al., 2018, p. 18).

Previous studies demonstrated that the air infiltration from the entrance door can be reduced greatly by installing revolving doors, vestibules, and air curtains. (Hyung Jun An et al., 2018, p. 18). In EEnvest project, a testing process according to (Hyung Jun An et al., 2018, p. 18) was followed by simulating the air infiltration losses of different types of doors in the office building models (Annex 1) and calculated the heat load losses for both heating and cooling.

Furthermore, to evaluate the behaviour of different types of entrances in an office building, three different office user behaviours were reproduced. The first is based on an office building in Sweden (Nordic climate) where the entrance and exit time range was from 8:00 to 17:00. Included in the calculation is an hour of flexibility for arriving and leaving work and a lunch break at around 12:00. The calculation model considers an influx of 450 people in three different impact levels: "high" 450 people, "medium" with a reduction in influx of 33% and "low" with a reduction in influx of 66%. The same test was repeated to the other location, Paris (Continental climate) and Roma (Mediterranean climate)

Correction factors

Table 30 Overview of the external doors correction factors related to the building features adopted for energy gap indicator.

BUILDING FEATURE	ENERGY PERFORMANCE GAP		
	AIR INFILTRATION		
	Building exposure (wind)		Vestibule (door)
	High	Low	Yes
External doors	1	0.9	0.75

Table 31 Overview of the external doors correction factors related to the adopted protocols for energy gap indicator.

PROTOCOLS (PROCEDURES AND VERIFICATION PROCESSES)	ENERGY PERFORMANCE GAP							
	Air infiltration				Thermal bridge			
	CasaClima, Passive House certification, LEED, Blower Door Test		Maintenance program - Construction		CasaClima, Passive House certification, LEED, Blower Door Test		Maintenance program - Construction	
	Impact (No = 1) Yes	Probability (No = 1) Yes	Impact	Probability (No = 1) Yes	I Impact (No = 1) Yes	Probability (No = 1) Yes	Impact	Probability (No = 1) Yes
External doors	0.2	0.8	-	0.5	0.2	0.8	-	0.9

Damage

The common damages found for doors are caused by air or water infiltration and air condensation. These negative occurrences have also different level of impact.

Furthermore, other technical problems are linked to the automatic control system when it is present.

Correction factors

Table 32 Overview of the external doors correction factors related to the building features adopted for the damage indicator.

BUILDING FEATURE	DAMAGE			
	Service life (static issues and water infiltration)	Condensation	Glass breakages	Automatic control system
	Close to the sea	Close to the sea	Close to the sea	Close to the sea
	Probability (Yes = 1) No	Probability (Yes = 1) No	Probability (Yes = 1) No	Probability (Yes = 1) No
External doors	0.8	-	-	-

Table 33 Overview of the external doors correction factors related to the adopted protocols for damage indicator.

PROTOCOLS (PROCEDURES AND VERIFICATION PROCESSES)	**DAMAGE**			
	CasaClima, PHPP, LEED Blower Door Test,		Maintenance program - Construction	
	Impact	Probability (No = 1) Yes	Impact (No = 1) Yes	Probability (No = 1) Yes
External doors	-	0.8	-	0.5

4.2 BUILDING SERVICES AND RES SYSTEMS

One of the most important correction factors identified for the technical system is the maintenance program.

Adopt a maintenance program means to reduce the technical risk in terms of (i) energy performance gap of building services, as consumption deviations, and (ii) technical damages, as failures in the operation of technical system, breakages, and service life of the building elements.

4.2.1 Heat Pumps

Energy gap

For heat pumps (HP), the energy gap was identified with the system performance degradation. This degradation can be visualized as a lower heat pump capacity in terms of kW and a lower coefficient of performance (COP). Reliable data about performance degradation could not be provided by the interviewed heat pump manufactures, due to the complex measurements required to identify this kind of data. Nevertheless, data from scientific literature was found. A study investigated the performance of a R410A split residential heat pump with an 8.8 kW nominal heating capacity, by imposing 5 faults: compressor valve leakage, outdoor improper air flow, indoor improper air flow, liquid line restriction, refrigerant undercharge, and refrigerant overcharge (Yoon, Payne, and Domanski 2011). These imposed faults led to a performance (capacity and COP) degradation ranging between -5% and -15%, which in turn led to a final energy consumption for heating ranging between 1% and 3% respectively. This reduced final energy consumption was calculated by simulating a reference office building equipped with a HP in the PHPP tool and lowering the HP capacity and COP according to the data provided by the literature source.

Damage

Problems associated to damages caused by malfunctions and failures were identified combining interviews and literature data. Two studies (Madani and Roccatello 2014), (Madani 2014) analysed 37,000 heat pumps faults to manufacture in original equipment manufacturer reported during the warranty period from the beginning of 2010 to the end of 2012 and 8,659 reported to an insurance company. Systems involved in the investigation are air/air, air/water, brine/water (geothermal HP) and exhaust air HP. For the technical risk analysis, faults reported during the warranty period have been omitted as these do not cause an economic damage, focusing only on those occurred after the warranty was expired (Madani and Roccatello 2014).

