D1.1

Digitalization Requirements and KPIs

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Project Acronym	SMARTeeSTORY
Project Title	Integrated, interoperable, smart and user-centred building automation and control system for better energy performance of non-residential historic buildings coupling physics & data-based approaches
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Deliverable Lead Partner	TECNALIA
Contributors	RINA-C, REA, AEA, TUD, SE, RTU, CUERVA, TERA
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Table of Contents

List of Tables

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List of Figures

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List of Abbreviations

Acronym	Description
CAPEX	CAPital EXpenditures
D	Deliverable
DHW	Domestic Hot Water
EC	European Commission
EU	European Union
FEC	Final Energy Consumption
FFC	Fossil Fuel Consumption
GHG	GreenHouse Gases
IEQ	Indoor Environmental Quality
IRR	Internal Rate of Return
IS	Impact Score
KPI	Key Performance Indicator
LCOE	Levelized Cost Of Energy
NZEB	Nearly Zero Energy Buildings
OPEX	OPerational EXpenditures
PBP	Pay Back Period
PEC	Primary Energy Consumption
RES	Renewable Energy Sources
RH	Relative Humidity
RMSE	Root Mean Square Error
SRI	Smartness Readiness Indicator
SRS	Smartness Readiness Service
ST	Sub Task
T	Task
WP	Work Package

Executive Summary

This document represents the deliverable D1.1 "Digitalization requirements and KPIs" for historic buildings and users of the European project "Integrated, interoperable, smart and user-centered building automation and control system for better energy performance of non-residential historic buildings coupling physics & data-based approaches" hereinafter also referred with its respective project acronym SMARTeeSTORY.

Deliverable D1.1 summarizes the work performed in T1.1, which includes ST 1.1.1, 1.1.2 and 1.1.3. The main objective of the overall task is to define the requirements for digitalization on historic buildings, taking special attention to the specific requirements and constraints of historic buildings. Users of this type of buildings and market needs are characterized via a participatory approach to engage this relevant stakeholder and better address the digitalization process. Likewise, specific KPIs are defined to measure the improvement that digitalization brings to historic buildings and their users.

Specifically, the STs performed the following activities and goals:

- ST 1.1.1, led by TECNALIA, researched the requirements for digitalization and adaptation of historic buildings to current energy efficient needs.
- ST 1.1.2, led by TUD, characterized the users' needs of historic buildings via a participatory approach. The objective of this task is to setup the co-innovation and participatory environment (workshops and interviews) for recruiting and engaging with the essential building user groups (end users, operators, energy manager, facility manager, owners) to capture their needs.
- ST 1.1.3, led by RINA-C, identified performance indicators to be used as evaluation framework during demonstration phase with a specific focus on SRI.

1 Introduction

Historic buildings are those buildings in which interventions may affect the Cultural Heritage to which they are related, taking special attention to the specific requirements and constrains. Due to their nature, historic buildings have severe limitations and constrains for energy efficient interventions. Digital technologies are crucial to decarbonize this sector, unleashing the full potential of flexible energy generation and consumption, enabling more use of renewable energy, supporting energy systems integration, improving user's comfort and ensuring interoperability of energy data, platforms and services while promoting the development of a competitive market for digital energy services and infrastructure that are cyber-secure, efficient, and sustainable.

In order to fully exploit this potential within the SMARTeeSTORY project, the objectives, requirements and means of verification must be defined on the first stages of the project, not only on those aspects related to energy efficiency, but also to users' wellbeing. The present deliverable D1.1 "Digitalization requirements and KPIs for historic buildings and users" summarizes the work performed on this regard under T1.1, with the overall aim to define the requirements for digitalization on all historic buildings. Users of this type of buildings and market needs are characterized via a participatory approach to engage this relevant stakeholder and better address the digitalization process. Likewise, specific Key Performance Indicators (KPIs) are defined to measure the improvement that digitalization brings to historic buildings and their users.

Specifically, the STs performed the following activities and goals:

- ST 1.1.1, led by TECNALIA, researched the requirements for digitalization and adaptation of historic buildings to current energy efficient needs, stating the aspects that matter most for achieving the objectives SMARTeeSTORY decided on.
- ST 1.1.2, led by TUD, characterized the users and market needs of historic buildings via a participatory approach. The objective of this task is to setup the co-innovation and participatory environment (workshops and interviews) for recruiting and engaging with the essential building user groups (end users, operators, energy manager, facility manager, owners) to capture their needs.
- ST 1.1.3, led by RINA-C, identified performance indicators that will be used as evaluation framework during demonstration phase with a specific focus on SRI.

TECNALIA is the lead beneficiary of this public report, and it was supported by the participant partners for the development of the deliverable, specially TUD (leader of ST1.1.2) and RINA-C (leader of ST1.1.3).

1.1 Purpose and scope of the document

One of the main scientific and technological objectives of the SMARTeeSTORY project consists of establishing a framework for historic buildings' digitalization, coupling preservation and adaptation to current necessities of energy efficiency. In this sense, mapping digitalization needs and KPIs for historic buildings, users and technical systems is one of the key aspects. Those needs must be converted into requirements for the identification of optimal digitalization kits and software architectures for energy management in historic buildings. As a result, the creation of a web application for assessing techno-economic feasibility of historic buildings digitalization based on Smart Readiness Indicator (SRI) assessment methodology will be achieved in T1.5 (D1.5).

This first report addresses the definition of set of requirements for digitalization approaches in historical buildings across EU, setting-up of the co-innovation environment to assess user comfort and satisfaction and definition of the list of KPIs to evaluate the performance of installed system.

1.2 Contributions of partners

Table 1 depicts the main contributions from project partners in the development of this deliverable.

Participant Short Name	Contributions
AEA	• Review of regulations and policies about constraints and protective measures adopted to preserve historic buildings Granada demo-site-specific KPIs
RINA-C	• SRI calculation based on method B • KPIs to evaluate the performance of the installed system Impacts of increasing the level of SRI on KPIs
RTU/REA	• Review of regulations and policies about constraints and protective measures adopted to preserve historic buildings Riga demo-site-specific KPIs
TECNALIA	Digitalization requirements for historic buildings across EU
TUD	• Review of regulations and policies about constraints and protective measures adopted to preserve historic buildings • User needs characterization via a participatory approach • User comfort KPIs Delft demo-site-specific KPIs

Table 1. Contributions of partners

1.3 Relation to other activities in the project

Table 2 shows the relation of T1.1 to other activities in the project.

Activity (Deliverable Number)	Description
T1.4	Starting from the outputs of T1.1, T1.2, T1.3 and T2.2, the objective of this task is to define the general architecture of the SMARTeeSTORY system and provide the technical specifications of the services that it will incorporate, setting up the general development framework for WP4.
T1.5	Design tool for historic buildings digitalization based on SRI methodology based on the experience gained in the framework of SMARTeeSTORY project about critical aspects, barriers and constraints related to listed buildings from one side also leveraging on opportunities and advantages that smart devices can bring where energy renovation is not an option.

Activity (Deliverable Number)	Description
T3.3	This task will define the control strategies and optimization criteria and Development of Controls based on the work performed in T1.1.
T5.3	This task will carry on the executive design of demonstrator's interventions based on the work performed in T1.1.

Table 2. Relation to other activities in the project

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2 Deviations

The initial delivery date of this deliverable D1.1 "Digitalization Requirements and KPIs" of 31st of October of 2023 has been revised and delayed to 4th of December of 2023.

Bureaucratic delays in securing the required authorization prevented the conduction of both the workshop and questionnaire for the Granada demo-site. Consequently, essential data pertaining to user needs and requirements, including Indoor Environmental Quality (IEQ), comfort, and well-being, for Granada demo-site are currently unavailable. The missing data will be promptly collected as soon as the once the authorization to conduct the workshop and questionnaire is granted. The collected data for the Granada demo-site will be included inside the documents of the reporting period (M18).

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3 Digitalization requirements for historical buildings across European Union

The term Historical Buildings refers to Cultural Heritage buildings, i.e., which are Heritage in their own right, or which are included in or form part of a wider Heritage Asset. In short, all those buildings in which energy or digital performance interventions may affect the Cultural Heritage to which they are related.

According to the UNESCO, Cultural Heritage includes artefacts, monuments, a group of buildings and sites, museums that have a diversity of values including symbolic, historic, artistic, aesthetic, ethnological or anthropological, scientific, and social significance. It includes tangible heritage (movable, immobile, and underwater), intangible cultural heritage embedded into cultural, and natural heritage artefacts, sites, or monuments[1]. For the present deliverable, the following classification of Historical Building may be considered:

- UNESCO World Heritage List's Historic Building;[2]
- Historical Building listed at national or regional or local level;
- Non-protected nor listed Historical Building.

In the specific case of Listed Historic Buildings, any intervention must comply with internationally recognized conservation standards. In this sense, minimum interventions should be considered that allow the correct use of the building, the preservation of authenticity, reversibility and compatibility of the materials and interventions to be carried out[3]. However, there are countless buildings within heritage assets (e.g., Historic Centers) that are protected, but do not have clear legislation on the most appropriate and adequate interventions.

There are different types of protection that refer to different aspects of a building that need to be protected. It is relevant to note that the restrictions are unlimited and different in any case. Hereafter a short list of protection examples is deployed:

- Comprehensive protection (a very strict protection, where everything in the building must be maintained);
- Protection of the historic structure;
- Protection of certain fabrics or constructions inside the building;
- Protection of the form of the building;
- Protection of the whole façade (or just the color or shape for example);
- Protection of all materials used (or materials of structure or finishes).
- Soft levels of protection such as "structural protection" (a building where almost everything can be done except demolition).

To better illustrate the digitalization requirements and barriers, an extensive review at EU27 and demonstrator member states level of regulations and policies has been performed about constraints and protective measures adopted to preserve the conditions that make historical

[1] https://uis.unesco.org/en/glossary
[2] https://whc.unesco.org/en/list/
[3] For detailed criteria the several international standards & charters may be consulted. From Athens Charter 1931 to Krakow Charter 2000.

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buildings artifacts of cultural and social relevance. In parallel, an inventory of already existing best practices has been developed to create a common shared framework about barriers, legislative impediments, opportunities, and incentives. In particular, the inventory addresses the adoption of specific energy conservation measures not only those increasing energy performances when energy renovation measures are not an option, i.e., non-intrusive energy optimization via digitalization, but also not affecting the specific sensible elements of the historical buildings.

3.1 Review of regulations and policies about constraints and protective measures adopted to preserve historical buildings

As noted above, the level of protection and the priorities for preservation vary greatly from one EU Member State to another, but also from one building to another, due to their different historical contexts. Below are some general considerations and protective measures typically adopted to preserve historic buildings in the EU:

- Heritage Designation;
- Building Codes and Regulations;
- Conservation and Restoration Guidelines (best practices and methodologies);
- Environmental and Sustainability Considerations;
- Funding and Incentives;
- Public Awareness and Education;
- Monitoring and Enforcement;
- International Cooperation.

Hereunder in Table 3 are identified the reference documents at international and EU level. As the SMARTeeSTORY demonstrators are in Riga (Latvia), Delft (The Netherlands), and Granada (Spain), hereafter is also presented the reference documents in each of the demonstrator member states in terms of preservation of historical buildings.

LEVEL	REFERENCE DOCUMENTS
International	UNESCO's Convention Concerning the protection of the World Cultural and Natural Heritage (1972, ratified in 2012) [1]
EU	• EU Work Plan for Culture 2023-2026 [2] • European cultural Heritage Green Paper (2021) [3] • EN 16883:2017 for Conservation of cultural heritage – Guidelines for improving the energy performance of historic buildings [4] • European Convention on Offences Relating to Cultural Property (2017) [5] • Directive 2012/27/EU of the European Parliament and of the Council on energy efficiency (2012) [6] • Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings – recast (2010) [7]

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LEVEL	REFERENCE DOCUMENTS
	• European Convention for the Protection of the Architectural Heritage 1989 (revised in 1992) [8] • European Cultural Convention (1954) [9]
LATVIA	• Law of the Republic of Latvia "On the Protection of Cultural Monuments" (1992) [10] • List of cultural monuments protected by the state (1998)[4] • Law on Preservation and Protection of the Historic Centre of Riga (2003) [11] • Regulations Regarding the Preservation and Protection of the Historic Centre of Riga (2004) [12] • Masterplan of the Historic Centre of Riga and its protection zone (2013) [13]
NETHERLANDS	• The 2016 Heritage Act (Erfgoedwet), which lays down rules governing the disposal of cultural property by the government; The Cultural Heritage Agency is responsible for the preservation and maintenance of cultural heritage in the Netherlands. The agency awards grants for monuments, historic buildings, archaeology, and cultural landscapes, and implements the Heritage Act. • The Spatial Planning Act (Wet op de Ruimtelijke Ordening 2007 (WRO), (Wet op de Ruimtelijke Ordening 2007 (WRO) (Wet op de Ruimtelijke Ordening 2007 (WRO) which includes the Environment & Planning Act (change into Omgevingswet, will take into effect in 2021).
SPAIN	• Law 16/1985, of 25th of June, of Spanish Historical Heritage (1985) [11] and other relevant Royal Decrees on this matter such as RD 111/1986 and RD 1680/1991 • Board of Classification, Valuation and Export of Historical Heritage Assets [12] • Law 1/1991, amended by Law 14/2007, of Historical Heritage of Andalusia (2007) [13] • General Urban Development Plan of Granada (2001) [14] • General Catalogue of Andalusian Historical Heritage [15]

Table 3. Reference documents in terms of regulations and policies about constraints and protective measures adopted to preserve historical buildings.

Based on these documents, the following review of regulations and policies about constraints and protective measures adopted are obtained at demonstrator member states level.

[4] Monument (mantojums.lv)

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3.1.1 Latvia

The Historic Centre of Riga, the capital of Latvia, holds the prestigious recognition of being a UNESCO heritage site. Consequently, pursuing traditional energy renovation methods is not a viable choice. The main limitations for retrofitting are height and visual identity. Thus, extra thermal insulation of thermal bridges is limited as well as installation of PV or solar thermal can face significant limitation. The access of heavy trucks and crane in historic center can play a crucial role in selection of renovation package and installation of alternative HVAC and renewable energy systems.

General

According to the "Regulations Regarding the Preservation and Protection of the Historic Centre of Riga" [12], upon performing the maintenance, renovation, conservation, or restoration of culturally and historically unique, valuable buildings, the volume of the building, the form of its roof, the finish of its facades, its historically original windows and doors, its construction system and planning, as well as its culturally and historically valuable interiors and furnishings shall be preserved. If a culturally and historically valuable building is damaged to such extent that its renovation and restoration is not possible and the cultural and historic value of the relevant building is lost, in its place only the construction of a building of the same volume and building materials shall be permitted, preserving the existing authentic cultural and historic values.

Energy renovation

In accordance with the binding regulatory framework, the implementation of measures to improve the energy efficiency of cultural and historical buildings requires a careful, professional, and successive approach. Environmentally friendly construction materials should be used for the energy renovation of historical buildings, these buildings should be renovated with traditional construction methods that are less energy-intensive, and a high-quality urban environment should be maintained or restored.

Upon performing the energy renovation, historical buildings should be surveyed, and the spots of heat loss determined. After that, a complex of measures for energy renovation solutions should be developed, taking care of cultural and historical values to be preserved. Before deciding on a radical intervention in the construction of the building and its architectural decoration, the possibility of preserving the value of the building in the long term should be foreseen and other alternative options should be considered.

During energy renovation it is prohibited to simplify the facade architecture, to change the original historical windows and outer doors in the building facades which are visible from the public space, as well as to use a plate glass and plastic finish, to change the shape and type of roofing, to build new skylights visible from the public space, to place energy generation equipment if it reduces the value of the cultural historical environment looking from the public space.

Design of energy renovation works must ensure the preservation of the original visual and technical condition of the building's architectural and interior decoration details. All planned energy renovation works must be coordinated with local construction regulatory institutions.

In June 2023 elaboration of a new Masterplan for the Historical Centre of Riga [13] has been launched. One of its objectives is to integrate recent UNESCO policies and recommendations on energy renovation and energy management of cultural and historical heritage in Riga's planning framework.

Digitalization

In Latvia, there is still no regulation on digitization of buildings adopted, however, the Digital Transformation Guidelines of Latvia 2021-2027[5] stipulates the requirement to establish a system of digitization of land use, built environment and buildings by 2027.

3.1.2 The Netherlands

In the Netherlands, there are no regulations that directly address the requirements of historic or heritage buildings in terms of digitalization. The Dutch Digital Heritage Network[6] is a partnership in the Netherlands that focuses on developing a system of national facilities and services for improving the visibility, usability, and sustainability of digital heritage. However, this network and related strategies focus on the sharing of knowledge about heritage buildings, and it does not focus on the operation and performance of the buildings themselves.

The digitalization requirements of Dutch buildings are indirectly dictated by two other ambitions: the digitalization of the cadaster and the nearly-zero or zero energy performance requirements. However, the digitalization requirements derived from the energy performance of new buildings do not impact historic and listed buildings, which are exempted.

The main requirement for the energy performance of new buildings is the energy performance coefficient (in Dutch the "energieprestatiecoefficient'), setting minimum energy performance (MEP) for new buildings. This indicator is based on the estimated total primary energy consumption of a building based on a series of indicators, e.g., heating, ventilation, and lighting, adjusted to the useful floor area and the renewable energy produced by the building. This indicates the building energy performance in MJ/m^2. From 1st January 2021, all new construction, both residential and non-residential construction, must meet the requirements for Nearly Energy-Neutral Buildings (BENG)[7]. These requirements arise from the Energy Agreement for sustainable growth and from the European Energy Performance of Buildings Directive (EPBD). Therefore, these strict requirements do not apply to historic buildings, unless the building is undergoing large renovations in houses and offices. The target buildings of SMARTeeSTORY are buildings where deep renovations are not an option, so they are not required to meet the BENG standards. However, starting from 2023, buildings labelled 'C' or lower (maximum of value between 190.01 to 250 kWh per square meter per year) based on the new rating system will not be allowed to lease office space. If deep renovation is not an option, for these buildings digitalization and smart building operation represent key options.

3.1.3 Spain

The Region of Andalusia is one of the European regions with the highest historical value and with abundant and rich construction heritage. In Andalusia there are 24,000 cataloged public real estate properties that potentially may be retrofitted.

In Spain, Law 16/1985, of June 25, on Spanish Historical Heritage, and its Royal Decrees 11/1986 and Royal Decree 1680/1991, which establish Assets of Cultural Interest, apply.

Andalusia has full competence in matters of preservation of historical heritage. And therefore, in Andalusia, those Assets of Cultural Interest declared in accordance with Law 16/1985, of June 25,

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5 Ministru kabineta 2021. gada 7. jūlija rīkojums Nr. 490 "Par Digitālās transformācijas pamatnostādnēm 2021.–2027. gadam". https://likumi.lv/ta/id/324715

6 Dutch Digital Heritage Network - Netwerk Digitaal Erfgoed

7 Energieprestatie - BENG (rvo.nl)

of the Spanish Historical Heritage, located in Andalusia, are registered in the General Catalog of Andalusian Historical Heritage.

In Andalusia, as underlined, Law 14/2007, of November 26, on the Historical Heritage of Andalusia, applies for the protection of the Andalusian historical heritage, including assets of cultural interest of Andalusia in accordance with article 13.

Furthermore, and in accordance with its article 19 regarding visual or perceptual pollution, it defines that intervention, use or action in the property or its protective environment that degrades the values of a real estate component of the Historical Heritage and any interference that prevents or distort your contemplation. Thus, the municipalities in which assets are registered in the General Catalog of the Historical Heritage of Andalusia must include in urban planning or in municipal building and urbanization ordinances measures that prevent visual or perceptual contamination. Such measures will include, among others, the control of the following elements: a) Constructions or installations of a permanent or temporary nature that, due to their height, volume or distance, may disturb their perception. b) The facilities necessary for energy supplies, generation and consumption. c) The necessary facilities for telecommunications.

Thus, the protection of Historical Heritage also includes its defense against what has been called "visual or perceptual pollution." The impact that certain elements and facilities produce on our heritage requires combining the demands of the technologies that affect our daily lives with the preservation of environmental quality, making it necessary to coordinate the actions of the different Public Administrations.

In this sense, the location of certain elements and the construction of energy and telecommunications facilities that directly affect the values and contemplation of the assets affected by the declaration of cultural interest are subject to authorization from the Cultural Administration.

Accordingly with this norm the installation of renewable energy sources or some other high-efficiency systems in the historic centers of the great majority of the 785 Andalusian municipalities is therefore complex.

The building of the Royal Chancellery of Granada was declared a national historical-artistic monument by Royal Decree 99/1977 of January 4 (BOE of 02/04/1977), and therefore considered registered as an Asset of Cultural Interest.

The demonstrative building is registered in the General Catalogue of Andalusian Historical Heritage in the Inventory of Registered Assets Granade. Building of Chancellery (Real Cancillería) General Catalog of Historical Heritage of Andalusia (Catálogo General de Patrimonio Histórico Andaluz CGPHA)[8].

3.2 Inventory of already existing best practices

The inventory of best practices has the below outcomes about barriers, legislative impediments, opportunities, and incentives. In particular, the inventory addresses the adoption of specific energy conservation measures not only those increasing energy performances when energy renovation measures are not an option, i.e., non-intrusive energy optimization via digitalization, but also not affecting the specific sensible elements of the historical buildings.

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[8] Catálogo General del Patrimonio Histórico Andaluz - Junta de Andalucía (juntadeandalucia.es)

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Non-technical barriers for energy interventions in historical buildings can be classified as follows: financial, cultural, societal, and political. In the first case, the lack of appropriate funding schemes and public financial incentives presents a significant financial obstacle for building. Secondly, cultural barriers arise from conflicting interpretations of architectural traditions and urban regeneration typologies among stakeholders, particularly when retrofitting multi-occupancy buildings, where varying owner interests can pose societal challenges. Apart from these, political barriers may arise when municipal administrations fail to act in energy planning and managing larger-scale urban retrofitting initiatives. In these sense, **legislative impediments** consisting of the protection of historic buildings and districts set clear limitations to action on such building elements during retrofitting procedures.

The last recasting proposal of the EPBD relies on the importance of converting the building stock into a zero-emissions building stock by 2050, by reinforcing renovation strategies and providing new **incentives**, allowing Member States to create an energy efficiency roadmap in line with the objectives set by the EU. This situation brings new **opportunities** for the building sector to implement new technologies that allow buildings to adapt to recent needs. As far as historic buildings as concerned, they are excluded from most of the mandatory requirements set by the EPBD as long as it is technically and economically unfeasible.

By taking this into account, a review of reference project in the topic of energy retrofitting and digitalization of historic buildings has been developed and it is presented hereafter, in order to identify already existing best practices in this topic.

REFERENCE PROJECT	BRIEF	BEST PRACTICES
Competence Centre for the Conservation of Cultural Heritage (4CH-D4.1) – 2022	Reports on and reviews guidelines and standards aimed at setting up a documentation system, based on State-of-the-Art technology including 3D for advanced digitization and tailored to the needs of conservation deriving from the European Cultural Heritage Community	- Optimized and time-saving procedures for data capturing and processing - The need of society to be actively involved in cultural heritage activities, not only as an observer but also as a creator - The need of comprehensive risk assessment methods for cultural heritage affected by climate change and natural hazards - Spreading knowledge on remote sensing applications for cultural heritage sites - Common protocols implementation guidelines and sharing of lessons learned for regeneration and adaptive reuse of historic city centres - The need of high-resolution interactive 3D visualization tools - Smart monitoring systems with minimally invasive installation and analysis systems to identify deterioration processes - Facilitate digital models sharing and information exchange - Reduced specialised equipment knowledge for diagnosis studies - Time upgradable 3D modelling - Visually organize 3D digital archives by the display of different level of information (BIM+GIS) - Provision of infrastructure and services for data sharing, access, and re-use

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		- Availability of tools to gather and integrate diverse digital materials, archive them appropriately and make the information accessible Guidelines, protocols, and standard procedure for data capturing and data processing in terms of project's scope: basic.
Cost Efficient Options and Financing Mechanisms for nearly Zero Energy Renovation of existing Building Stock (CERTUS – D2.4) - 2015	Analysis of potential materials, equipment and solutions considered in the project case studies to achieve nearly zero energy buildings (NZEB) focusing on reducing energy losses through envelope, renewable energy sources, equipment for energy efficiency improvement and technologies for a rational use of energy	Development of technical guidelines for cost efficient options and financing mechanisms for nearly zero energy renovation of existing building stock, which include specific content on historic buildings deep restoration about energy efficiency and use of renewable energy systems. Main aspects on which to focus de retrofitting of historic buildings: - Improving comfort and indoor environmental quality - Improving durability of the building as a conservation measure by improving its thermal performances thus ensuring its use and maintenance - Reducing energy consumption and CO_2 emissions Intervention topics: - Building envelope - Building equipment - Lighting, including the use of both artificial light sources, as well as natural illumination - Passive solutions - Introduction of systems to produce renewable energy
Energy Efficiency for EU Historic Districts Sustainability (EFFESUS – D2.1 & D2.3) - 2016	Researched and developed appropriate solutions for retrofitting historic buildings in European urban districts. Development of a state-of-the-art repository of energy efficiency measures and renewable energy technologies which are tried, tested and commercially available. To reduce the environmental impact of EU valuable urban heritage by making significant improvements to its EE while conserving and even promoting the cultural, historic, urban, and architectural value of EU historic cities.	- Impact indicators areas: indoor environmental conditions, building and urban fabric compatibility, historical values and conservation principles, embodied energy, operational energy, economic return - 13 retrofit issues classified by retrofit steps grouping 85 potential retrofit measures, including conservation aspects to consider and conditions under which it works well, energy saving potential, key parameters for efficiency calculation and tools. List of retrofit issues: Baseline assessment; Energy management; Airtightness; Ventilation; Daylight and solar loads; Solar reflectance of external materials; Thermal performance of external envelope; Thermal mass of building; HVAC enhancement and retro-commissioning; Electrical equipment; Energy storage; Handover and evaluation
Efficient Energy for EU Cultural Heritage (3ENCULT) – 2011	Report on energy efficiency solutions in historic buildings, the project bridges the gap between conservation of historic buildings and climate protection.	Core issues for discussion about the path to energy efficiency individual solutions for historic buildings: - Interior insulation - Airtightness - Moisture transport problems at beam ends - Windows

		- Integration of shading systems within window/glazing system - Integration of space saving ventilation systems with heat recovery - Analysis of the cost-effectiveness of automatic airflow volume balancing heat recovery - Daylighting - Artificial lighting - Passive heating and cooling - Active energy efficiency solutions - Renewable Energy Sources (RES) integration
Renovating Historic Buildings Towards Zero Energy (Task 59) - 2021	How to cost-effectively save energy in the retrofit of historic and protected buildings fulfilling conservation compatibility, energy efficiency towards nZEB, technical compatibility and functionality. A parallel aim was to propose a list of criteria to assess the suitability of the solution when applied to a specific historic building.	- Documentation and assessment of conservation compatible energy retrofit technologies: - Integrated approach for the identification of conservation compatible retrofit materials and solutions in historic buildings - Conventional and innovative solutions for conservation and thermal enhancement of window systems in historic buildings - Materials and solutions for wall insulation in historic buildings - Energy and cost-efficient HVAC-systems and strategies with high conservation compatibility - Integrated solar thermal and photovoltaic systems with high conservation compatibility
Conservation of Cultural Heritage - Guidelines for improving the energy performance of historic buildings (EN16883:2017) – 2017	Standard providing guidelines for sustainability improving the energy performance of historic buildings while respecting their heritage significance. It presents a normative working procedure for selecting measures to improve energy performance.	- The procedure assesses the impact of those measures in relation to preserving the character-defining elements of the building. - Definition of a risk criteria consider technical compatibility, heritage significance of the building, economic viability, energy, indoor environmental quality, impact on the outdoor environment and aspects of use
Commission Recommendation on building modernisation (2019/1019/EU) - 2019	These procedures may differentiate between different types of buildings, to address specific types for which technical, economic, or functional feasibility is an issue, such as historical or listed buildings.	- Technical building systems and their inspections, including requirements on the installation of self-regulating devices and building automation and control systems - Provisions on the calculation of primary energy factors - Verification and enforcement - Summary of recommendations - Recommendations relating to technical buildings systems and their inspections, self-regulating devices, and BACS
The EU Smart Building innovation platform (SmartBuilt4EU – D3.2) - 2023	Solution packages for Smart Buildings considering two case studies: residential building and office building .	- Smart building solution packages: - Energy efficiency - Comfort, health and well-being - Smart grid readiness - Informed users - Modelling and simulation packages: - Modelling and simulation environment - Building models - Control models

European Cultural Heritage Green Paper (Policy) – European Heritage Network (Europa Nostra) - 2021	Green Paper, Putting Europe's shared heritage at the heart of the European Green Deal. (2.1.4 Building and renovating in an energy and resource efficient way)	Key recommendations for policymakers and heritage operators: - Enlist the heritage sector in the Renovation Wave - Utilise new guidance on the Energy Efficiency First principle to help public authorities to address energy performance standards while safeguarding cultural values - Promote energy and resource efficiency in all historic buildings while supporting the development of new approaches to energy performance standards that allow alternate pathways to compliance based on smart, "whole house" planning and performance assessment, adapted to the needs and values of historic buildings and traditional building systems - Ensure adequate treatment of heritage buildings within the new SRI, with a tailored scheme for the smartness assessments of services installed in (officially protected) historic buildings - Match any extension of building performance standards to heritage buildings with commensurate public incentives - Increase funding of public heritage agencies in order to support energy efficiency efforts - Promote routine maintenance and good conservation practice in reducing GHG emissions and increasing resilience - Address energy property and feature the adaptative reuse of historic buildings for affordable housing - Include cultural heritage in the new European Urban Initiative - Link heritage trades, skills, and education to the demands of the Renovation Wave - Include tools adapted to historic buildings and traditional building systems in new BIM methodology - Incorporate the heritage in the expanded High-Level Forum on construction - Duly integrate the full breadth of cultural in all the multidimensionality elements of the New European Bauhaus
Brains for Building's Energy Systems (B4B) - (2021-2025)	Project focused on developing methods to harness big data from smart meters, building management systems and IoT devices to reduce energy consumption, increase comfort and respond to user behaviour, local energy-demand suppliers and maintenance.	A total of 12 buildings (living labs and validation cases) prototypes of methods and algorithms are tested and validated. Main results of this project are: - Prototype software plug-ins for self-diagnostic systematic errors and energy waste in building installations. - Prototypes of smart software plug-ins for error detection, diagnosis and predictive condition-based maintenance. - Open source HVAC & electrical installations model and algorithm prediction o supply and demand energy.

		- Methods and prototypes of AI-based software plug-in for flexible multi-object energy optimization. - Methodology & data for a user-centred approach in smart building control. - Prototypes of user-oriented interfaces for healthy indoor climate, energy efficiency and energy flexibility of the building. - Standardized methodology for secure and ethical access to and use of data (collection, management and use). - Linked data at systemic level, leading to system integration via APIs. - Standardized methodologies and guidelines for determining and transforming buildings into 'smart readiness'. - Ensures the knowledge and experiences are shared in a learning community, resulting in the development of new partnerships and practical application in educational programs.

Table 4. Review of reference project to identify already existing best practices.

3.3 Set of requirements

The review of legislation and best practices outlines the essential considerations for introducing digitalization in historical buildings to preserve their historical and cultural significance while leveraging digital tools for energy efficiency, user comfort, and sustainability. The main points for historical buildings preservation could be summarized as follows:

- **Historical Integrity Preservation:** Prioritize maintaining the building's historical and architectural value by minimizing physical changes, respecting original materials, and discreetly integrating digital elements.
- **Compatibility and Scalability:** Choose digital solutions that work well with the existing infrastructure and can adapt to future technological advancements.
- **Energy Efficiency:** Incorporate technologies like smart lighting, HVAC systems, and energy monitoring tools to minimize energy consumption while ensuring occupant comfort.
- **User Comfort and Satisfaction:** Implement digital features that enhance user comfort, such as personalized climate control and user-friendly interfaces.
- **Data Security and Privacy:** Ensure compliance with EU regulations regarding data security and privacy, especially concerning personal data collected through digital systems.
- **Maintenance and Monitoring:** Consider long-term maintenance and monitoring requirements, including remote monitoring and predictive maintenance, without harming the historical fabric.

Once the digitalization approach is established, creating a co-innovation environment becomes crucial. This collaborative space allows stakeholders to collectively evaluate and refine the digital solutions. User feedback and iterative improvements help identify potential issues and areas for enhancement.

3.4 Objectives related to energy efficiency and users' wellbeing SMARTeeSTORY decided on

SMARTeeSTORY project is expected to contribute to energy and CO_2 savings due to control strategies based on accurate prediction models and due to the inclusion of user dimension, both behavior, preferences, and communication mechanism.

In this sense, the set of KPIs that matter most for achieving the objectives, measuring the effectiveness and efficiency of the digitalization approach in historical buildings must be defined considering these main aspects:

- **Energy Consumption Reduction:** Measure the reduction in energy consumption achieved through digital technologies compared to traditional systems.
- **Occupant Comfort:** Assess occupant satisfaction and indoor environmental quality using surveys, interviews, or sensors.
- **Preservation of Historical Integrity:** Evaluate how well the digitalization approach preserves the building's historical significance.
- **Return On Investment (ROI) and Maintenance Costs:** Analyse the impact of digital solutions on maintenance and operation expenses.
- **Adaptability and Flexibility:** Evaluate how well the digital systems can adapt to future needs and technological advancements.
- **User Interaction and Experience:** Assess the ease of use and accessibility of digital interfaces within the building.
- **Sustainability:** Measure the environmental impact, including reductions in carbon footprint and resource consumption.

In this regard, objectives related to energy efficiency are summarized in Table 5 for each demo site, pointing out the scale and significance of the project's contribution to the expected outcomes and impacts.

	Riga demo	Delft demo	Granada demo
Floor area [m^2]	882	500	2,000
Expected energy savings [%]	37	29	21
Baseline specific primary energy [$MWh/m^2 \cdot year$]	0.19	0.38	0.12
Future specific primary energy [$MWh/m^2 \cdot year$]	0.12	0.24	0.09
Baseline specific CO_2 emissions [$kgCO_2/m^2 \cdot year$]	30.5	60.1	17.0
Future specific CO_2 emissions [$kgCO_2/m^2 \cdot year$]	19.2	37.9	13.4
Primary energy savings [MWh/year]	63	71	51
Reduction of the greenhouse gas emissions [$kgCO_2$/year]	9,968	11,122	7,100
Reduction of energy related operational costs [€/year]	3,980	5,247	6,200

Investment requested [k€]	48	42	51
Payback time [years]	12.1	8	8.2

Table 5. Expected objectives values for each demonstrator in terms of energy efficiency.

Thanks to SMARTeeSTORY installations, the energy efficiency and the health and well-being impact criteria considered in the SRI methodology are expected to reach high values after the intervention. Focusing on users' wellbeing, Riga demo aims to reach a 82% score, Delft demo will increase to 78% and Granada will reach 74%. In particular, the impact category related to information to occupants will be introduced in Riga for which the baseline scenario level is 0%. In terms of comfort impact criteria, Delft and Granada are expected to reach ratings equal to 84%, while Riga should the best demo reaching the 92%.

Further information on KPIs is included in section 6.

3.5 Digitalization approach across EU

Within this task RINA-C will apply method B of SRI assessment methodology, the "expert" approach to define the interventions (further defined in T5.3), thus the specific requirements, at each demo site as well as the control strategies to manage the smart solutions (T3.3).

Starting from the assessment already performed during the proposal phase using the method A for the SRI calculation, the actual conditions of each demo, in addition to the foreseen interventions, have been further investigated in order to provide more accurate SRI values applying the more complete method B. In comparison to the method A, with the method B all the SRS included in the Excel file used for the SRI assessment are activated if they are not forced to be excluded from the calculation because not applicable at the intervention area taken into account. In this chapter the review of the SRSs levels, for the baseline and the future scenario, in addition to the new SRI values, is reported.

3.5.1 Delft

In Table 6 the baseline scenario levels and the future scenario ones for each SRSs included in the method B assessment and considered as applicable at the demo site are reported.