Most common and costliest faults among the 4 categories of HPs are associated with the following components:

- Compressor
- Fan
- Control and electronics
- Shuttle valve (geothermal HP only)

CORRECTION FACTORS

Interviewed HP manufacturers stated that nowadays HPs are characterized by high system reliability, some key factors that led to this are the following good practices:

- awareness of the importance of a yearly maintenance plan;
- strongly improved durability (especially for some experienced manufactures);
- HP installer is required a specific training course.

Interviews highlighted that HP customers are in general more aware of the maintenance relevance as a mitigation measure, even though this is not mandatory as in the case of gas boilers.

For these reasons, the presence of a detailed maintenance program was considered as a mitigation measure against the abovementioned problems. The correction factor associated with this measure was estimated around 0.5, which means that the probability of negative occurrences is reduced by 50%.

Table 34. Correction factors for technical risk evaluation of heat pumps.

CORRECTION FACTOR	PROCESS	
	MAINTENANCE PROGRAM	
	Yes	No
ENERGY PERFORMANCE GAP		
Compressor/reversing valve leakage	0.5	1
Condenser air flow	0.5	1
Evaporator air flow	0.5	1
Refrigerant liquid line restriction	0.5	1
Refrigerant overcharge	0.5	1
DAMAGE		
Fan	0.5	1
Control and electronics	0.5	1
Compressor	0.5	1
Shuttle valve	0.5	1

4.2.2 District heating

District heating systems were already discussed in deliverable 2.1 chapter 4.1 as the first explanatory measure for the technical risk assessment methodology developed in EEnvest project.

The correction factors connected to this system are:

Table 35. Correction factors for technical risk evaluation of district heating substations.

CORRECTION FACTOR	PROTOCOLS		
	Automatic meter reading system	Certification (PED, F101/F103-3)	Fouling detection
ENERGY PERFORMANCE GAP			
Unsuitable heat load pattern	0.2	-	-
Low average annual temperature difference	0.2	-	-
Poor substation control	0.2	-	-
DAMAGE			
Water leakage	-	0.5	-
Heat exchanger	-	0.5	0.0
Control Valve	-	0.5	-
Actuators	-	0.5	-
Control system and controller	-	0.5	-
Inferior gaskets	-	0.5	-
Circulation pumps	-	0.5	-

4.2.3 Gas and LPG boilers

Energy gap

A detailed faults breakdown, which causes an energy performance gap in gas condensing boilers in commercial buildings, could not be determined from literature. However, several studies assess the efficiency and analyses its degradation. Therefore, an average efficiency degradation ranging from 2% up to 10%, over the heating season was adopted and applied to the heating energy consumption to calculate the performance gap.

For the DHW consumption, a different approach was followed. In fact, DHW consumption is not among the required platform input (generally not accessible at an early project stage), therefore this data was estimated starting from the number of occupants. For office buildings a value around 10l/per person/per day was adopted (Fuentes, Arce, and Salom 2018). Having determined the energy consumption associated to hot water production, the energy gap due to boiler efficiency degradation was calculated using the above-mentioned percentages (2-10%).

Damage

More information on common commercial gas boiler faults could be found. The most common problems which a condensing boiler faces during its operation are:

- Lime scale water pipes/heat exchanger
- Thermostat issues
- Pressure loss
- Frozen condensate pipe
- Leaks

For each of them a cost for fixing the damage and an associated probability were estimated.

CORRECTION FACTORS

The presence of a maintenance program was added as a correction factor for the damages. The probability of one of these occurrences is reduced by 50% in presence of a maintenance program. Furthermore, for the damage associated to a frozen condensate pipe another correction factor was inserted, which considers if the pipe is installed in a protected space. In this case the probability of a frozen condensate pipe is strongly reduced.

Table 36. Correction factors for technical risk evaluation of gas and LPG liquid propane gas boilers.

CORRECTION FACTOR	PROCESS		BUILDING FEATURE	
	MAINTENANCE PROGRAM		LOCATION	
	Yes	No	Indoor	Outdoor
DAMAGE				
Lime scale water pipes/heat exchanger	0.5	1	-	-
Thermostat issues	0.5	1	-	-
Pressure loss	0.5	1	-	-
Frozen condensate pipe	-	-	0.05	1
Leaks	0.5	1	-	-

4.2.4 Biomass boilers

Energy gap

An energy performance gap in biomass boilers is caused by factors, such as inappropriate combustion, poor cleaning, control not properly set, etc. These faults result in a degraded seasonal efficiency, quantified in the interview process in a range between 5% and 10%. A lower efficiency is responsible for a corresponding increase of the final energy consumption of the biomass boiler.

Damage

Biomass boilers have a life expectancy of around 20 years, which is higher than the average gas boilers, around 10-15 years. Most relevant faults, which may occur during the service life and entail a damage for the system are the following:

- Ignition failure (due to fuel, air supply)
- Control system
- System fuel/feed auger not functioning
- Vacuum System timed out (no fuel at boiler)
- Damage of the hopper due to high thermal load

According to the interviews, one of the main causes responsible for some of the above-mentioned faults (inappropriate combustion, ignition failure, auger not functioning) is fuel not in compliance with the norm ISO 17225:2014 (ISO 17225-1 2014).

Pellet quality, if not in compliance with the norm, strongly depends on the region where is produced or bought.