Table 6. Baseline and future SRSs levels for Delft demo

Domain	SRS	Baseline SRS level	Future SRS level
Heating	Heat emission control	Individual room control (e.g. thermostatic valves, or electronic controller)	Individual room control with communication and occupancy detection

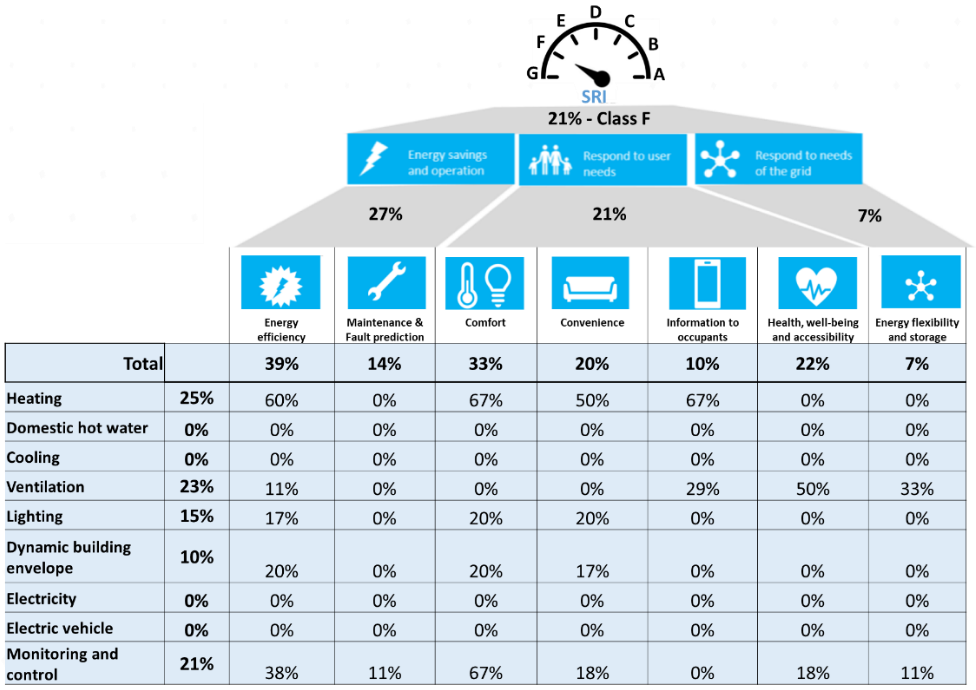
	Control of distribution fluid temperature (supply or return air flow or water flow) - Similar function can be applied to the control of direct electric heating networks	Outside temperature compensated control	
	Control of distribution pumps in networks	Variable speed pump control (pump unit (internal) estimations)	
	Report information regarding heating system performance	None	Central or remote reporting of performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection
	Flexibility and grid interaction	Scheduled operation of heating system	Optimized control of heating system based on local predictions and grid signals (e.g. through model predictive control)
Ventilation	Supply air flow control at the room level	No ventilation system or manual control	Local Demand Control based on air quality sensors (CO_2, VOC,...) with local flow from/to the zone regulated by dampers
	Air flow or pressure control at the air handler level	On off time control: Continuously supplies of air flow for a maximum load of all rooms during nominal occupancy time	Automatic flow or pressure control without pressure reset: Load dependent supplies of air flow for the demand of all connected rooms.

	Free cooling with mechanical ventilation system	No automatic control	
	Reporting information regarding IAQ	Air quality sensors (e.g. CO_2) and real time autonomous monitoring	Real time monitoring & historical information of IAQ available to occupants + warning on maintenance needs or occupant actions (e.g. window opening)
Lighting	Occupancy control for indoor lighting	Manual on/off switch + additional sweeping extinction signal	Automatic detection (manual on / dimmed or auto off)
	Control artificial lighting power based on daylight levels	Manual (central)	Automatic dimming including scene-based light control (during time intervals, dynamic and adapted lighting scenes are set, for example, in terms of illuminance level, different correlated color temperature (CCT) and the possibility to change the light distribution within the space according to e. g. design, human needs, visual tasks)
Dynamic building envelope	Window solar shading control	Motorized operation with manual control	Predictive blind control (e.g. based on weather forecast)
	Window open/closed control, combined with HVAC system	Manual operation or only fixed windows	Open/closed detection to shut down heating or cooling systems

	Reporting information regarding performance of dynamic building envelope systems	No reporting	Position of each product, fault detection, predictive maintenance, real-time & historical sensor data (wind, lux, temperature…)
Electricity	Reporting information regarding electricity consumption	None	real-time feedback or benchmarking on appliance level with automated personalized recommendations
Monitoring and control	Run time management of HVAC systems	Runtime setting of heating and cooling plants following a predefined time schedule	Heating and cooling plant on/off control based on predictive control or grid signals
	Detecting faults of technical building systems and providing support to the diagnosis of these faults	No central indication of detected faults and alarms	With central indication of detected faults and alarms for at least 2 relevant TBS
	Occupancy detection: connected services	Occupancy detection for individual functions, e.g. lighting	Centralized occupant detection which feeds into several TBS such as lighting and heating
	Central reporting of TBS performance and energy use	Central or remote reporting of real-time energy use per energy carrier	Central or remote reporting of real-time energy use per energy carrier, combining TBS of all main domains in one interface
	Reporting information regarding demand side management performance and operation	None	Reporting information on current DSM status, including manage energy flows
	Override of DSM control	No DSM control	Manual override and reactivation of DSM control by the building user

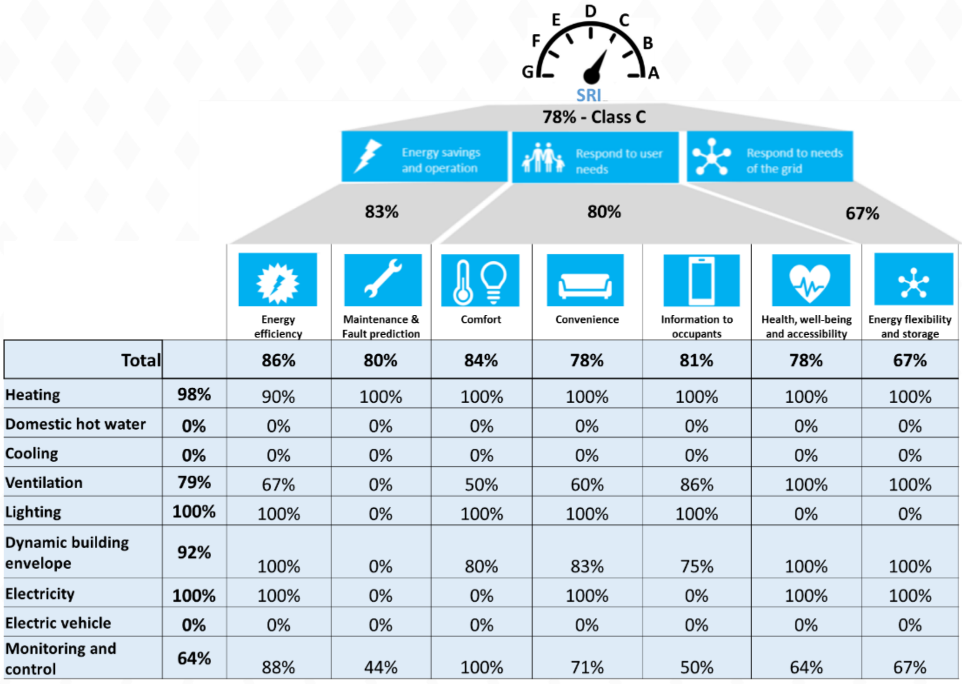
	Single platform that allows automated control & coordination between TBS + optimization of energy flow based on occupancy, weather and grid signals	None	Single platform that allows automated control & coordination between TBS + optimization of energy flow based on occupancy, weather and grid signals

The SRI values obtained for the baseline and the future scenario applying the method B are respectively 21% (class F) and 78% (class C). Moreover, in Figure 1 the impact scores for each impact criteria and each domain are reported for the baseline scenario calculation and the same for the foreseen future scenario is in Figure 2. Finally, in Table 7 the comparison between the assessment developed using the method A and B is reported. The difference obtained applying the two methods between the baseline values and between the future ones are due to further SRSs (maintaining a low level) included in the assessment, in addition to the change in the SRSs levels or the remove of some SRSs from the list of the applicable ones caused by the deeper knowledge of the systems acquired in the first months of the project.



		Energy efficiency	Maintenance & Fault prediction	Comfort	Convenience	Information to occupants	Health, well-being and accessibility	Energy flexibility and storage
Total		**39%**	**14%**	**33%**	**20%**	**10%**	**22%**	**7%**
Heating	**25%**	60%	0%	67%	50%	67%	0%	0%
Domestic hot water	**0%**	0%	0%	0%	0%	0%	0%	0%
Cooling	**0%**	0%	0%	0%	0%	0%	0%	0%
Ventilation	**23%**	11%	0%	0%	0%	29%	50%	33%
Lighting	**15%**	17%	0%	20%	20%	0%	0%	0%
Dynamic building envelope	**10%**	20%	0%	20%	17%	0%	0%	0%
Electricity	**0%**	0%	0%	0%	0%	0%	0%	0%
Electric vehicle	**0%**	0%	0%	0%	0%	0%	0%	0%
Monitoring and control	**21%**	38%	11%	67%	18%	0%	18%	11%

Figure 1. Detailed impact scores view for baseline scenario, method B assessment and Delft demo.



SRI
78% - Class C

	Energy savings and operation		Respond to user needs				Respond to needs of the grid
	83%		80%				67%
	Energy efficiency	Maintenance & Fault prediction	Comfort	Convenience	Information to occupants	Health, well-being and accessibility	Energy flexibility and storage
Total	**86%**	**80%**	**84%**	**78%**	**81%**	**78%**	**67%**
Heating **98%**	90%	100%	100%	100%	100%	100%	100%
Domestic hot water **0%**	0%	0%	0%	0%	0%	0%	0%
Cooling **0%**	0%	0%	0%	0%	0%	0%	0%
Ventilation **79%**	67%	0%	50%	60%	86%	100%	100%
Lighting **100%**	100%	0%	100%	100%	100%	0%	0%
Dynamic building envelope **92%**	100%	0%	80%	83%	75%	100%	100%
Electricity **100%**	100%	0%	0%	100%	0%	100%	100%
Electric vehicle **0%**	0%	0%	0%	0%	0%	0%	0%
Monitoring and control **64%**	88%	44%	100%	71%	50%	64%	67%

Figure 2. Detailed impact scores view for foreseen future scenario, method B assessment and Delft demo.

Table 7. Comparison of SRI values evaluated with method A and B for the Delft demo.

	Baseline scenario	Future scenario
Method A SRI assessment	22%, class F	89%, class B
Method B SRI assessment	21%, class F	78%, class C

3.5.2 Granada

In Table 8 the baseline scenario levels and the future scenario ones for each SRSs included in the method B assessment and considered as applicable at the demo site are reported.

Table 8. Baseline and future SRSs levels for Granada demo

Domain	SRS	Baseline SRS level	Future SRS level
Heating	Heat emission control	Individual room control (e.g. thermostatic valves, or electronic controller)	Individual room control with communication and occupancy detection

	Control of distribution fluid temperature (supply or return air flow or water flow) - Similar function can be applied to the control of direct electric heating networks	No automatic control	Demand based control
	Control of distribution pumps in networks	On off control	
	Thermal Energy Storage (TES) for building heating (excluding TABS)	Continuous storage operation	Heat storage capable of flexible control through grid signals (e.g. DSM)
	Heat generator control (for heat pumps)	On/Off-control of heat generator	Variable control of heat generator capacity depending on the load AND external signals from grid
	Report information regarding heating system performance	None	Central or remote reporting of performance evaluation including forecasting and/or benchmarking
	Flexibility and grid interaction	Scheduled operation of heating system	Heating system capable of flexible control through grid signals (e.g. DSM)
Cooling	Cooling emission control	Individual room control	Individual room control with communication and occupancy detection
	Control of distribution network chilled water temperature (supply or return)	Constant temperature control	Demand based control

	Control of distribution pumps in networks	On off control	
	Control of Thermal Energy Storage (TES) operation	Continuous storage operation	Cold storage capable of flexible control through grid signals (e.g. DSM)
	Generator control for cooling	On/Off-control of cooling production	Variable control of cooling production capacity depending on the load AND external signals from grid
	Report information regarding cooling system performance	Central or remote reporting of current performance KPIs (e.g. temperatures, submetering energy usage)	Central or remote reporting of performance evaluation including forecasting and/or benchmarking
	Flexibility and grid interaction	No automatic control	Optimized control of cooling system based on local predictions and grid signals (e.g. through model predictive control)
Lighting	Occupancy control for indoor lighting	Manual on/off switch	Automatic detection (manual on / dimmed or auto off)
Electricity	Reporting information regarding electricity consumption	None	real-time feedback or benchmarking on appliance level with automated personalized recommendations

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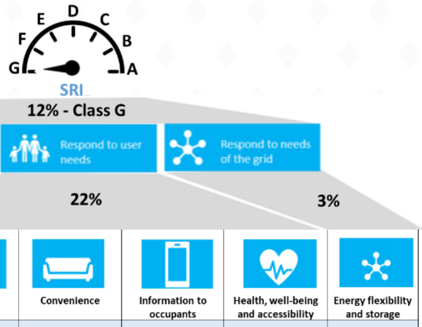
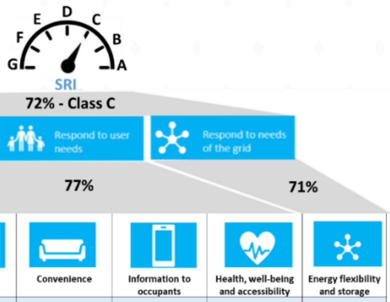
Monitoring and control	Run time management of HVAC systems	Runtime setting of heating and cooling plants following a predefined time schedule	Heating and cooling plant on/off control based on predictive control or grid signals
	Detecting faults of technical building systems and providing support to the diagnosis of these faults	No central indication of detected faults and alarms	With central indication of detected faults and alarms for at least 2 relevant TBS
	Occupancy detection: connected services	None	Centralized occupant detection which feeds into several TBS such as lighting and heating
	Central reporting of TBS performance and energy use	None	Central or remote reporting of real-time energy use per energy carrier, combining TBS of at least 2 domains in one interface
	Reporting information regarding demand side management performance and operation	None	Reporting information on current DSM status, including managed energy flows
	Override of DSM control	No DSM control	Manual override and reactivation of DSM control by the building user
	Single platform that allows automated control & coordination between TBS + optimization of energy flow based on occupancy, weather and grid signals	None	Single platform that allows automated control & coordination between TBS

The SRI values obtained for the baseline and the future scenario applying the method B are respectively 12% (class G) and 72% (class C). Moreover, in the impact scores for each impact criteria and each domain are reported for the baseline scenario calculation and the same for the foreseen future scenario is in. Finally, in the comparison between the assessment developed using the method A and B is reported. The difference obtained applying the two methods between the baseline values and also between the future ones are due to the further SRSs (maintaining a low level) included in the assessment, in addition to the change in the SRSs levels or the remove of some SRSs from the list of the applicable ones caused by the deeper knowledge of the systems acquired in the first months of the project.



		Energy efficiency	Maintenance & Fault prediction	Comfort	Convenience	Information to occupants	Health, well-being and accessibility	Energy flexibility and storage
Total		21%	3%	27%	16%	4%	43%	3%
Heating	14%	19%	0%	33%	36%	60%	0%	0%
Domestic hot water	0%	0%	0%	0%	0%	0%	0%	0%
Cooling	20%	35%	0%	20%	27%	60%	20%	25%
Ventilation	0%	0%	0%	0%	0%	0%	0%	0%
Lighting	15%	17%	0%	20%	20%	0%	0%	0%
Dynamic building envelope	0%	0%	0%	0%	0%	0%	0%	0%
Electricity	0%	0%	0%	0%	0%	0%	0%	0%
Electric vehicle	0%	0%	0%	0%	0%	0%	0%	0%
Monitoring and control	9%	13%	11%	33%	6%	0%	0%	0%

Figure 3. Detailed impact scores view for baseline scenario, method B assessment and Granada demo.



		Energy efficiency	Maintenance & Fault prediction	Comfort	Convenience	Information to occupants	Health, well-being and accessibility	Energy flexibility and storage
Total		75%	58%	84%	71%	75%	74%	71%
Heating	74%	67%	73%	75%	91%	80%	60%	100%
Domestic hot water	0%	0%	0%	0%	0%	0%	0%	0%
Cooling	93%	100%	100%	100%	91%	100%	60%	100%
Ventilation	0%	0%	0%	0%	0%	0%	0%	0%
Lighting	64%	83%	0%	60%	60%	33%	0%	0%
Dynamic building envelope	0%	0%	0%	0%	0%	0%	0%	0%
Electricity	100%	100%	0%	0%	100%	0%	100%	100%
Electric vehicle	0%	0%	0%	0%	0%	0%	0%	0%
Monitoring and control	58%	75%	44%	100%	59%	50%	55%	56%

Figure 4. Detailed impact scores view for foreseen future scenario, method B assessment and Granada demo.

Table 9. Comparison of SRI values evaluated with method A and B for the Granada demo.

	Baseline scenario	Future scenario
Method A SRI assessment	7%, class G	92%, class A
Method B SRI assessment	12%, class G	72%, class C

3.5.3 Riga

In Table 10 the baseline scenario levels and the future scenario ones for each SRSs included in the method B assessment and considered as applicable at the demo site are reported.

Table 10. Baseline and future SRSs levels for Riga demo.

Domain	SRS	Baseline SRS level	Future SRS level
Heating	Heat emission control	Individual room control (e.g. thermostatic valves, or electronic controller)	Individual room control with communication and occupancy detection
	Control of distribution fluid temperature (supply or return air flow or water flow) - Similar function can be applied to the control of direct electric heating networks	Outside temperature compensated control	Demand based control
	Control of distribution pumps in networks	Variable speed pump control (pump unit (internal) estimations)	
	Heat generator control (all except heat pumps)	Variable temperature control depending on outdoor temperature	Variable temperature control depending on the load (e.g. depending on supply water temperature set point)

	Report information regarding heating system performance	None	Central or remote reporting of performance evaluation including forecasting and/or benchmarking
	Flexibility and grid interaction	Scheduled operation of heating system	Optimized control of heating system based on local predictions and grid signals (e.g. through model predictive control)
DHW	Report information regarding domestic hot water performance	None	Performance evaluation including forecasting and/or benchmarking
Cooling	Cooling emission control	Individual room control	Individual room control with communication and occupancy detection
	Interlock: avoiding simultaneous heating and cooling in the same room	No interlock	Total interlock (control system ensures no simultaneous heating and cooling can take place)
	Generator control for cooling	On/Off-control of cooling production	Variable control of cooling production capacity depending on the load AND external signals from grid
	Report information regarding cooling system performance	None	Central or remote reporting of performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection
	Flexibility and grid interaction	No automatic control	Optimized control of cooling system based on local predictions and grid signals (e.g. through model predictive control)

Ventilation	Supply air flow control at the room level	No ventilation system or manual control	Central Demand Control based on air quality sensors (CO2, VOC, humidity, ...)
	Air flow or pressure control at the air handler level	On off time control: Continuously supplies of air flow for a maximum load of all rooms during nominal occupancy time	Automatic flow or pressure control without pressure reset: Load dependent supplies of air flow for the demand of all connected rooms.
	Heat recovery control: prevention of overheating	Modulate or bypass heat recovery based on sensors in air exhaust	
	Supply air temperature control at the air handling unit level	Constant setpoint: A control loop enables to control the supply air temperature, the setpoint is constant and can only be modified by a manual action	Variable set point with load dependent compensation. A control loop enables to control the supply air temperature. The setpoint is defined as a function of the loads in the room
	Reporting information regarding IAQ	None	Real time monitoring & historical information of IAQ available to occupants + warning on maintenance needs or occupant actions (e.g. window opening)
Lighting	Occupancy control for indoor lighting	Manual on/off switch	Automatic detection (manual on / dimmed or auto off)

	Control artificial lighting power based on daylight levels	Manual (central)	Automatic dimming including scene-based light control (during time intervals, dynamic and adapted lighting scenes are set, for example, in terms of illuminance level, different correlated color temperature (CCT) and the possibility to change the light distribution within the space according to e. g. design, human needs, visual tasks)
Dynamic building envelope	Window solar shading control	Motorized operation with manual control	Combined light/blind/HVAC control
	Window open/closed control, combined with HVAC system	Manual operation or only fixed windows	Level 2 + Centralized coordination of operable windows, e.g. to control free natural night cooling
	Reporting information regarding performance of dynamic building envelope systems	No reporting	Position of each product, fault detection, predictive maintenance, real-time & historical sensor data (wind, lux, temperature...)
Electricity	Reporting information regarding local electricity generation	None	Performance evaluation including forecasting and/or benchmarking

	Storage of (locally generated) electricity	None	On site storage of energy (e.g. electric battery or thermal storage) with controller optimizing the use of locally generated electricity and possibility to feed back into the grid
	Optimizing self-consumption of locally generated electricity	None	Automated management of local electricity consumption based on current and predicted energy needs and renewable energy availability
	Support of (micro)grid operation modes	None	Automated management of (building-level) electricity consumption and supply, with potential to continue limited off-grid operation (island mode)
	Reporting information regarding energy storage	None	Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection
	Reporting information regarding electricity consumption	None	real-time feedback or benchmarking on appliance level
Electric vehicle charging	EV Charging Capacity	not present	>50% of parking spaces has recharging point

	EV Charging Grid balancing	Not present (uncontrolled charging)	1-way controlled charging (e.g. including desired departure time and grid signals for optimization)
	EV charging information and connectivity	No information available	Reporting information on EV charging status to occupant
Monitoring and control	Run time management of HVAC systems	Runtime setting of heating and cooling plants following a predefined time schedule	Heating and cooling plant on/off control based on predictive control or grid signals
	Detecting faults of technical building systems and providing support to the diagnosis of these faults	No central indication of detected faults and alarms	With central indication of detected faults and alarms for all relevant TBS
	Occupancy detection: connected services	None	Centralized occupant detection which feeds into several TBS such as lighting and heating
	Central reporting of TBS performance and energy use	None	Central or remote reporting of real-time energy use per energy carrier, combining TBS of all main domains in one interface

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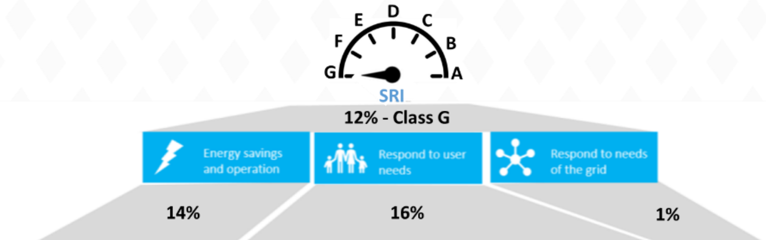
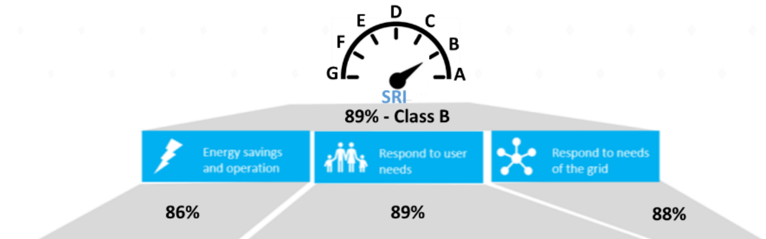
	Reporting information regarding demand side management performance and operation	None	Reporting information on current, historical and predicted DSM status, including managed energy flows
	Override of DSM control	No DSM control	Scheduled override of DSM control and reactivation with optimized control
	Single platform that allows automated control & coordination between TBS + optimization of energy flow based on occupancy, weather and grid signals	None	Single platform that allows automated control & coordination between TBS + optimization of energy flow based on occupancy, weather and grid signals

The SRI values obtained for the baseline and the future scenario applying the method B are respectively 12% (class G) and 89% (class B). Moreover, in the impact scores for each impact criteria and each domain are reported for the baseline scenario calculation and the same for the foreseen future scenario is in. Finally, in the comparison between the assessment developed using the method A and B is reported. The difference obtained applying the two methods between the baseline values are due to the different number of SRSs included in the assessment, in addition to some few changes in the SRSs levels caused by the deeper knowledge of the systems acquired in the first months of the project.



		Energy efficiency	Maintenance & Fault prediction	Comfort	Convenience	Information to occupants	Health, well-being and accessibility	Energy flexibility and storage
Total		**27%**	**0%**	**27%**	**13%**	**0%**	**23%**	**1%**
Heating	**21%**	41%	0%	50%	50%	67%	0%	0%
Domestic hot water	**0%**	0%	0%	0%	0%	0%	0%	0%
Cooling	**10%**	7%	0%	14%	29%	67%	0%	0%
Ventilation	**16%**	27%	0%	29%	33%	13%	0%	0%
Lighting	**0%**	0%	0%	0%	0%	0%	0%	0%
Dynamic building envelope	**10%**	20%	0%	20%	17%	0%	0%	0%
Electricity	**0%**	0%	0%	0%	0%	0%	0%	0%
Electric vehicle	**0%**	0%	-50%	0%	0%	0%	0%	0%
Monitoring and control	**9%**	13%	11%	33%	6%	0%	0%	0%

Figure 5. Detailed impact scores view for baseline scenario, method B assessment and Riga demo.



		Energy efficiency	Maintenance & Fault prediction	Comfort	Convenience	Information to occupants	Health, well-being and accessibility	Energy flexibility and storage
Total		**94%**	**79%**	**92%**	**88%**	**94%**	**82%**	**88%**
Heating	**91%**	100%	100%	100%	88%	100%	50%	100%
Domestic hot water	**67%**	100%	0%	0%	0%	0%	50%	100%
Cooling	**96%**	100%	89%	100%	100%	100%	100%	100%
Ventilation	**90%**	82%	0%	86%	83%	88%	100%	100%
Lighting	**100%**	100%	0%	100%	100%	100%	0%	0%
Dynamic building envelope	**82%**	80%	0%	60%	83%	50%	100%	100%
Electricity	**87%**	80%	100%	0%	80%	0%	67%	100%
Electric vehicle	**44%**	0%	25%	0%	100%	0%	0%	67%
Monitoring and control	**81%**	88%	67%	100%	88%	75%	91%	89%

Figure 6. Detailed impact scores view for foreseen future scenario, method B assessment and Riga demo.

Table 11. Comparison of SRI values evaluated with method A and B for the Riga demo.

	Baseline scenario	Future scenario
Method A SRI assessment	15%, class G	93%, class A
Method B SRI assessment	12%, class G	89%, class B

3.6 Conclusion

Buildings, neighborhoods, and landscapes are often thought of as being historic solely because they are old. Does that mean that all old places should be protected and preserved? The decision to protect historic places rests in the meaning they bring to our lives as places that define and mark our history. When we refer to Historical Building we mean Cultural Heritage buildings, protected or not. We mean buildings that are Heritage by its own or buildings that are included or part of any broader Heritage Asset, say for example an urban or rural Cultural Landscape. We mean all those buildings in which interventions can affect any Cultural Heritage they are related to.

Studying the appliance of innovative products or tools is always hard when focusing Cultural Heritage sites or assets. UNESCO defines Tangible Heritage *as those heritage which are considered worthy of preservation for the future; including buildings and historic places, monuments, artifacts, etc. These include objects significant to the archaeology, architecture, science or technology of a specific culture*[9]. Historical Buildings include therefore on its own definition the need of passing the existing good to next generations, so interventions will always be questionable.

It is impossible to study and define the criteria that defines the interventions that can (or cannot) be made in each of the mentioned "types" of Historic Buildings, but limitations to the improvement of the SRI are rather low or inexistent as they don't affect **structure of the building, external façade colour or texture, external façade shape, internal area of the building, etc.** Usually, in any case, the protection grades' restrictions are not as detailed as those that have been shown. Regardless of the origin of the protection (UNESCO, National authority or local government) it is not very usual to find a protection grade that limits SRI improvement of buildings as protection grades normally state generic restrictions (such as full protection, structural protection, façade protection), but not for digitalization techniques.

So that, the significant aspect when studying the applicability of the solutions developed in SMARTeeSTORY is that, in general terms, the technologies included in the project approach don't affect the "protection grade" of the building, not matter if this protection comes from UNESCO or a local authority. And, in most cases to understand if the solution is applicable as the legislation

[9] http://www.unesco.org/new/en/cairo/culture/tangible-cultural-heritage/

should be followed in any case, a specific case to case study would be advisable to assure the heritage preservation.

Therefore, the requirements for digitalization and adaptation of historic buildings to current energy efficient needs would be all those requirements common to regular buildings besides façade renovation and RES installation, namely non-intrusive energy optimization via cost-effective digitalization that reduce energy consumption and increase occupant comfort while preserving the Historical Integrity.

In addition to this, accordingly with T1.1.1 description, the SRI value for each demo site has been evaluated again, respect to the one already presented in the proposal phase, using the calculation Method B instead of Method A (i.e., the simplified one). The calculation has been performed after a deeper insight of the foreseen interventions that have been identified as possible downstream technical visits and bilateral meetings with the demo owner and the other partners. For each demo, the SRS that can be implemented have been listed and both baseline and supposed future scenario calculation have been performed obtaining the results reported in Table 12.

Table 12. Summary of SRI assessment with calculation method B

Demo	Baseline Scenario	Future Scenario
Delft	21%, class F	78%, class C
Granada	12%, class G	72%, class C
Riga	12%, class G	89%, class B

4 Users' needs characterization via a participatory approach

The objective of this task is to setup the co-innovation and participatory environment (workshops and interviews) for recruiting and engaging with the essential building user groups (end users, operators, energy manager, facility manager, owners) to capture their needs with regards to: (i) technological enhancement and digitalization of the historical building; (ii) other requirements related to IEQ, comfort and well-being. In addition, these workshops had the objective of explaining the research project, including the data collection process and the ethical implications of the participation. Among the different techniques for end Users eXperience (UX), partner TUD adopted a set of tools deriving from the design thinking methodology while clustering and interacting with user by means of on-line questionnaire and physical workshops. The next section describes in detail the overall methodology and results from the workshops. As explained in the annex on the deviations, because of administrative barriers, the workshop in the demo site of Granada could not be held by the deadline of the deliverable. Therefore, the final section, generically describes results from informal interview with users during the technical visit, but further assessments are required.

Follow-up workshops will also be held during the implementation phase to co-design the final interfaces with the users and introduced users to the new SMARTeeSTORY system.

4.1 Overall methodology

Two workshops with end-users and facility managers were organized respectively on the 11th of October 2023 in Riga and on the 16th of October in Delft. Follow-up interviews were also held consequently to the workshop to engage with the participants that were not present during the workshop. In Delft, the workshop was held in English, since the participants all declared high knowledge of English language, while in Riga all the information and sessions were translated in Latvian by an official translator. Figure 7 shows images from the workshop in Delft and Granada.

The participants of the workshops were all the users of the intervention area., Their participation in the workshops was requested by e-mail or face-to-face on both demo-sites. A total of 13 participants were involved in the interviews and workshop in Riga, while a total of 22 participated to the interview and workshop in Delft. In Delft, three facility managers were interviewed, while in Riga there was only one facility manager responsible for the intervention area.

All participants received an information consent sheet, where information about the project, workshop description and data privacy concerns were reported (attached in Appendix). Each participant was explicitly asked for consent to attend the workshop.

Users' characteristics differ from one demo-site to another, and also within demo-sites. In Riga demo-site, users are mainly involved in administrative tasks for the Municipality and most of them have building technology background. On the other hand, Delft demo-site is occupied by researchers and scientific staff of the faculty of Architecture, most of them with technical backgrounds on building sciences. Facility managers have technical profiles on both demo-sites with many years of experience in both sites.

Figure 7. Images from the workshops held in Riga and Delft: a. discussion on the perceived knowledge on how the current building works in Riga; b. discussion on the user requirements with smart building controls in Riga; c. Explanation by the researchers on the overall research project in Riga; d. interaction part on the level of importance and requirements of users with smart controls in Delft; e. interactive session on how the current building works in Delft.

The workshop was divided in three parts: (i) introduction and information on the overall research project, including voluntary consent for participation to the workshop; (ii) one time survey on overall occupant satisfaction with the current building operation and performance; (iii) interactive and participatory session. The interactive and participatory session was divided in three main parts: (i) "Let's talk about the building" where participants perception and current knowledge on the current performance of the building were evaluated; (ii) "What is a smart office?", where participants perception of smart office buildings and personal definition of smartness were assessed; (iii) user requirements with smart controls and dashboard design. Figure 8 shows the overall program of the workshop. In total, the workshop lasted for a maximum of two hours.

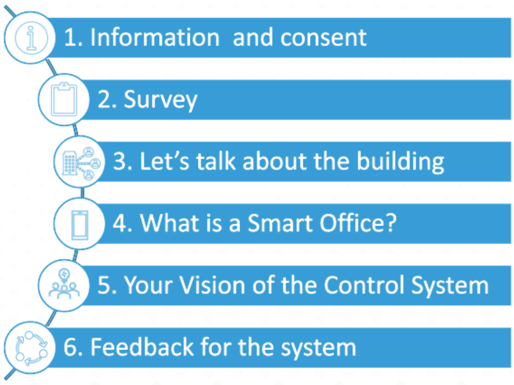


Figure 8. Timeline of the workshops.

The first part of the interactive session aimed at assessing the current understanding and perception of the building operation and performance of the users. For this, participants were divided in groups, depending on the office area, and were asked together to draw a mind map of the building performance and operation. For this, a template was provided to facilitate the discussions among the groups. Figure 9 shows the template for guiding the participants in developing the mind maps. The performances and operations were divided per comfort domain and, ultimately, energy performance.

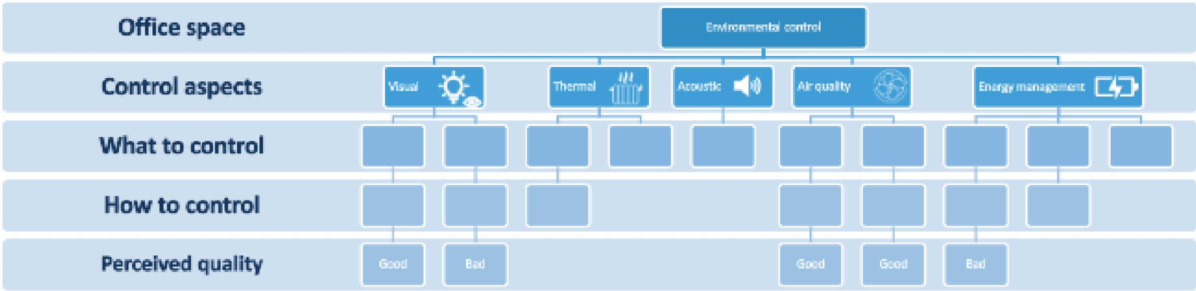


Figure 9. Template for the participants' mind map regarding the current operation and performance of the building. Participants were asked to fill in the information either by writing and drawing directly on the template or via the use of post-it.

The second part of the workshop was focused on the perception of smart building performance, operation and feedback systems for end users and facility managers. For this part, both the use of dynamic real-time and web-based questionnaires were employed to gauge the discussion, Table 13 reports the questions and the format used for the discussion.

Table 13. Questions and point of discussion during the second part of the workshop.

Question	Format	Type of user
What is a smart building for you?	Word cloud map and group discussions	End users and FM
How smart is this office / building? Can you explain why?	Interactive survey and group discussions	End users and FM

The third part of the session focused on the user requirements with smart and automated controls, and feedback or information systems. For this, users were again divided in groups per office area and asked to work together by filling in an importance – necessity chart, as shown in Figure 10. In addition to this part, web-based questionnaires were used to gauge the discussion, Table 14 reports the questions and format employed in this last stage.