CORRECTION FACTORS

Based on the technical risks, the identified correction factors for biomass boilers are:

- Fuel in compliance with the norm ISO 17225:2014. As specified above, a high-quality fuel can mitigate ignition failures, incorrect combustion and problems to the fuel auger. 0.2 is the corresponding correction factor, which reduces the probability of those damages and 0.5 for the performance gap.
- Yearly maintenance program: normally maintenance is foreseen every 2 years. However, a yearly check can ensure the best system functioning. In this case as well, a correction factor of 0.5 is adopted for the efficiency degradation, damages to the control, vacuum and hopper systems, if a detailed maintenance program is foreseen.
- Remote monitoring system: many companies providing biomass boilers systems offer a remote monitoring system, especially for commercial applications, which permits to anticipate and solve possible faults and failures. The correction factor associated with the implementation of remote monitoring system was estimated as 0.5 for every fault reported, as this mitigation measure acts on all of them.
- The installation of a wood boiler instead of the more common pellet one, has been taken into consideration by adding a correction factor which, in this case, increases the probability of fault. These systems are typically more prone to malfunctions, as the fuel management is more delicate, thus have higher maintenance requirements.

Table 37. Correction factors for technical risk evaluation of biomass boilers.

CORRECTION FACTORS	PROTOCOLS							
	Maintenance program		Pellet quality ISO 17225:2014		Remote monitoring system		Wood boiler	
	Yes	No	Yes	No	Yes	No	Yes	No
ENERGY PERFORMANCE GAP								
Degradation efficiency curve	0.5	1	0.5	1	0.5	1	-	-
DAMAGE								
Ignition failure (due to fuel, air supply)	-	-	0.2	1	0.5	1	1.5	1
Control system	0.5	1	-	-	0.5	1	1.5	1
System fuel/feed Auger not functioning	-	-	0.2	1	0.5	1	1.5	1
Vacuum System timed out (no fuel at boiler)	0.5	1	-	-	0.5	1	1.5	1
Damage of the hopper due to high thermal load	0.5	1	-	-	0.5	1	1.5	1

4.2.5 Combined Heat and Power (CHP)

A combined heat and power unit (CHP) produces electricity with a generator and uses the waste heat from exhaust gases to provide hot water, thanks to a heat recovery system. In this case the heat recovery part is assessed, as heating/DHW generation system for commercial buildings.

Combined heat and power systems (CHP) are not common as other generation systems, nevertheless they have been included in this risk assessment. Since it was not possible to find interviewees on this topic and literature on risk assessment for CHP is scarce, further in-depth analysis is required.

Energy gap

A study (Thomson et al. 2000) analysed the fouling impact on the heat recovery of CHP systems. One of the conclusions is that fouling on the exchanger can lead to an overall efficiency reduction of 25%.

Damage

As done for other components, fouling was included among damages as well, since an intervention is required to clean the heat exchanger's surfaces, causing an economic impact.

CORRECTION FACTORS

The above-mentioned study proposes a fault diagnosis method for early detection of fouling of the heat recovery system applying a statistical process control. Regardless the specific measure, a dedicated fouling detection is suggested as mitigation measure and inserted in the correction factors, along with a good maintenance program. Both correction factors have a value of 0.5 acting on the probability the associated problem occurred.

Table 38. Correction factors for technical risk evaluation of combined heat and power systems.

CORRECTION FACTOR	PROCESS			
	Maintenance program		Fouling detection	
	Yes	No	Yes	No
ENERGY PERFORMANCE GAP				
Degradation efficiency curve	0.5	1	0.5	1
DAMAGE				
Heat exchanger fouling	0.5	1	0.5	1

4.2.6 Emission system

In the category "emission systems", radiant floor, radiant ceiling, and fan coils were considered for the implementation of renovation measures of commercial buildings.

Energy gap

The main problem associated with a performance degradation of a radiant system is the wrong insulation installation. For example, a radiant floor correctly designed and installed delivers 90% of its heating power to the indoor space. Only 10% goes in the wrong direction. In systems where the insulation has the wrong thickness or the U-value is too high (limit is 0.75 m2K/W), the useful heating power transferred to the indoor space can sink up to 70%.

Another source of performance degradation is the control system and the circulation pump efficiency. The global Radiant System Energy Efficiency (RSEE) is composed by these two elements. Efficiency of control system ranges between 91% and 97% and the efficiency of a circulation pump between 98% and 100%.

Concerning fan coils a performance degradation associated to filter's fouling has been considered.

Damage

The most relevant problems which cause a damage in emission systems are:

- Radiant floor
    - Manifold wrong connections
    - Leaks: rare problem. Mainly due to holes in the floor for furniture fixing.
    - Screed not made correctly (expansion joints):
    - Insulation damaged rare problem as well. Difficult correction (skirting repositioning)
    - Air in the system: frequent problem, easy intervention (vent valve).
- Radiant ceiling
    - (same as above)
    - Condensation problem on the plasterboard panel
    - Damage due to wrong installation of lighting system
- Fan coil
    - Pipes
    - Fan/Blower motor failure
    - Dirty filters
    - Control system failure

CORRECTION FACTORS

Identified technical risk correction factors for radiant systems are:

- Maintenance program: as done in the previous building system elements the application of a detailed maintenance program reduces by 50% the probability of faults in control systems and filters for fan coils (energy performance gap) and air in the system fault (damage).
- Pressure test based on UNI EN 1264-4/ISO[11] and EN UNI 11855-5[12]: before the screed execution, the pipes are tested with 6bar pressure (operating pressure 2.5-3bar). This test excludes manifold wrong connections and leaks at installation time.
- Screed stress test based on EN 1264. The preheating cycle of a floor heating system (also called Thermal Shock) is a process of checking the final quality of the installation (system + screed). This test excludes the above-mentioned problem "screed not made correctly". If a crack appears during the stress test, this can be repaired with resin.
- Insulation material labelled CE, DOP (Declaration of Performance)[13]: If the insulation material has a bad quality can be compressed and reduce its insulating properties.
- Humidity control (radiant ceiling): humidity control in the false ceiling to prevent condensation.