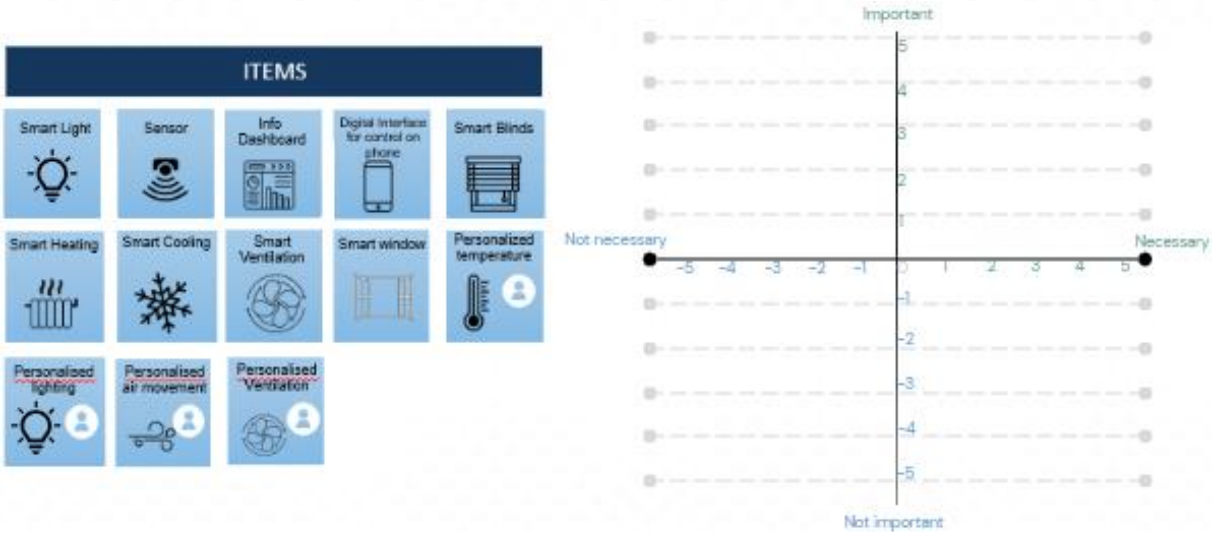


Figure 10 Chart of importance vs necessity on user requirements with smart building. The items on the left were provided as stickers for the end users to easily placed them across the chart.

Table 14. Questions and point of discussion during the third part of the workshop.

Question	Format	Type of user
Where would you like to have access for controlling and regulating the environment?	Interactive survey and group discussion	End users
What would you like to control your office space? and how?	Interactive survey and group discussion	End users
How would you like to give feedback in terms of interface?	Interactive survey and group discussion	End users
How often would you like to give feedback to the system?	Interactive survey and group discussion	End users
How satisfied are you with the level of convenience of the building? Including ease-to-use, performance and other aspects.	Interactive survey and group discussion	Facility managers
How satisfied are you with the level / format of information you receive from the building?	Interactive survey and group discussion	Facility managers

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Finally, facility managers were also interviewed on the question reported in Table 15.

Table 15. Questions asked to the facility managers to assess main barriers and requirements for the implementation of smarter systems and controls in buildings.

Question	Format
What the main barriers currently exist to achieve the desired level of smartness?	Interview
To overcome these barriers, what results are most important from SMARTeeSTORY?	Interview
To what extent, user behavior in building can be allowed in a smart buildings? What role do you envision for the end user?	Interview

4.2 User perception of building performance and operation

This section reports the results from the first part of the workshop, where end-users were asked to describe their building through mind maps. During the workshop, participants were split into groups, depending on their office area and each collaboratively constructed a mind map (Figure 11). Each mind map described building services and their operational methods, along with the perceived quality, described as "good" or "bad." A summary table was generated, combining information from both mind maps for each demonstration site, as reported in Table 16 and Table 17.

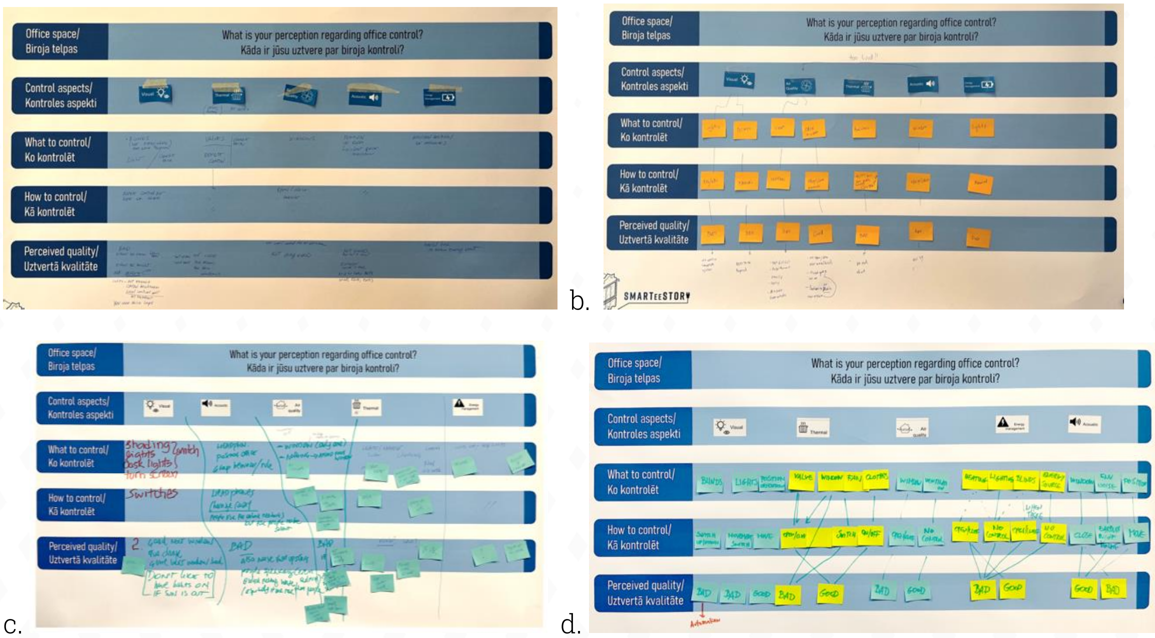

Figure 11. Images of the mind maps developed in Riga and Delft: (a. b.) Mind maps from two groups of participants in Riga with 6 people each. (c. d). Images of mind maps from Delft carried out by two groups of people (4 and 2 respectively). Participants were grouped according to their location in the building, so participants in similar building zones build the map up together.

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Table 16. Summary of the occupant perception of the building operation in Riga.

Control aspect	What to control	How to control	Perceived quality	Reason
Visual	Lights	Manual. On / Off	Bad	Smarter system needed for switching them on or off, or change intensity.
Visual	Blinds	Manual	Bad	Need to be repaired in several windows, insufficient to control overheating or glare.
Air quality	Ventilation	Automated. No override allowed.	Bad	Smelly / Noisy often. No personal control allowed.
Air quality	Window opening	Manual. Open / Close	Good	It's not good but ok. Several times noise is a problem.
Thermal	Radiator	Automated and personal control allowed through valves	Bad	No real effect. In small offices, users feel cold often.
Thermal	Cooling	Manual	Bad	Locally distributed, few areas with thermal differences that are too strong.
Acoustic	Windows	Manual. Open / Close	Bad	Noisy
Acoustic	HVAC	Automated, no personal control allowed except for cooling units in open space.	Bad	Noisy, especially cooling unit in open space.
Position in the room	Personal location	Free movement in open space	Good	To avoid uncomfortable thermal or acoustic conditions
Energy management	Lights	Manual	Bad	No automatic control, difficult to remember. Dimming is not an option.

Overall, end users in Riga demonstrated a comprehensive understanding of their office environment, identifying various issues significantly impacting their experience within the workspace. Table 17 reports information on the overall perception of available environmental control aspects in Riga. While windows opening was deemed the most positively rated system for occupants to interact with, occupants were still dissatisfied with them. The key issues highlighted encompassed deficiencies in the smartness of automated control systems, in terms of lack of local control and responsiveness to actual user needs. Instances of malfunction, unpleasant odors, and excessive noise, notably concerning ventilation and windows, were reported. Participants expressed skepticism about the tangible effects when the HVAC systems were utilized.

Table 17. Summary of the occupant perception of the building operation in Delft.

Control aspects	What to control	How to control	Perceived quality	Reason
Visual	Blinds	Automated with manual control through switches for up / down	Bad	Automation is not logic, often not following weather and very different from user expectations. Blinds are too dark when down, the space either is too bright or too dark.
Visual	Lights	First floor: manual control for switching on, automated turned off by movement. Second floor: automated by movement.	Bad	Do not like to have lights on even if sun is out, or very annoying lights turn off if you don't move even if you are in the space. In addition, very annoying there is no personal control on II floor.
Visual	Position on office	Move desk location	Good	
Visual	Desk lamps	Manual On / Off	Good / Bad	Personal offices are perceived to have bad task lighting, because of wrong intensity and difficulty for controlling the space.
Thermal	Radiator Valve	Automated temperature. Manual control of valves. Open / close	Good	Few users admit to be using them. Only the one in their proximity.
Thermal	Window opening	Manual. Open / close	Bad	Window cannot fully open, few broken. Very difficult to open them.
Thermal	ClimaRad	Manual Switch	Bad	Several users not aware of the unit or never managed to make it work. No feedback on functioning.
Thermal	Clothes	NA. On / Off	Good	Personal control of clothing very important in the space. Overheating is a problem at the upper floor, while generally people feel cold in winter.
Thermal	Blinds	Automated with Manual Switch up / down	Bad	For same reason of visual comfort. Only few users admitted to use the blinds for adjusting their thermal comfort.

Thermal	Ventilation unit	Automated	Bad	No personal control, sometimes drafts are noticeable.
Air quality	Window	Manual. Open / close	Bad	See Window thermal perception.
Air quality	Ventilation	Automated. No Personal control	Good	Stuffy perception sometimes. Odors especially in single offices.
Air quality	Air exchanger	Manual control unit	Bad	See above for thermal
Energy management	Heating	Semi-automated. Valves to open / close	Good	Only few people admitted to have active control of them.
Energy management	Lighting	Semi-automated first floor, fully automated second floor.	Bad	Especially important for task lights but currently missing
Energy management	Blinds	Semi-automated. Switches for open / close	Bad	Often not appropriate
Energy management	Appliances	No control	Bad	
Acoustic	Window	Close	Good	There is not much noise outside.
Acoustic	Environmental noise	Changing location or using earplugs	Good	People speaking is a problem in open space.
Acoustic	Group behavior	Turning down speaking	Bad	Noise from upstairs or corridor and people talking

Table 17 presents a summary of the mind maps developed in Delft. Few users were not aware of the systems for ventilation called “Climarad” in the space, or if aware, they reported dissatisfaction with their use because of absence in feedback and information from the system. Only very few users were aware of the central mechanical ventilation system. Fully automated components where personal control is not allowed (e.g., lights on upper floor) were rated poorly since it is difficult to tailored them to occupant needs. The automated control of the shading devices was the automated components with the most frequent and poorly rated performance, since almost all the end users reported strong dissatisfaction with the convenience of the automated control. This automated control was also the one most frequently used to express the lack of smartness of the building. The acoustic environmental domain received the most favorable evaluation, attributed to the effectiveness of utilized building elements such as position in the office, window openings and earbuds (personal devices), however people speaking is a main problem in open space offices, especially when colleagues do online meetings. Overall, environmental aspects under occupants' direct control—such as office positioning, desk lamps, radiator valves, window operation, and clothing level—were positively rated ('good'). However, automation systems faced challenges due to occupants' limited understanding of control logic (e.g., blinds and lighting), instances of malfunction (e.g., window openings and air exchangers), or causing disruption to occupants (e.g., fans and group behavior). These factors contributed to a less favorable perception of automated systems among the occupants.

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4.3 User expectations with smart building

4.3.1 End users

End-users were asked about their personal definition of smart buildings via Mentimeter, Figure 12 shows the word cloud elaborated on the bases of their responses. Overall, there was a general understanding of a smart building as a building characterized by automated controls, measurement devices for environmental or energy monitoring, and efficient performance towards energy and comfort. In particular, in Riga several users mentioned personal and microclimate to indicate the capability of a smart building to adapt and meet user requirements in terms of personalized comfort. In Delft, where the users have a stronger technical background on the topic, participants mentioned also "digitalization" to refer to the overall capability of a smart building to collect and store data, but also concept such "robustness", adaptive and "responsive" to describe the capability of a smart building to adapt to changing outdoor and indoor conditions.

In Delft, few of the users mentioned for them a smart building should be able to guess and predict their requirements with minimal impact, while few others mentioned that a smart building should instead being able of detecting when the occupant is inside the building and never try to substitute the end user in the decision making of the control of the space, but rather act as an "*advisor*" able to preserve the personal control and agency.

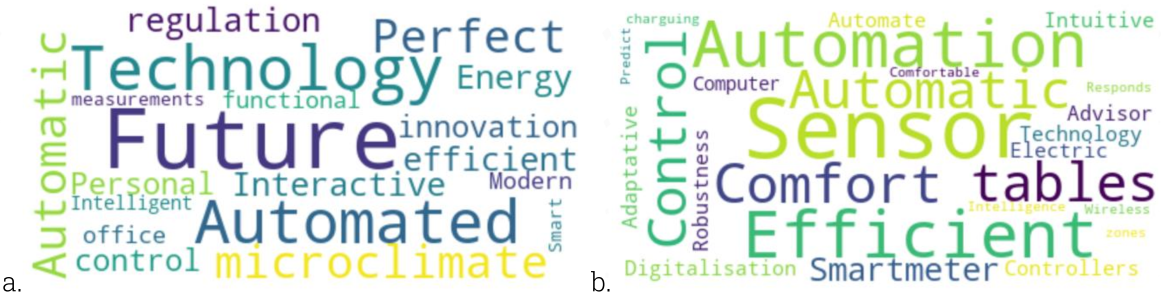

Figure 12. a. Word Cloud map from the end user's description of what are the characteristics of a smart building: a. Riga end-users; b. Delft end-users.

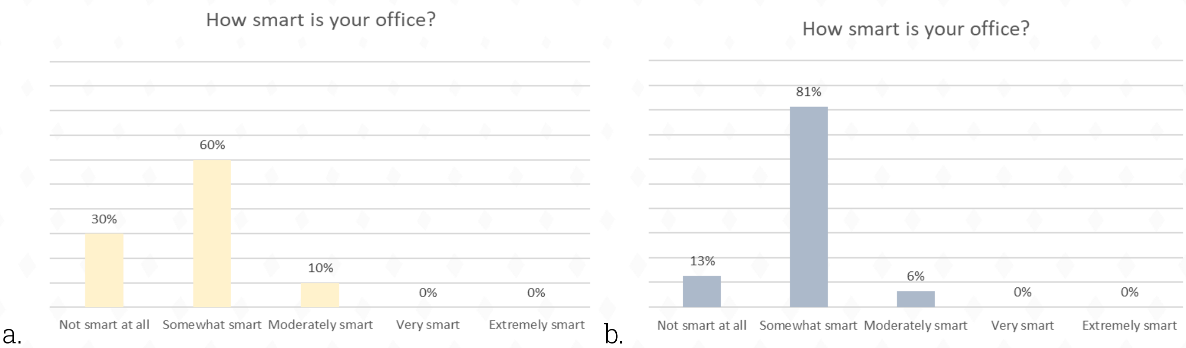

Figure 13. End-users' perception of current smartness of the demo site building: a. Riga, b. Delft

In terms of perceived smartness of the building, on the base of their own personal definition of smartness, the two demo sites showed similar results. In Riga, commencing with the lower end, it's notable that 30% of respondents believe their office is "Not smart at all." Moving up the scale, a significant majority, constituting 60%, view their office as "Somewhat smart." A smaller but noteworthy proportion, 10%, consider their office to be "Moderately smart." Interestingly, none of the respondents characterized their office as "Very smart" or "Extremely smart." In Delft, the majority of respondents (81%) perceive their office as "Somewhat smart," while a smaller percentage feel it is "Not smart at all" (13%) or "Moderately smart" (6%). Nobody voted for the options "Very smart" or "Extremely smart." The end users that perceived some level of smartness in the building in Delft referred to the building capacity of turning on or off lights depending on occupancy.

4.3.2 Facility managers

The facility managers of both demo sites participated to the workshops and were interviewed on their perception of the current performance of the building.

First, the facility managers were asked on their current perception of the level of smartness of the system. In Riga, the facility managers highlighted the importance for smart buildings of providing **local and granular control** of the building. This would include both the monitoring and capability of controlling building actuators and components in a granular manner to provide personalized and tailored control actions, and therefore environmental conditions. The possibility of **remote control and data information retrieving** was also highlighted, in order to avoid the current time-consuming process of fault detection. **Prediction and optimization** were also named as crucial performances of smart buildings. For instance, the possibility of controlling the temperature on the base of external outdoor temperature or electricity market prices. This would be especially important once the electric vehicle charging will be available, and it could then be optimized to respond to the grid requirements. In terms of perceived smartness of the current BMS, the FM indicated poor score (1 out of 5) since the current system lacks remote warnings and a control, including presence of a digital model. Malfunctions are primarily attributed to energy efficiency issues, particularly due to a large, glazed façade causing heat losses in winter and overheating in summer, along with significant thermal differences between floors and across the same open space office on the top floor, which is currently hindering HVAC performance. This also stresses the importance for the Riga demo site of a local and tailored control strategy that can provide adapt energy services to actual needs. The facility manager also reported other issues related to the outdated BMS, such as limited BMS application, challenging time schedules, and the need for better technical expertise if implementing advanced technologies.

In terms of users override and personal control, the facility managers did not see any potential drawback, but reported that automation should be preferable, and it should offer support to users in order to free them from energy or environmental management tasks.

About the main barriers for achieving a higher level of smartness, in Riga it was highlighted that budget and **economic investments** are certainly a barrier but also the **lack of technical expertise** available for implementing smart building controls. Consequently, **scalable and easy to replicate** solutions were highlighted as paramount for the success of SMARTeeSTORY and its replication across the country. It was envisioned that to solve the current lack of smart controls in buildings, the methodology and system proposed should be easy to implement without the need for high technical expertise.

In Delft, the facility managers defined smart buildings as a building that can **predict and optimize**, **learning from the data** collected, leveraging on artificial intelligence to anticipate needs and requirements. In addition, local and granular control was also reported as a main feature of a smart building, as well as **integrated control** of different building components and services, seen as a crucial factor for energy and environmental performance. In Delft, both facility managers defined the current BMS as moderately smart (3 out 5 in a Likert scale), since several control strategies are already present. When evaluating the smartness of the heating system, for instance, they reported to find the system already moderately smart since it is already currently responding to the outdoor temperature signals thanks to the weather station and the central forecast system.

The facility managers reported the current BMS as a system easy to use, however only once a specialized course is taken by the users to learn how to implement changes. It is also worth mentioning that this referred to the principal BMS system, which regulates the heating and the ventilation, while other systems have currently a separate control system that is only managed by specific subcontractors. The ease of use was also mainly reported because the system in its current form is very basic and simple, but when additional functions will be available this may be a barrier for useability. If a specialized course is required, any new smart system would have a limited applicability and scalability. The facility managers indicated the importance of systems that are **intuitive and easy to use**.