For fan coils a regular maintenance program was added as correction factor.

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[11] https://standards.iteh.ai/catalog/standards/cen/4823be82-4955-4c68-bd24-89defc682a6a/en-1264-4-2009

[12] http://store.uni.com/catalogo/uni-en-iso-11855-5-2015?josso_back_to=http://store.uni.com/josso-security-check.php&josso_cmd=login_optional&josso_partnerapp_host=store.uni.com

[13] https://ec.europa.eu/growth/sectors/construction/product-regulation/performance-declaration_en

Table 39. Correction factors for technical risk evaluation of emission systems.

CORRECTION FACTORS		PROCESS									
		Maintenance program		Pressure test (UNI EN 1264-4/ISO EN UNI 11855-6)		Screed stress test (EN-1264)		Material labelled CE, DOP		Humidity control installed	
		Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
		ENERGY PERFORMANCE GAP									
Radiant floor/ceiling/wall	Control system	0.5	1	-	-	-	-	-	-	-	-
	Wrong insulation thickness	-	-	-	-	-	-	-	-	-	-
Fan coil	Dirty filters	0.5	1	-	-	-	-	-	-	-	-
		DAMAGE									
Radiant floor/ceiling	Manifold wrong connections	-	-	0	1	-	-	-	-	-	-
	Leaks	-	-	0	1	-	-	-	-	-	-
	Screed not made correctly (expansion joints)	-	-	-	-	0	1	-	-	-	-
	Insulation damaged	-	-	-	-	-	-	0	1	-	-
	Air in the system	0	1								
Radiant ceiling/wall	Condensation on the plasterboard panel	-	-	-	-	-	-	-	-	0	1
	Damage due to wrong installation of lighting system	-	-	-	-	-	-	-	-	-	-
Fan coil	Pipes	0	1	-	-	-	-	-	-	-	-
	Fan/Blower motor failure	0	1	-	-	-	-	-	-	-	-
	Dirty filters	0	1	-	-	-	-	-	-	-	-
	Control system failure	0	1	-	-	-	-	-	-	-	-

4.2.7 Distribution system

Energy gap

Energy performance gap for distribution networks was determined calculating the effects of a lower distribution efficiency on the final thermal energy consumption. The distribution system efficiency depends on the year of construction and the configuration and it can range between 0.92 and 0.98, which, in turn, means a performance loss between 8% and 2%. These values were adopted to define the energy gap associated with a distribution system.

Damage:

To identify damages in distribution networks, main components were listed. Faults, which affect these components, require an intervention to fix the faulty component or to replace it (according to the damage level).

- Manifold
- High efficiency circulation pumps
- Valves
- Strainer
- Diaphragm expansion vessel
- Pipes

CORRECTION FACTORS

As fault mitigation, measure the presence of a general maintenance program for the whole distribution system was considered.

Table 40. Correction factors for technical risk evaluation of heat pumps distribution systems.

CORRECTION FACTORS	PROCESS	
	Maintenance program	
	Yes	No
ENERGY PERFORMANCE GAP		
Lower distribution efficiency	0.5	1
DAMAGE		
Manifold	0.5	1
High efficiency circulation pumps	0.5	1
Valves	0.5	1
Strainer	0.5	1
Diaphragm expansion vessel	0.5	1
Pipes	0.5	1

4.2.8 Electric boilers

Energy gap

Electric boilers in commercial building are usually installed for DHW production. The same approach illustrated for gas boilers for calculating the energy performance gap in case of DHW production was adopted. In this case, as the system has less critical components, the degradation of the efficiency curve is lower than in the case of a gas boiler.

Damage

Common commercial electric boiler faults are:

- Lime scale water pipes/heat exchanger
- Thermostat issues
- Pressure loss
- Leaks

CORRECTION FACTORS

The presence of a maintenance program was added as a correction factor for the energy performance gap and damages.

Table 41. Correction factors for technical risk evaluation of electric boilers.

CORRECTION FACTORS	PROCESS	
	Maintenance program	
	Yes	No
ENERGY PERFORMANCE GAP		
Degradation efficiency curve	0.5	1
DAMAGE		
Lime scale water pipes/heat exchanger	0.5	1
Thermostat issues	0.5	1
Pressure loss	0.5	1
Leaks	0.5	1

4.2.9 Cooling system – Chiller

Energy gap

In a commercial building energy consumed by chillers producing chilled water for air-conditioning is a relevant share of the building energy consumption, therefore an efficiency degradation due to faulty systems can have a strong impact on the energy bill. Something that needs to be considered is that chiller efficiency has been growing in the last decades steadily (Department of Climate Change and Energy Efficiency n.d.) improving its reliability in terms of risk assessment.

In this case too, the energy performance gap of cooling systems was assessed as a generic efficiency degradation, which is caused by several factors such as biased sensors, fouling, faulty circulation pump, refrigerant leaks, etc. Good maintenance is essential to prevent chillers' efficiency from decreasing. For instance, (Department of Climate Change and Energy Efficiency n.d.) reports that "when open circuit cooling towers are used, chiller condensers must be monitored for fouling. A 0.6mm layer of fouling (including dust, dirt, pollen, moisture, etc.) on the finned coils (responsible for heat exchange) is estimated to increase chiller power consumption by 20%". This percentage can be assumed also for generic poor maintained chillers (Inc. s.d.).

Furthermore, a non-optimal user behaviour was also included in the assessment to determine the energy performance gap of a cooling system, in particular the users manually change the cooling set-point (Gaetani 2018) to increase the indoor thermal comfort. The energy gap associated with these kinds of variation at manual set-point (done by the users), it was estimated by energy simulation, changing the set-point of one and two degrees, from standard (regulation) level of 26°C to 25°C and 24°C. In this way a range of impact of the user behaviour has been determined.

Damage

Main faults and failures, which require an intervention to fix them, are listed below:

- Faulty expansion device
- Refrigerant leaks: a chiller loses refrigerant during its operational life. This leak is strongly dependant from year of construction, as recent systems improvements strongly limited it. Refrigerant must be refilled when too low.
- Control failure
- Condenser fouling: as mentioned for the energy gap, surfaces of heat exchangers must stay as clean as possible to guarantee optimal heat transfer efficiency. If bad maintenance takes place a special intervention will be required to clean the condenser surfaces.

CORRECTION FACTORS

As mentioned above, a well-defined and regular maintenance program is essential for the good functioning of a cooling system. Therefore, this was added as a correction factor (0.5) in the risk calculation.

The performance degradation due to non-optimal user behaviour was simulated on a reference office building with a window-to-wall ratio (WWR) of 0.41. To extend the reliability of this energy performance gap, another correction factor was added to consider the influence of the window-wall ratio (WWR) of the building. Simulations performed on office buildings showed that for an increasing WWR, the impact of the user behaviour decreases. A formula, which considers the energy gap variation according to WWR was implemented in the calculation. A couple of values are reported in Table 42.

Table 42. Correction factors for technical risk evaluation of cooling systems.

CORRECTION FACTORS	PROCESS		BUILDING FEATURES
	Maintenance program		WWR
	Yes	No	
ENERGY PERFORMANCE GAP			
User behaviour	-	-	WWR=0.65 – C.F.=0.7 WWR=0.41 – C.F.=1
Efficiency degradation	0.5	1	-
DAMAGE			
Expansion device	0.5	1	-
Refrigerant leaks	0.5	1	-
Control failure	0.5	1	-
Condenser fouling	0.5	1	-

4.2.10 Mechanical ventilation system

Energy gap

In the case of mechanical ventilation systems, to calculate the energy performance gap caused by faults and malfunctions a standard value was adopted: an average electricity consumption of the ventilation system equal to 3kWh/m^2year. This value is an approximation coming from the analysis of several case studies.

- *Actual heat recovery efficiency*: manufacturers indicate nominal heat recovery efficiency for specific temperature conditions. These conditions are not always verified during the system operation. A declared efficiency of 80%, drops up to 60% over the whole winter season, and up to 50% or even less during the summer season. This lower heat recovery performance has a strong impact on the building heating demand.
- *Frost protection*: to protect the heat recovery system from low temperature and electric resistance is often installed. This resistance causes an extra energy consumption, which can be estimated around 0.4W/m^3h, as operating when outside temperature is particularly low.
- *Dirty filters*: air handling unit filters collect dust and dirty particles in the air, these create extra pressure drops. The motor absorbs more power to guarantee the required air flow rate. Filter fouling causes an increased fan energy consumption ranging between 5% (for 10% of fan pressure increase) and 9% (for a 20% of fan pressure increase) (Zhang and Hong 2017). This value was used as input for a simulation performed on six buildings in PHPP. The resulting increased auxiliary electricity consumption for wintertime and summertime ventilation ranges between 4% and 7.5%. Outdoor air intake damper fouling: the same approach of the previous point was followed here since the effects on the fan energy consumption are the same.
- Leakages: bent / not sealed ducts determine an increased pressure drop. Also, here the same approach followed for dirty filters was applied, although in this case a lower pressure drop was considered. This causes increased auxiliary electricity consumption for wintertime and summertime ventilation ranges between 1% and 3%.

Damage

Two interviews agreed on the most relevant faults affecting air-handling units, however a discrepancy on the probability associated emerged. For this reason, an average value between the two interviewees was selected. Air handling unit faults are:

- Fan/Blower motor failure: failures, which require an intervention to fix it or a replacement (i.e., motor belt malfunction or breakage).
- Bearings damage
- Dirty filters: filters should be cleaned twice a year to prevent fouling.
- Control system failure
- Condensate drains malfunction: replacement, cleaning or repositioning of condensate pipes which do not evacuate water properly.