Currently, the facility managers were sufficiently satisfied with the overall information received on malfunctions and overall performance, however they also indicated that information on local conditions and performances is not available. Information on local end user behavior and actuators performances was indicated as useful information to have to assess the impact on the energy performance.

An important aspect highlighted by the facility managers was the interface for retrieving and managing the BMS, which is currently relying on a web-based application only accessible from the laptop. While the possibility of having remote access via mobile phone was ranked quite importantly, since facility managers often work outside the office and have to inspection several buildings during the day. Therefore, mobile friendly interfaces are important.

In terms of the current barriers for the implementation of smart services, economic investment and available budget was not considered as a barrier, since in Netherlands funding are currently available for accelerating the energy transition. However, the **lack of information and evidence on what smart services** can effectively improve the building performance without bringing unnecessary complexity and problems was named as the main barrier. In this sense, data and evidence on the reliability and actual performance of the smart services or systems needs to be proved to be implemented.

Despite recent advances in the field, the facility managers also claimed the need for more **evidence and practical applications** of AI-enhanced smart systems, which could support a large adoption of advanced control systems. In particular, lack of specialized expertise in this field, **cybersecurity and privacy** were listed among the main concerns, especially the possibility of hackers to enter in the buildings and access confidential data being TU Delft a knowledge institution. If these barriers were solved, the scalability of the SMARTeeSTORY system would not be a problem as far as the main contractors that are in the management of the buildings are involved.

In terms of information, recommendations to users and managers on how to consume less energy was indicated as important. Personal control and allowing user to override by users is mentioned to not be a problem for the operation of the BMS, while **larger engagement and awareness** of users. Overall, it was often mentioned that smart regulation of occupied spaces depending on user personal preference is a smart action that should be implemented.

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Figure 14. Word cloud representing the main concepts and words mentioned by the facility managers with respect of their expectations of a smart building.

4.4 User expectations and requirements with smart buildings

4.4.1 Control and information requirements

Convenience, control, feedback and information interfaces or modes of interaction were also explored in the workshops. Figure 15 shows the answers from the interactive survey. In Riga, a unanimous 100% of respondents expressed a preference for having access on their phones to control and regulate their environment, rather than on dashboards on walls or web-based desktop apps (Figure 15.a). No respondents selected options such as having control on the wall, on the computer, or expressed a lack of need or importance regarding control access. In the context of having personal control on the building, a unanimous consensus emerges among respondents. Each participant expresses a keen interest in assuming control over critical aspects, including lighting (100%), heating (100%), and cooling (100%), shown in Figure 15.b. The visual quality is deemed very important with 89% of participants requiring control over blinds and shadings. Similarly, users reported strong importance of personal control over the ventilation system. Window operation was also mentioned by the 67% of the participants.

In Delft, most respondents (47%) prefer to have access to controls for regulating their environment in a location away from their desk, such as on the wall by means of informative dashboard (Figure 15.c). It is worth mentioning that office spaces in Delft are relatively smaller than in Riga. A smaller percentage find it important and convenient to have access on their phone (18%), while nobody indicated a preference for accessing controls on their computer. Some respondents either do not feel the need for such controls (6%) or find it not important to them (29%). It appears that respondents have diverse preferences when it comes to controlling elements in their office space. The options with the highest percentages of votes are "Blinds/Shading" (55%), "Heating" (45%), "Ventilation" (45%), and "Window's opening" (45%). "Lighting" also received a significant portion of the votes at 40%. "Cooling" is selected by 25% of the respondents (Figure 15.d).

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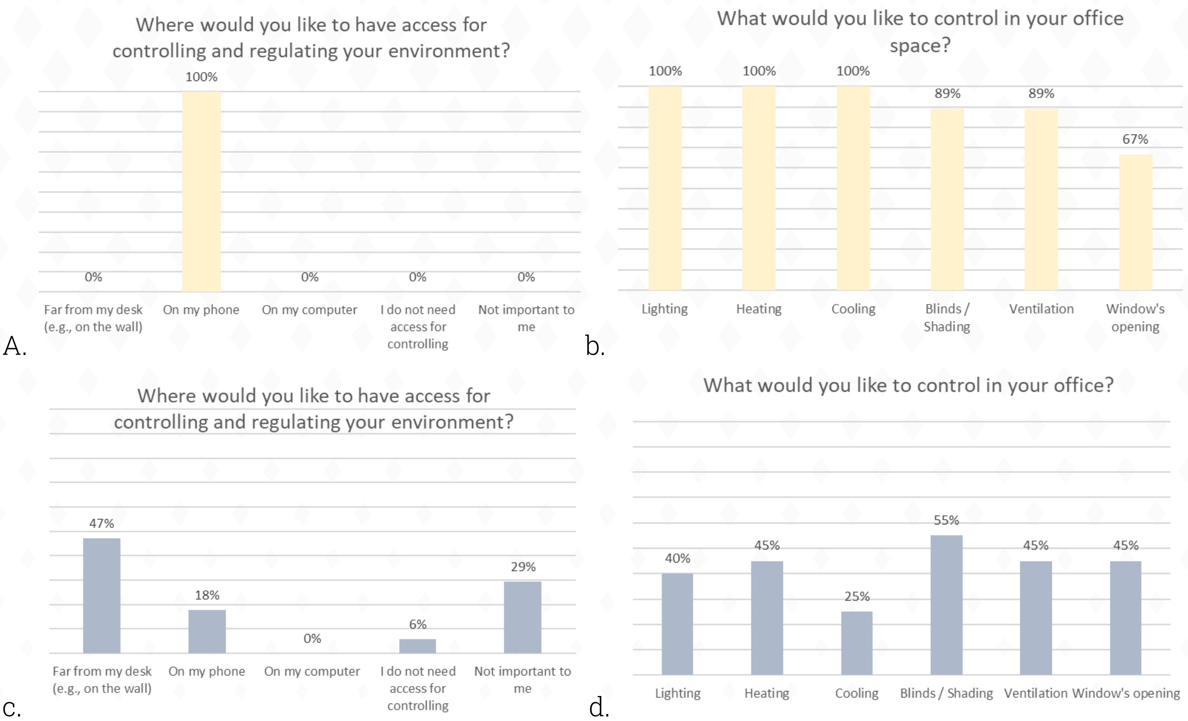

Figure 15a. Riga participants' preferences for location and type of interface for personal control, b. Riga participants' importance with the environmental domain of personal control; c. Delft participants' preferences for location and type of interface for personal control; d. Delft participants' importance with the environmental domain of personal control

4.4.2 Feedback system

In Riga, when it comes to providing feedback, the majority of respondents (83%) expressed a strong preference for the digital and efficient methods, such the use of QR codes and phones (see Figure 16.a). A smaller but notable proportion, constituting 8%, indicates a preference for utilizing a polling station for feedback. Likewise, another 8% of participants preferred the more traditional route of email and computer for providing their insights. Interestingly, no respondents opted for the conventional physical paper-based forms, highlighting a clear inclination towards digital channels for feedback mechanisms. When it comes to giving feedback for the control system, preferences among respondents vary (see Figure 16.b). A substantial 40% are up for providing feedback sometimes, indicating a more occasional approach. Another 40% are keen on giving feedback very often, suggesting a desire for regular communication. Meanwhile, 20% prefer an always-on feedback mode. Interestingly, nobody leans towards giving feedback rarely or never.

In Delft, the majority of respondents (71%) prefers to give feedback using QR codes and their phones, indicating a preference for a digital and mobile-friendly approach (see Figure 16.c). A smaller percentage preferred using a polling station (14%) or email and computer (14%). Nobody indicated a preference for providing feedback through physical forms, as well as in Riga. The majority of respondents (44%) prefer to give feedback sometimes, indicating that they are open to providing input on the control system periodically. A significant portion also chose to give feedback rarely (31%). There are smaller percentages of respondents who prefer to give feedback very often (13%) or never (6%), while another 6% indicated a preference for giving feedback always.

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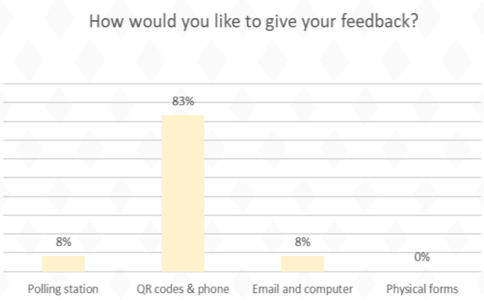
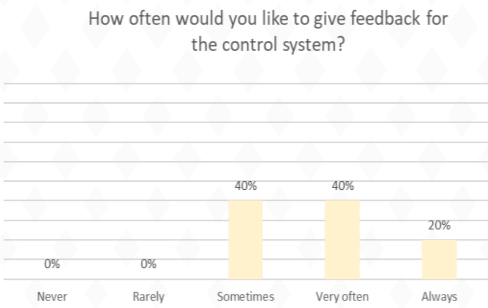


a.



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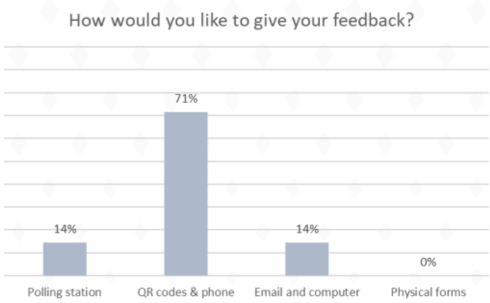

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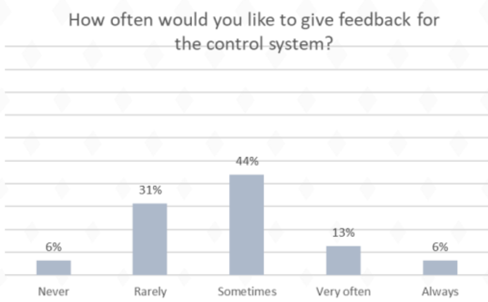
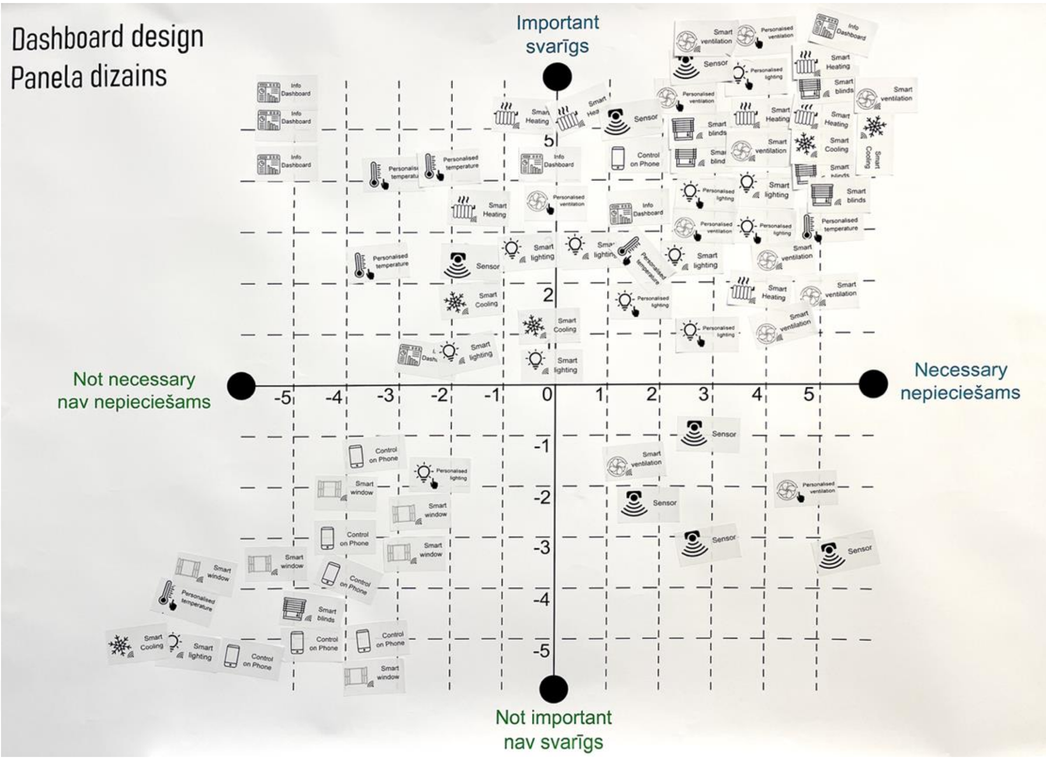


d.

Figure 16 a. Riga participants expression of preferences in terms of interfaces for feedback, b. Riga participants expression of preferences in terms of frequency of feedback; c. Delft participants' expression of preferences for feedback interfaces; d. Delft participants expression of preferences for frequency of feedback.

4.4.3 Importance vs necessity of smart buildings functionality



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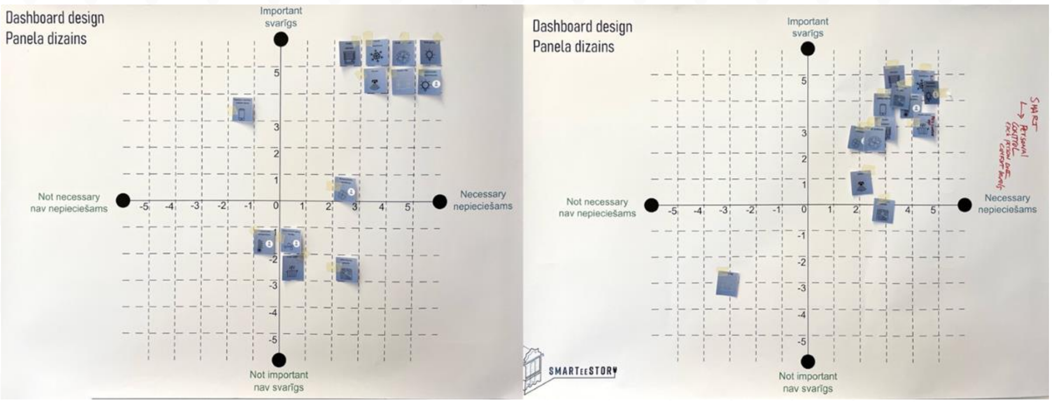
b. 

Figure 17. Results of the importance vs necessity smart building functionality activity. a. Image of the cartesian scale fill in with smart building items for Delft. b. Picture of 2 cartesian scales that were filled with smart building items in Riga.

In both Riga and Delft, participants were asked to discuss the necessity and importance levels of various building items, including smart heating, lighting, windows, cooling, ventilation, personalized lights, temperature, and ventilation, as well as dashboards, information, and sensors. Within the workshop activity, 'necessity' describes indispensable factors that are crucial for users' satisfaction in the building, while 'importance level' refers to the personal significance of these factors within the office context, which however does not compromise users' productivity in the office. Figure 17 illustrates the outcomes of this activity conducted on paper. In Riga, the exercise was conducted among two separate groups, as well as in Delft, where all participants placed stickers representing building items on a unified Cartesian scale depending on the type of space.

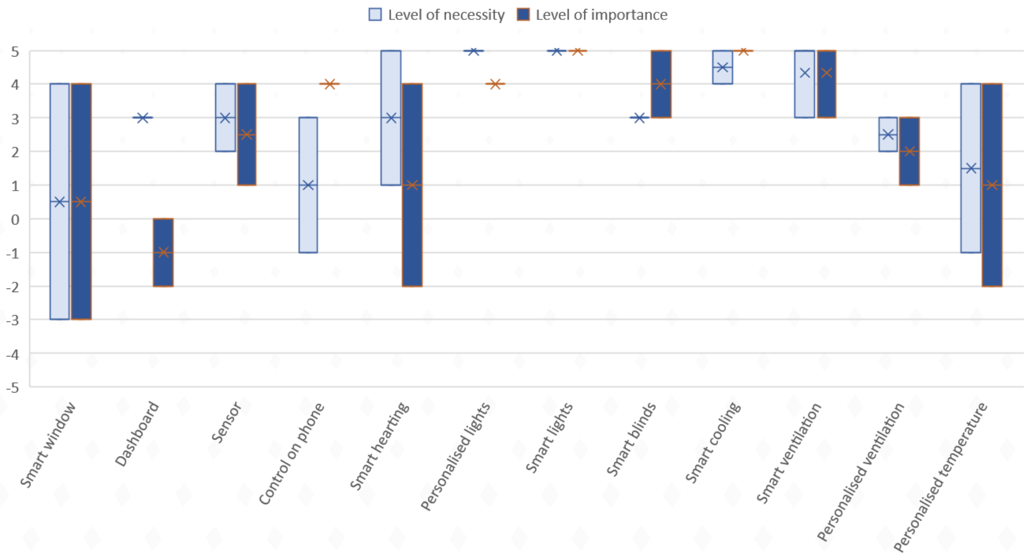


Figure 18. Distribution of necessity and level of importance for each of smart building items asked for during the workshop activity in Riga demonstrator site.

Figure 18 shows the results from the workshop participants in Riga, which highlighted the significance of various elements within their workspace, emphasizing the necessity of information dashboards, sensors, smart heaters, lights, blinds, cooling systems, personalized lighting, and ventilation. In particular, the elements considered necessary align closely with those considered important for an optimal office environment—such as sensors for local control, personal and smart lighting, blinds, cooling systems, and personalized ventilation. These findings suggest that visual, thermal, and air quality domains hold critical importance within their workspace, so better user control accessibility and reliability are required. Moreover, insights from sensors and effective environmental control emerged as key priorities. The perceptions regarding smart windows and personalized temperatures exhibited a wide spectrum, reflecting diverse user requirement profiles. This information is useful to understand which domain are required to be priorities when it comes to the digitalization of the environment.

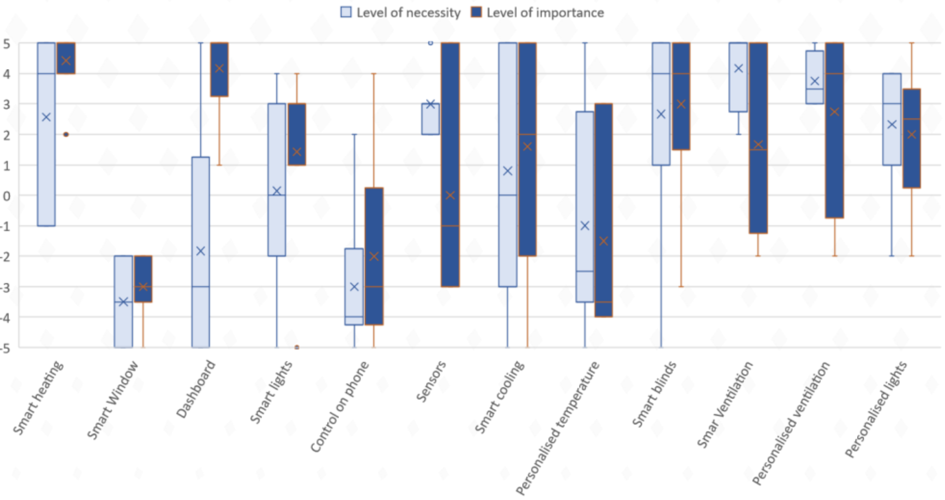


Figure 19. Distribution of necessity and level of importance for each of smart building items asked for during the workshop activity in Delft demonstrator site.

In Delft, participants expressed their perceptions regarding the necessity and importance of various elements defining a smart building (Figure 19). Similarly, to Riga, elements such as sensors, smart blinds, ventilation (both smart and personalized), and personalized lighting were considered necessary in their workspace. This underlines the importance of information gathering at local and granular, effective, and intelligent façade control, as well as personalized options for lighting and air quality.

The most important items for end users where smart heating and dashboards, even if users did not consider it necessary, in particular dashboard were considered important but not necessary. This was therefore differently perceived than in Riga, where users instead expressed these items to be necessary but not important for them. Effectively, Delft end users seemed more eager to gain information on the building given the technical background. Conversely, elements such as smart windows, mobile-controlled systems, and personalized temperature settings were neither considered necessary nor important within their workspace.

4.5 Granada – results from preliminary conversations with users

Initial conversations with users and facility managers in the demo site at Granada have highlighted the following patterns. Ensuring optimal thermal, visual, and acoustic comfort in office spaces is crucial for the well-being and productivity of the occupants. However, challenges have been identified, particularly in managing temperature fluctuations. Overheating during summer and inadequate control and thermal supply from the central heating in winter have led to dissatisfaction among users. The implementation of COVID-19 ventilation measures, such as frequent window opening, has also contributed to thermal discomfort.

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To address these issues, the widespread adoption of local thermal comfort devices has proven to be an effective response for thermal comfort, however this has severe energy impacts. While glare from small windows is generally not a concern, specific areas like "Informatica y Gabinete de prensa" face challenges. Moreover, poor daylight provision in offices with small, side-facing windows necessitates constant artificial lighting use. Unfortunately, the placement of luminaires on the ceiling often results in glare, impacting the overall visual comfort of occupants. Noise is another factor affecting the workspace ambiance, especially when windows are open and face a busy road. The acoustic insulation of windows facing the main square needs improvement to minimize disruptions.

A lack of understanding on how to control and manage the space efficiently has been observed among users. Simple actions, such as opening windows, are frequently employed instead of utilizing more sophisticated systems that could offer better comfort. The control mechanisms for air conditioning splits, fan coils, and lights vary in their level of user acceptance and awareness. While air conditioning splits rely on user-controlled remote settings, fan coils are automated but can be overridden. Lighting systems, on the other hand, are manually controlled. The facility manager seeks local monitoring information to streamline tasks and gain insights into the space's performance. There is a desire to move beyond basic on/off controls and implement remote control capabilities, ensuring a more responsive and efficient management of the entire area. Facility managers seeks the promotion of user awareness is a key aspect of enhancing overall comfort. Users should be encouraged to understand the impact of their actions on the workspace. Implementing schedules for system operations can contribute to better energy efficiency and comfort. By fostering a comprehensive understanding of the space and its systems, occupants can actively contribute to creating a more comfortable and efficient work environment.

4.6 Conclusion

The participatory approach for engaging end-users and facility managers in the project and in the process of transitioning the building was overall crucial and deemed successful for gathering further understanding of user needs and requirements. This was particular evident from the interest and participation of people to the sessions. Individual and contextual factors play a key role in user acceptance and satisfaction with smart automated controls; therefore, it was important to understand specific user needs in the demo-site buildings.

The main findings are a multi-domain evaluation of the perceived performance of the building from the user perspective, which highlighted that users in the demo buildings are largely aware of how the building works and how to interact for improving the environmental quality or their satisfaction with the indoor environment. In addition, fully automated systems were confirmed, as shown in the scientific literature, to make users dissatisfied with the controls, while lack of local and personalized control is often also a factor of dissatisfaction, as well as the mismatch between user requirements and automation control targets.

In terms of smart buildings, users in both building associated smart building performance to optimal energy and microclimate control, information was not explicitly mentioned but sensors and prediction were considered key factors in smart buildings. There was instead a discussion on whether smart controls should anticipate user needs, predicting them without causing any disruption, or should rather be activated only when the users are not in the space to optimize resource consumption, limiting smart controls to have an advisory role when space are occupied.

Overall, it was often mentioned that smart regulation of occupied spaces depending on user personal preference is a smart action that should be implemented.

Facility managers envisioned smart buildings as buildings with AI-enhanced controls that can predict and optimize the performance, providing as well local and granular information and control. They all highlighted the importance of scalable and easy to use solutions, which can be deployed with low investment costs but more importantly without the need for high technical expertise. In this sense, it is crucial to gather evidence and data on the correct reliability and functioning of the new services for their widespread adoption. Interestingly, while end users tended to rate low the current level of smartness of the buildings, in Delft facility managers rated medium-high the current level.

In terms of interfaces and convenience, users preferred interfaces on the mobile phone to provide feedback, while they were split in two main groups when it comes to location and interface for personal control, with a few preferring mobile-phone based (especially in Riga) and a few with strong preference on wall-based information dashboard, which could be always accessible regardless of having or not a phone. It is worth mentioning that Delft offices are smaller than in Riga and they are often visited by external users that work at the university in a part-time mode, this may be a factor in preferring dashboards over phone-based controls. End users would not mind provide frequent feedback as far as the system is not disruptive for them and the feedback action fast and not time consuming.

Finally, the level of importance and necessity of smart services was explored with end users. Overall, information on building performance is not considered a necessity and it could be important only for the users in Delft. Ventilation, lighting, and heating were considered key domains (both in terms of importance and necessity) where to apply smart regulation and control, while opening of vents seems less relevant.

5 KPIs to evaluate the impact of interventions and related increased levels of SRS

In this section, the performance indicators and the related equations to assess them are identified. These key performance indicators (KPIs) will be used as an evaluation framework during the demonstration phase with a specific focus on evaluating the impact of the SRI. The SRI describes how the interventions on that increase the level of digitalization can improve the smart readiness level of a building, but it does not indicate to what extent these interventions can impact the economic, environmental, user-related, informatic and energy performance, but it implicitly assumes that better performances would derive from an upgrade of the digital services. Therefore, this section analyses the impacts induced by an increase in SRI level in the context of historic buildings and in terms of economic, energy, user-related and environmental benefits. This framework will then be validated by the monitoring campaign in the pre and post intervention phases in T5.5. A special section of the panel will be dedicated to informatic KPIs, which assess how digitalization can impact not only the operational phase but also during the phase of the design and the deployment of the informatic system.

5.1 Scope and general context

The purpose of the present work is to define the key performance indicators that will be used to measure the performance of the demo sites buildings before and after the introduction of additional Smart Readiness Services (SRSs). These indices are defined with the acronym KPIs (Key Performance Indicators).

These KPIs will enable to quantify and assess the overall economic, environmental, user-related, informatic and energy impact of the introduced SRSs for each demo site.

5.2 Overall methodology

The methodology adopted consists of the following steps:

1) definition of KPIs to evaluate the SRSs impact on:

- Energy performance;

- Environmental performance;

- Economic performance;

- User-related aspects, such as comfort & user satisfaction, convenience, user well-being and health;

- IT system complexity

KPIs can be specific to each technical domain of the SRS, e.g., energy savings from a specific domain, or describe the overall joint performance of all the SRSs on a specific aspect, e.g., user comfort.

2) Mapping of the relationships between the KPIs and each technical domain of the SRS (Table 18 in chapter 5.3.1 Energy and environmental KPIs).

3) Identification of which KPIs are applicable in each demo-site, on the bases of the SRSs that are feasible to be implemented - the indication of which KPIs are applied to each site is shown in the tables Table 18, Table 19, Table 20 and Table 21 in chapter 5.3.

4) Definition of methods for quantifying of each KPI for each demo-site – the methodology for measuring and calculating each defined KPIs is reported in chapter 5.4.

5.3 KPIs panel

5.3.1 Energy and environmental KPIs

In this section of the KPIs panel, the energy and environmental KPIs are reported. These KPIs can vary depending on the demo site and on the technical domains and can be calculated with equations reported in paragraph 5.4.

The following table shows the Demo site-specific KPIs, grouped by technical domain. The three rightmost columns indicate which demo sites the KPIs are applicable to. It is also indicated if the KPIs refer to the baseline scenario, to the future scenario or represent a variation in performance between baseline and future scenario.

Table 18. Demo-site related KPIs

Technical domain	KPI	Abbreviation	Index	Unit	Riga Demo	Delft Demo	Granada Demo
Heating	Useful energy - baseline	UE_B	H 1.1	kWh/year	X	X	X
	Useful energy – future	UE_F	H 1.2	kWh/year	X	X	X
	Useful energy - variation	UE_V	H 1.3	%	X	X	X
	Final energy consumption - baseline	FEC_B	H 2.1	kWh/year	X	X	X
	Final energy consumption – future	FEC_F	H 2.2	kWh/year	X	X	X
	Final energy consumption - variation	FEC_V	H 2.3	%	X	X	X
	Primary energy consumption - baseline	PEC_B	H 3.1	kWh/year	X		X
	Primary energy consumption - future	PEC_F	H 3.2	kWh/year	X		X
	Primary energy consumption - variation	PEC_V	H 3.3	%	X		X
	GHG emissions - baseline	GHG emissions_B	H 4.1	Kg CO2 eq /year	X	X	X
	GHG emissions - future	GHG emissions_F	H 4.2	Kg CO2 eq /year	X	X	X
	GHG emissions – variation	GHG emissions_V	H 4.3	%	X	X	X

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	Fossil fuel consumption - baseline	FFC_B	H 5.1	Sm^3/year		X	
	Fossil fuel consumption – future	FFC_F	H 5.2	Sm^3/year		X	
	Fossil fuel consumption - variation	FFC_V	H 5.3	%		X	
DHW	Useful energy - baseline	UE_B	DHW 1.1	kWh/year	X		
	Useful energy – future	UE_F	DHW 1.2	kWh/year	X		
	Useful energy - variation	UE_V	DHW 1.3	%	X		
	Final energy consumption - baseline	FEC_B	DHW 2.1	kWh/year	X		
	Final energy consumption - future	FEC_F	DHW 2.2	kWh/year	X		
	Final energy consumption - variation	FEC_V	DHW 2.3	%	X		
	Primary energy consumption - baseline	PEC_B	DHW 3.1	kWh/year	X		
	Primary energy consumption - future	PEC_F	DHW 3.2	kWh/year	X		
	Primary energy consumption - variation	PEC_V	DHW 3.3	%	X		
	GHG emissions - baseline	GHG emissions_B	DHW 4.1	Kg CO2 eq /year	X		
	GHG emissions - future	GHG emissions_F	DHW 4.2	Kg CO2 eq /year	X		
	GHG emissions – variation	GHG emissions_V	DHW 4.3	%	X		
Cooling	Useful energy - baseline	UE_B	C 1.1	kWh/year			X
	Useful energy – future	UE_F	C 1.2	kWh/year			X
	Useful energy - variation	UE_V	C 1.3	%			X
	Final energy consumption - baseline	FEC_B	C 2.1	kWh/year	X		X
	Final energy consumption - future	FEC_F	C 2.2	kWh/year	X		X
	Final energy consumption - variation	FEC_V	C 2.3	%	X		X
	Primary energy consumption - baseline	PEC_B	C 3.1	kWh/year	X		X
	Primary energy consumption - future	PEC_F	C 3.2	kWh/year	X		X

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	Primary energy consumption - variation	PEC_V	C 3.3	%	X		X
	GHG emissions - baseline	GHG emissions_B	C 4.1	Kg CO2 eq /year	X		X
	GHG emissions - future	GHG emissions_F	C 4.2	Kg CO2 eq /year	X		X
	GHG emissions – variation	GHG emissions_V	C 4.3	%	X		X
Ventilation	Useful energy - baseline	UE_B	V 1.1	kWh/year	X		
	Useful energy – future	UE_F	V 1.2	kWh/year	X		
	Useful energy - variation	UE_V	V 1.3	%	X		
	Final energy consumption - baseline	FEC_B	V 2.1	kWh/year	X	X	
	Final energy consumption - future	FEC_F	V 2.2	kWh/year	X	X	
	Final energy consumption - variation	FEC_V	V 2.3	%	X	X	
	Primary energy consumption - baseline	PEC_B	V 3.1	kWh/year	X	X	
	Primary energy consumption - future	PEC_F	V 3.2	kWh/year	X	X	
	Primary energy consumption - variation	PEC_V	V 3.3	%	X	X	
	GHG emissions - baseline	GHG emissions_B	V 4.1	Kg CO2 eq /year	X	X	
	GHG emissions - future	GHG emissions_F	V 4.2	Kg CO2 eq /year	X	X	
	GHG emissions – variation	GHG emissions_V	V 4.3	%	X	X	
	Indoor relative humidity - baseline	RH_B	V 5.1	%	X	X	
	Indoor relative humidity - future	RH_F	V 5.2	%	X	X	
	Indoor relative humidity - variation	RH_V	V 5.3	%	X	X	
	Indoor CO2 concentration - baseline	CO2 conc_B	V 6.1	ppm	X	X	
	Indoor CO2 concentration - future	CO2 conc_F	V 6.2	ppm	X	X	
	Indoor CO2 concentration - variation	CO2 conc_V	V 6.3	%	X	X	

	Indoor PM10 concentration - baseline	PM10 conc_B	V 7.1	ppm	X	X	
	Indoor PM10 concentration - future	PM10 conc_F	V 7.2	ppm	X	X	
	Indoor PM10 concentration - variation	PM10 conc_V	V 7.3	%	X	X	
Lighting	Final energy consumption - baseline	FEC_B	L 1.1	kWh/year	X	X	X
	Final energy consumption - future	FEC_F	L 1.2	kWh/year	X	X	X
	Final energy consumption - variation	FEC_V	L 1.3	%	X	X	X
	Primary energy consumption - baseline	PEC_B	L 2.1	kWh/year	X	X	X
	Primary energy consumption - future	PEC_F	L 2.2	kWh/year	X	X	X
	Primary energy consumption - variation	PEC_V	L 2.3	%	X	X	X
	GHG emissions - baseline	GHG emissions_B	L 3.1	Kg CO2 eq /year	X	X	X
	GHG emissions - future	GHG emissions_F	L 3.2	Kg CO2 eq /year	X	X	X
	GHG emissions – variation	GHG emissions_V	L 3.3	%	X	X	X
	Lux at desk level - baseline	LDL_B	L 4.1	lux	X	X	X
	Lux at desk level - future	LDL_F	L 4.2	lux	X	X	X
	Lux at desk level - variation	LDL_V	L 4.3	%	X	X	X
Electricity	Final energy consumption - baseline	FEC_B	E 1.1	kWh/year	X	X	X
	Final energy consumption - future	FEC_F	E 1.2	kWh/year	X	X	X
	Final energy consumption - variation	FEC_V	E 1.3	%	X	X	X
	Primary energy consumption - baseline	PEC_B	E 2.1	kWh/year	X	X	X
	Primary energy consumption - future	PEC_F	E 2.2	kWh/year	X	X	X
	Primary energy consumption - variation	PEC_V	E 2.3	%	X	X	X
	GHG emissions - baseline	GHG emissions_B	E 3.1	Kg CO2 eq /year	X	X	X

	GHG emissions - future	GHG emissions_F	E 3.2	Kg CO2 eq /year	X	X	X
	GHG emissions – variation	GHG emissions_V	E 3.3	%	X	X	X
	RES exploitation - baseline	RES expl_B	E 4.1	%	X		
	RES exploitation - future	RES expl_F	E 4.2	€	X		X
	RES exploitation - variation	RES expl_V	E 4.3	€	X		X
	OPEX variation for battery and BIPV	OPEX var	E 5.3	%	X		X
Electric Vehicles	Final energy consumption - future	FEC_F	EV 1.2	kWh/year	X		
	Primary energy consumption - future	PEC_F	EV 2.2	kWh/year	X		
	GHG emissions - future	GHG emissions_F	EV 2.3	Kg CO2 eq /year	X		
Dynamic Envelope	Final energy consumption - baseline	FEC_B	DE 1.1	kWh/year	X	X	
	Final energy consumption - future	FEC_F	DE 1.2	kWh/year	X	X	
	Final energy consumption - variation	FEC_V	DE 1.3	%	X	X	
	Primary energy consumption - baseline	PEC_B	DE 2.1	kWh/year	X	X	
	Primary energy consumption - future	PEC_F	DE 2.2	kWh/year	X	X	
	Primary energy consumption - variation	PEC_V	DE 2.3	%	X	X	
	GHG emissions - baseline	GHG emissions_B	DE 3.1	Kg CO2 eq /year	X	X	
	GHG emissions - future	GHG emissions_F	DE 3.2	Kg CO2 eq /year	X	X	
	GHG emissions – variation	GHG emissions_V	DE 3.3	%	X	X	

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5.3.2 Economic KPIs

Table 19. Economic KPIs

KPI	Symbol	Index	UoM	Riga	Delft	Granada
Cost of investment- future	InvCost	ECO 1	€	X	X	x
Payback period - future	PBP	ECO 2	years	X	X	x
Internal return rate - future	IRR	ECO 3	%	X	X	x
Levelized cost of energy - future	LCOE_F	ECO 4	€/kWh	X	X	x
OPEX baseline	OPEX_B	ECO 5	€/year	X	X	x
OPEX future	OPEX_F	ECO 6	€/year	X	X	x
OPEX variation	OPEX_V	ECO 7	%	X	X	x

5.3.3 Informatic KPIs

All the Informatic KPIs will be evaluated only in the future scenario.