CORRECTION FACTORS

The most relevant mitigation measure is by far a yearly maintenance program, which can deal with all the above-mentioned faults. Therefore, if a maintenance program is present, a correction factor reduces the probability of having one of these faults by 50%, as done in the previous cases. Furthermore, a fouling detection system was considered as mitigation measure to prevent the associated energy performance gap, in this case the correction factor was set to 0.1.

Table 43. Correction factors for technical risk evaluation of mechanical ventilation systems.

CORRECTION FACTORS	PROCESS			
	Maintenance program		Fouling detection	
	Yes	No	Yes	No
ENERGY PERFORMANCE GAP				
Actual heat recovery efficiency*	-	-	-	-
Frost protection: El. energy consumption*	-	-	-	-
Dirty filters	0.5	1	0.1	1
Outdoor air intake damper fouling	0.5	1	0.1	1
Leakages: Bent / not sealed ducts	0.5	1	-	-
DAMAGE				
Fan/Blower motor failure	0.5	1	-	-
Dirty filters	0.5	1	-	-
Bearings damage	0.5	1	-	-
Control system failure	0.5	1	-	-
Condensate drains malfunction	0.5	1	-	-
**Numeric value of this correction factor is currently missing.*				

4.2.11 Lighting system

Damage

LED lamps are extremely resilient and long-lasting, but there can be failures connected to manufacturing process or due other factors that can lead to LED lighting failing, as:

- temperature fluctuations, due to a too much higher/low temperature of the environment where the LED is located (lamp), LED lamp might expire before it is normal lifespan[14].
- efficiency droop, it can happen every time the LED lamp is fired up and the electrical current that runs through the LEDs increases, the luminous efficacy of the LEDs drops up to 20%. This event is frequent in industrial sector.
- structural issues due to the structure of the LED lamp, LEDs themselves, or how they are connected, or the lamp. *It is just not very frequent.*
- use low quality materials parts of LED by the manufacturer[15,16]

To avoid negative issues in the lighting system functionality is necessary to have a maintenance programme, or an active monitoring whereby managing faults can be detected and repaired for minimal impact on functionality and downtime. Used for fault sensing, the LED voltage measure is the most easily measured parameter for detecting an individual LED's

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[14] https://www.shineretrofits.com/knowledge-base/lighting-learning-center/why-do-led-s-fail.html

[15] https://www.shineretrofits.com/knowledge-base/lighting-learning-center/why-do-led-s-fail.html

[16] https://www.reminetwork.com/articles/led-lamps/

status. Since LEDs are normally used in strings of multiple LEDs, an open-circuit LED causes the entire string to go dark. The most straightforward approach is to use locally powered circuits for detection, which in turn use a cascaded current signal as a fault indicator.

Failure rate of 10% when the maintenance will occur once during lifetime of fixture[17]

Table 44. Correction factors for technical risk evaluation of lighting systems

CORRECTION FACTORS	PROCESS	
	DAMAGE	
	Maintenance program	
	Yes	No
Failure detection - malfunction	0.5	1

4.3 RENEWABLE ENERGY SOURCE (RES)

4.3.1 Photovoltaic system

Data for this building service category comes from the EU H2020 SolarBankability project[18], which aimed to contribute to establish a common practice for professional risk assessment based on technical and commercial due diligence. Focus on photovoltaic (PV) installations.

In this case, energy performance gap and damage are not considered separately, but are two sides of the same coin. In fact, the scenario in which efficiency losses are considered is a scenario where an intervention to fix those faults was foreseen, otherwise a further efficiency degradation (higher energy gap) should be considered.

PV faults were considered all together without dividing them in subcategories such as modules, inverters, etc.

Energy gap

The energy performance gap was assessed as % representing the lost energy production due to faults and failures. Three levels were identified: low, medium, and high. Each level has a different impact on the energy production, ranging from 11% to 22%. The probability of a faulty operation comes from the number of affected PV plants. Since no further data about probability distribution among impact levels was available, this one was equally divided (33.3%) (Moser et al. n.d.), (Jahn et al. 2018).

Damage

As mentioned above damages were defined as the cost for fixing failures, which cause the energy performance gap. The damage severity is strongly dependent from the mitigation measures that are introduced in the following section. As starting point a cost for fixing failures of 95.7 €/kWh/year was determined by Solar Bankability project in the case of no mitigation measures applied.

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[17] https://www1.eere.energy.gov/buildings/publications/pdfs/ssl/beckwith_depreciation_seattlemsslc2011.pdf

[18] H2020 Solar Bankability project - Improving the Financeability and Attractiveness of Sustainable Energy Investments in Photovoltaics: Quantifying and Managing the Technical Risk for Current and New Business Models. Grant agreement ID: 649997 https://cordis.europa.eu/project/id/649997

CORRECTION FACTORS

Mitigation measures were analysed and their impact on the energy performance gap was determined, together with their cost expressed as €/kWp/year.

- Preventive measures
  - Component testing
  - Design review + construction monitoring
  - Qualification of Engineering, Procurement and Construction (EPC)
  - Basic Monitoring system
- Corrective measures
  - Advanced Inspection
  - Visual Inspection
  - Spare part management

Simulations carried out in (Moser et al. n.d.), (Jahn et al. 2018) determined that the best combination of the above-mentioned mitigation measures in terms of performance loss reduction is the qualification of EPC with an advanced monitoring system. The estimated performance loss in case of adoption of both measures is 0.7%. The implementation has an estimated cost of 2.15 €/kWp/year.

Furthermore, the project analysed the cost for fixing failures for all the different combination of the mitigation measures. The best combination is:

- Component testing
- Design review + construction monitoring
- Qualification of EPC
- Basic Monitoring system

The combination of these 4 elements reduces the cost for fixing failures at 13.1 €/kWp/year, which is in line with average maintenance contracts.

Table 45. Correction factors for technical risk evaluation of photovoltaic systems.

CORRECTION FACTORS PROCESS	PROCESS					
	MODULES, INVERTERS AND OTHERS					
	ENERGY PERFORMANCE GAP				DAMAGE	
	mid, high		low		low, mid, high	
	Yes	No	Yes	No	Yes	No
Component testing	0.967	1	0.967	1	0.753	1
Design review + construction monitoring	0.45	1	0.303	1	0.367	1
Qualification of EPC	0.728	1	0.491	1	0.687	1
Advanced monitoring system	0.163	1	0.11	1	0.953	1
Basic Monitoring system	0.6	1	0.405	1	0.978	1
Advanced Inspection	0.5	1	0.337	1	0.972	1

Visual Inspection	0.507	1	0.342	1	0.972	1
Spare part management	1	1	0.674	1	0.996	1

5. DATA MANAGEMENT IN WP2

H2020 projects require consortiums to describe the plan for management of data retrieved, used and analysed during the project. The full description of the data management is part of WP1 – Project Management, deliverable D1.3 - Data Management Plan.

To make it easier for the reader to consolidate the information about data management in the different WPs, this paragraph is meant to list and describe the data and information that were used for the development of Work package 2, this deliverable and EEnvest technical risk database.

The technical risk data collected in the WP2 comes from (i) literature, on several articles on different topics, in part reported in the Bibliography, (ii) interviews to building experts, building manager, Building and facility managers, Constructors, ESCO (iii) energy performance simulation.

Management of data – Technical Risk Database			
Source of data	Literature	Interviews Single and private interviews	Energy performance simulation
Use of data	Technical risk data will be collected to create the database: identification of the occurrences, cause-effects process, and impact-probability.	Interview's focus changes in relation to the stakeholders involved: • ESCO: building envelope elements and technical systems • Building and facility managers: building envelope elements and technical systems (maintenance issues) • Constructors: building envelope elements and technical systems • Building experts: as architects for building envelope elements, or mechanic engineers for technical systems Data and information collected are and will be used mainly to define the technical risks occurrences, impact and probability, and in the energy simulation. These data are no public. The data, one time analysed and homogenized using a same unit of measurement, will be integrated in the EEnvest technical risk database, in the platform.	The results obtained from the energy simulation process will be collected in the EEnvest technical risk database, in the platform.
Storage Location	MS SharePoint folder, shared with the EEnvest Consortium project partners and EURAC server	EURAC server – private data	MS SharePoint folder, shared with the EEnvest Consortium project partners and EURAC server
Expected results	EEnvest technical risk database, in the platform.		
Relation with other WPs	EEnvest database and technical risk calculation process will be uploaded in the EEnvest web platform, WP5. The probabilistic trend of each occurrences (impact-probability) will be used in WP3.		

The most important information obtained from the interviews done is about a company that deals with consulting and intervention in damage caused by installation or design defects in building restoration. The experience of this type of companies that work continuously in the field is essential both for the knowledge of the damage and the gaps that are created in this type of intervention, both in the recurrence of these damages. It is understood that some of the damages identified in the literature have almost no weight compared to others found at the construction site.

5.1 INTERVIEWS

The literature review could not provide all the data required to define and estimate probability and impact of technical risks, therefore interviews to companies and experts have been performed. For the building services the interview structure was divided in three parts:

1. Identification of the main system faults and failures, which cause an energy performance gap or a damage.
2. Estimate of the probability associated with the negative occurrence during its service life.
3. Quantification of the impact in terms of energy consumption and investment cost for the energy performance gap and the damage, respectively.

Table 46. Building systems – List of interviewed actors.

Building system	Company
Building envelope	Two building professionals
	Two facility managers of public buildings
	One insulation company
Heat pumps	One manufacturer
Gas boilers	One manufacturer
Biomass boilers	One manufacturer and distributor
Emission systems	Two design and installation company
Distribution system	Three design and installation company
Cooling system	One design and installation company
Mechanical ventilation	Two design and installation company
Electric system	One design and installation company

6. CONCLUSION

Technical risk analysis in building sector is a complex and multi-faceted theme that depends on several cause-effect choices taken from different actors (design teams, constructors, investors, users…) at different stages of the building project (design, construction, or operation).

This report follows D2.1, which presented the work done in WP2 on technical risks associated with energy renovation of commercial building, from its definition to the assessment. Two are indicators used to describe the technical risk: the *energy performance gap* and the *damage.* The first one assesses the deviation of the energy performances of the building compared to the performances defined during the design phase. The second one considers those negative occurrences (malfunctioning, errors, failure, or breakages of the installed components) which requires an economic investment to fix them. Both indicators (D51) will be used independently in the evaluation of the business plan in the EEnvest web-platform (WP5).

The mitigation measures, collected in this report and introduced in the EEnvest technical risk calculation assessment as correction factors, are important recommendations for EEnvest users. If adopted at the beginning of the project design can reduce the technical risks, limiting the negative effects (negative occurrences) of a specific cause.

The objective of this deliverable was to give indications to the stakeholders on how to reduce the risk associated with each renovation measure, in the form of design guidelines and calculation methodology. The calculation methodology builds upon results presented in D2.1 and is further developed in this report, including detailed appendixes.

The report provides to the designers insights through:

- an overview of general recommendation to adopt for de-risking the renovation process of commercial buildings;
- an overview on specific recommendation identified as mitigation measures, deriving from several sources, such as literature review, monitored buildings and interviews with the buildings professional. The mitigation measures presented are useful, reliable and can be implemented case by case;
- implementation examples of mitigation measures (called correction factors) in the EEnvest technical risk assessment for building energy renovation process of commercial buildings. Correction factors are determined depending on three groups of features: building features, renovation scenarios, procedures, and verification processes;
- correction factors database of the whole building: envelope and technical system, with numeric values, that modify the impact and the probability of negative occurrences, for both indicators, energy gap and damage.

The EEnvest technical risk assessment methodology, together with the identification of risk mitigation measures and quantification of their impact (both in energy and economic terms) is a pioneering research work in the field. In the months to come, the lead partner (EURAC) commits to enlarge the dataset through additional case studies, to provide more stability to the numerical model that will be the foundation of the EEnvest risk evaluation web-based platform, under development in WP6.

Annex 1 TECHNICAL RISK ENERGY PERFORMANCE SIMULATION METHODOLOGY

In this section it is described in detail how the energy performance simulations were structured to calculate the energy performance gap in terms of deviation of the heating demand (kWh/m^{2}year) from standard project conditions due to the negative occurrences associated with energy renovation measures. As mentioned above simulation activity was needed whenever energy performance gap data coming from literature or interviews could not directly relate to the building energy consumption. For example, a fault which causes a performance gap for the mechanical ventilation is the filters fouling. This fault is responsible for an increased electricity consumption, which in the end have an impact on the building energy consumption. A simulation performed on a reference office building allowed to determine the increase energy consumption associated with the filter fouling problem.

ENERGY PERFORMANCE SIMULATIONS METHODOLOGY: STANDARD CONDITION AND ANALYSED PARAMETERS

The simulations have been performed using reference building models obtained starting from real case studies of office buildings. The tool used to calculate the building energy performance is the PHPP[19], a static tool developed by the Passive House Institute (PHI)[20]. Input data of the PHPP tool were directly provided by the reference building design and construction team. The building models have been constructed using geometrical and structural data taken from the reference offices, however, to analyse the effects of building negative occurrences, parametric simulations have been launched varying PHPP input parameters and extracting the energy performance output of a wide number of conditions. To do that office building models were adapted to the minimum energy performance requirements for three different climate condition: Nordic, Continental and Mediterranean.

Building models

The buildings, which were adopted as reference for the simulations have the following characteristics:

Table 47. Reference building data for the simulations.

Reference building	Office 1	Office 2
Treated floor area	1,815 m^2	6,633 m^2
Exterior walls area	640 m^2	2,772m^2
Total envelope area	2,760 m^2	13,067 m^2
Windows area	299 m^2	2,446 m^2
Volume	5,632 m^3	39800 m^3
S/V ratio	0.32	0.16
W/W ratio	0.48	0.88

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[19] https://www.aecb.net/passive-house-planning-package-phpp-version-7-2012/

[20] https://passivehouse.com

Identification of the building features

At the beginning of the simulation process, to standardize the calculation of the impact of the many occurrences it has been identified and studied the dependence between the variables of building features (building dimension, shape, and other parameters characteristics of the structure and its elements) and the energy performance gap. For this purpose, a series of simulations has been performed to observe whether the entity of the energy gaps, which are caused by technical occurrences, is dependent on those variables.

Particularly, “Surface to Volume” (S/V) and “Glazing Ratio” (GR) have been considered. In the case of building envelope, analysing the impact of the thermal bridges and air infiltration caused by technical issues of the windows, the simulations showed how S/V and GR do not significantly affect the energy gaps caused by these occurrences. In fact, the approach is to quantify the energy gap in terms of specific affected area of the windows. Hence, the area of the case study is not relevant for the estimations.

Identification of the climate condition – three climates

As expected, a driving factor, which cannot be neglected, is the temperature gradient, directly related to the climatic conditions. To cover the entire range of European climates, from the colder to the warmer one, a set of three locations (European cities) have been selected to be the boundary conditions of the building performance simulations. These cities are Stockholm, representative for the Nordic climate, Paris, representative for the Continental climate, and Rome, representative for the Mediterranean climate. Each of these cities will be the reference for all the locations having heating degree days (HDD) included in a certain range. The ranges of HDDs calculated at 20°C are reported in Table 48.

Table 48. Climate standard – range in HDD to determinate the climate conditions.

Climate standard	Heating Degree Days	
Nordic climate	3,400	6,000
Continental	2,400	3,399
Mediterranean	0	2,399

To simplify the process in the EEnvest platform implementation, the energy performance gap values are related to the climate of Stockholm, taking it in consideration as standard conditions, while the results for the other two climates are calculated applying correction factors to the Stockholm results values.

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