Table 20. Informatic KPIs

	KPI	Index	UoM	Riga	Delft	Granada
Control system	Real time KPI	IT 1	milliseconds	X	X	x
	Response time KPI	IT 2	milliseconds	X	X	X
	System Response Time KPI	IT 3	minutes	X	X	x
	Sensor Reliability KPI	IT 4	milliseconds	X	X	x
	System Downtime KPI	IT 5	%	X	X	x
	Latency KPI	IT 6	%	x	X	x

5.3.4 User-related KPIs

5.3.4.1 Current assessment of user factors in the SRI

The smart readiness level of a building impacts the indoor environmental quality and the end user. In the SRI Framework, a smart building is defined as a building able to "adapt its operation to the needs of the occupant". Currently, the SRI identifies four main user-related impact of the smartness level: (i) convenience; (ii) comfort; (iii) health and well-being; (iv) information.

Convenience: refers to services which "make life easier" for the occupant (e.g., systems requiring fewer manual interactions).

Comfort: which refers to conscious and unconscious perception of the physical environment, including thermal comfort, acoustic comfort and visual performance (e.g., provision of sufficient lighting levels without glare).

Health and well-being: refer to smarter controls that can deliver an improved indoor air quality compared to traditional controls.

Information: which refers to the provision of information on building operation.

In the SRI framework, weights or percentage are proposed to assess the impact of each domain on the above-mentioned user-related impacts. However, the SRI framework is currently a qualitative framework that assess the level of smartness of the building by assessing only the presence of a service instead of its actual performance and impact towards energy efficiency, energy flexibility, maintenance, and user-related aspects [1]. Since the proposed weights are not grounded on real data, they could lead to inaccurate results that do not correspond to the true impact of the smart service implemented or same smart services could lead to different impacts depending on contextual conditions or user requirements. Therefore, user related KPIs are proposed to provide a framework for the performance assessment of user related factors in the pre-intervention and post-intervention phase.

5.3.4.2 SMARTeeSTORY approach to evaluating SRS impact on users

In SMARTeeSTORY, two different types of users are identified: (i) building owners and facility managers; (ii) end users or occupants. While the domains of comfort, health and well-being refer only to the second type users (the end users), convenience and information are relevant for both types of users. The overall strategy of SMARTeeSTORY is shown in figure below.

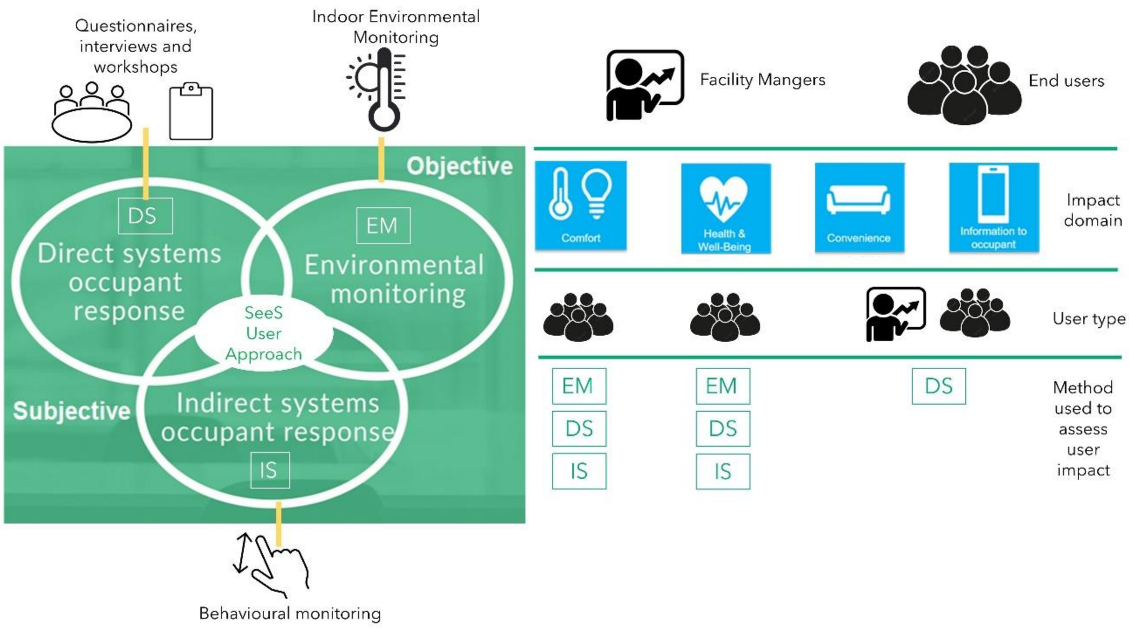

Figure 20. User-related KPIs and related methods for their assessment: Direct systems for occupant response, environmental monitoring, and indirect systems for occupant response.

Following previous research on occupant-building interaction, a mixed-method approach is used to capture user response to the above-mentioned domains, as further specified in section 5.4. Table 21 reports the KPI considered for assessing each of the user related impact per demo site.

Table 21. User-related KPIs

Domain	KPI	Index	Unit	Riga	Delft	Granada
Comfort KPIs 	Weighted percentage of hours outside the thermal comfort range	EM 1	%	X	X	X
	Weighted percentage of hours outside the visual comfort range	EM 2	%	X	X	X
	Hours of unobstructed window view	EM 3	%	X	X	X
	Hours outside recommended levels of noise	EM4	%	X	X	X
	Level of thermal satisfaction	DS 1	Likert scale from 1 to 5	X	X	X
	Number of reported thermal discomfort events	DS2	count	X	X	X
	Level of visual satisfaction with daylight availability, glare mitigation and outdoor view	DS3,4,5	Likert scale from 1 to 5	X	X	X
	Number of reported visual discomfort events	DS6	count	X	X	X
	Level of acoustic satisfaction	DS7	Likert scale from 1 to 5	X	X	X
	Number of user overrides of thermal comfort systems	IS1	count	X	X	X
	Number of user overrides of daylights and light systems	IS2	count	X	X	X
Health and well-being 	Time with pollutants concentration levels above recommended standards	EM5	%	X	X	X
	Satisfaction with air quality	DS7	Likert scale from 1 to 5	X	X	X
	Number of overrides of building systems related to the indoor air quality	IS6	Counts	X	X	X
Convenience 	Satisfaction with the overall automation system	DS8	Likert scale from 1 to 5	X	X	X
	Satisfaction with interfaces for personal control	DS9	Likert scale from 1 to 5	X	X	X
	Satisfaction with the frequency and interfaces for providing feedback	DS10	Likert scale from 1 to 5	X	X	X
Information	Satisfaction with the level of information received on the	DS11	Likert scale from 1 to 5	X	X	X

	performance and operation of the building					
	Satisfaction with the interfaces for receiving information on the building operation and performance	DS12	Likert scale from 1 to 5	X	X	X
	Satisfaction with the frequency of the information received	DS13	Likert scale from 1 to 5	X	X	X

5.4 Methodology for measuring and calculating the KPIs

5.4.1 Energy and environmental KPIs

5.4.1.1 Annual useful energy

Annual useful energy - baseline

The useful energy consists in the thermal energy possessed by the air flow used for environmental air conditioning (Heating, Cooling and Ventilation) or the thermal energy possessed by the domestic hot water (DHW).

In both cases, the useful energy can be calculated as the sum of the heat rate $\dot{\boldsymbol{Q}}_{\boldsymbol{i}}$ multiplied by the n intervals $\boldsymbol{\Delta t_i}$, as per the following formula:

$$Annual\ PE\_B\ [kWh/year]\ =\sum_{i=0}^{n}\dot{Q}_i\cdot\Delta t_i$$

The heat rate $\dot{\boldsymbol{Q}}_{\boldsymbol{i}}$ can be measured directly, sampling it n times during a year.

Alternatively, the heat rate can be calculated as:

$$\dot{Q}_i = \dot{m}_i\cdot c_p\cdot\Delta T_i$$

Where:

- $\dot{m}$ is the mass flow rate of the fluid
- c_p is the specific heat of the fluid at constant pressure
- ΔT is the temperature difference between the temperature of the flow entering the element that exchanges heat with the conditioned environment and the temperature of the outflow.

Alternatively, the useful energy KPI can be calculated from the final energy consumption KPI, reversing the equation in the chapter 5.4.1.2.

Annual useful energy - future

Same as the baseline.

Annual useful energy - variation

The variation between the baseline and future scenario, in percentage, can be expressed as:

$$Annual\ PE\_V\ = \frac{Annual\ PE\_B\ -\ Annual\ PE\_F}{Annual\ PE\_B} \cdot 100$$

5.4.1.2 Annual final energy consumption

Annual final energy consumption - baseline

For the technical domains Heating, Cooling, DHW and Ventilation the following equation is valid for the calculation of the annual energy consumption:

$$Annual\ FEC\_B\ [kWh/year]\ = \frac{Annual\ UE\_B}{\eta_B}$$

Where:

Annual PE_B is the annual Useful Energy

$\boldsymbol{\eta_B}$ Is the efficiency of the producing energy system, which varies for each demosite:

1) Coefficient Of Performance (COP) for the heat pump of the Granada demo site – the FEC is equal to the electrical consumption of the heat pumps.

2) Efficiency of the heat exchanger (district heating) for the Riga demo site – the FEC is equal to the heat transferred to the exchanger by the district heating.

3) Efficiency of the burners for Delft demo site – the FEC is equal to the thermal energy generated by the production point.

For the technical domains Lighting, Electricity, Electric Vehicles and Dynamic Envelope the annual FEC is equal to the electrical energy consumption related to each technical domain.

Annual final energy consumption - future

Same as the baseline.

Annual final energy consumption - variation

The variation between the baseline and future scenario, in percentage, can be expressed as:

$$Annual\ FEC\_V\ = \frac{Annual\ FEC\_B\ -\ Annual\ FEC\_F}{Annual\ FEC\_B} \cdot 100$$

Co-funded by the European Union

5.4.1.3 Annual primary energy consumption

Annual primary energy consumption – baseline

$$Annaul\ PEC\_B\ [kWh/year] = PEF \cdot annual\ FEC\_B$$

The Primary Energy Factor (**PEF**) is a constant value and depends on type of primary energy used and on the country. Its values can be retrieved from European databases (or evaluate knowing the energy mix deriving from the DHN in the case of Riga demo site).

Annual primary energy consumption - future

Same as the baseline.

Annual primary energy consumption - variation

The variation between the baseline and future scenario, in percentage, can be expressed as:

$$Annual\ PEC\_V = \frac{Annual\ PEC\_B - Annual\ PEC\_F}{Annual\ PEC\_B} \cdot 100$$

5.4.1.4 Annual GHG emissions

Annual GHG emissions - baseline

$$Annual\ GHG\ emissions_B = EF \cdot Annual\ PEC\_B$$

Where:

EF is the Emission Factor, it depends on:

- the country for the electrical grid (value retrieved from European databases),
- the specific energy mix for the DHN under study
- the used fossil fuel for thermal energy generation.

Annual PEC_B is the Primary Energy Consumption in the baseline scenario.

Annual GHG emissions - future

Same as the baseline.

Annual GHG emissions - variation

The variation between the baseline and future scenario, in percentage, can be expressed as:

$$Annual\ GHG\ emissions\_V = \frac{Annual\ GHG\ emissions\_B - Annual\ GHG\ emissions\_F}{Annual\ GHG\ emissions\_B} \cdot 100$$

5.4.1.5 Annual fossil fuel consumption

Annual fossil fuel consumption – baseline

The fossil fuel consumption (measured in Sm3 in case of natural gas) can be calculated with the following equation:

$$FFC\_B\ [Sm3/year] = \frac{FEC\_B}{LHV}$$

Where:

- FEC_B [kWh/year] is the annual Final Energy Consumption
- LHV [kWh/Sm3] is the Lower Heating Value of natural gas

Annual fossil fuel consumption - future

Same as the baseline.

Annual fossil fuel consumption - variation

The variation between the baseline and future scenario, in percentage, can be expressed as:

$$FFC\_V = \frac{FFC\_B - FFC\_F}{FFC\_B} \cdot 100$$

5.4.1.6 Renewable Energy Sources (RES) exploitation

Renewable Energy Sources (RES) exploitation - baseline

This KPI expresses the ratio between the renewable energy auto consumed and the Final Energy consumption, both evaluated over the course of a year.

$$RES\ expl\_B\ [\%] = \frac{Total\ used\ energy\ produced\ by\ RES\ (baseline)}{FEC\_B}$$

Renewable Energy Sources (RES) exploitation - future

Same as the baseline.

Renewable Energy Sources (RES) exploitation - variation

The variation between the baseline and future scenario, in percentage, can be expressed as:

$$RES\ expl\_V = \frac{RES\ expl\_B - RES\ expl\_F}{RES\ expl\_B} \cdot 100$$

5.4.1.7 OPEX variation for battery and BIPV

OPEX variation for battery and BIPV

The variation in OPEX thanks to the introduction of an electric battery and BIPV (Building Integrated Photovoltaics) can be calculated with the following integral over time dt (one year interval):

$$OPEX\ var = \int P_{unload}(t) \cdot Cost_{grid,el}(t) - P_{load,grid}(t) \cdot Cost_{grid,el}(t) - P_{BIPV}(t) \cdot OPEX_{BIPV}\ dt$$

Where:

- $\mathbf{P_{unload}(t)}$ [kW] it is the consumed electrical power released by the battery during the discharge phase, as a function of time
- $\mathbf{Cost_{grid,el}(t)}$ [€/kWh] is the cost of electricity from the grid, as a function of time
- $\mathbf{P_{load,grid}(t)}$ [kW] it is the electrical power coming from the grid with which the battery is charged, as a function of time
- $\mathbf{P_{BIPV}(t)}$ [kW] is the power generated by BIPVs and used for battery charging, as a function of time
- $\mathbf{OPEX_{BIPV}}$ [€/kWh] are the operating costs for the BIPV

5.4.1.8 Relative humidity

Indoor relative humidity - baseline

This KPI expresses the quality of the air from the point of view of relative humidity. Relative humidity is defined as the ratio between the density of water vapor in air and the saturation vapor density of water at the same temperature, expressed as a percentage:

$$r = \frac{density\ of\ water\ vapour}{saturation\ vapour\ density} \cdot 100$$

The indoor relative humidity KPI is defined as the standard deviation of the relative humidity compared to the set point value in a reference period:

$$RH_B = \sqrt{\frac{\sum_{i=1}^{N}(r_i - r_{set\ point})}{N}}$$

Where:

- i is the index of the measurements carried out
- N is the total number of measurements carried out in the reference period
- r_i is the i-the relative humidity
- $r_{set\ point}$ is the set point of the relative humidity

Indoor relative humidity - future

Same as the baseline.

Indoor relative humidity - variation

The variation between the baseline and future scenario, in percentage, can be expressed as:

$$RH\_V = \frac{RH\_B - RH\_F}{RH\_B} \cdot 100$$

5.4.1.9 Indoor CO_2 concentration

Indoor CO_2 concentration- baseline

This KPI expresses the quality of the air from the point of view of CO_2 concentration. It is defined as the concentration of CO_2 in the control volume in parts per million (ppm):

$$CO2\ ppm = \frac{kg\ of\ CO2\ in\ the\ control\ volume}{kg\ of\ air\ in\ the\ control\ volume} \cdot 10^6$$

The indoor CO_2 concentration KPI is defined as the standard deviation of the CO_2 concentration compared to the set point value in a reference period:

$$CO2\ conc\_B = \sqrt{\frac{\sum_{i=1}^{N}(CO2\ ppm_i - CO2\ ppm_{set\ point})}{N}}$$

Where:

- i is the index of the measurements carried out
- N is the total number of measurements carried out in the reference period
- $CO2\ ppm_i$ is the i-th CO_2 concentration
- $CO2\ ppm_{set\ point}$ is the set point of the CO_2 concentration

Indoor CO2 concentration - future

Same as the baseline.

Indoor CO2 concentration - variation

The variation between the baseline and future scenario, in percentage, can be expressed as:

$$CO2\ conc\_V = \frac{CO2\ conc\_B - CO2\ conc\_F}{CO2\ conc\_B} \cdot 100$$

5.4.1.10 Indoor PM10 concentration

Indoor PM10 concentration - baseline

This KPI expresses the quality of the air from the point of view of PM10 concentration. It is defined as the concentration of PM10 in the control volume in parts per million (ppm):

$$PM10\ ppm = \frac{kg\ of\ PM10\ in\ the\ control\ volume}{kg\ of\ PM10\ in\ the\ control\ volume} \cdot 10^6$$

The indoor PM10 concentration KPI is defined as the standard deviation of the PM10 concentration compared to the set point value in a reference period:

$$CO2\ conc\_B = \sqrt{\frac{\sum_{i=1}^{N}(PM10\ ppm_i - PM10\ ppm_{set\ point})}{N}}$$

Where:

- i is the index of the measurements carried out
- N is the total number of measurements carried out in the reference period
- $PM10_i$ is the i-th PM10 concentration
- $PM10_{set\ point}$ is the set point of the PM10 concentration

Renewable Energy Sources (RES) exploitation - future

Same as the baseline.

Renewable Energy Sources (RES) exploitation - variation

The variation between the baseline and future scenario, in percentage, can be expressed as:

$$PM10\ conc\_V = \frac{PM10\ conc\_B - PM10\ conc\_F}{PM10\ conc\_B} \cdot 100$$

5.4.1.11 Lux at desk level

Lux at desk level - baseline

This KPI is calculated as the standard deviation of the light intensity (measured in lux) at the desk level compared with the desired light intensity:

$$LDL\_B = \sqrt{\frac{\sum_{i=1}^{N}(LDL_i - LDL_{set\ point})}{N}}$$

Where:

- i is the index of the measurements carried out
- N is the total number of measurements carried out in the reference period
- LDL_i is the i-the light intensity expressed in lux
- $LDL_{set\ point}$ is the set point of the desired light intensity expressed in lux

Lux at desk level - future

Same as the baseline.

<u>Lux at desk level - variation</u>

The variation between the baseline and future scenario, in percentage, can be expressed as:

$$LDL\_V = \frac{LDL\_B - LDL\_F}{LDL\_B} \cdot 100$$

5.4.2 Economic KPIs

5.4.2.1 Cost of investment

The cost of investment parameter refers to the total estimated amount to be spent for the integration and installation of new technologies and tools, as simulated in the project. It can be calculated as:

$$InvCost\ [€] = \sum_{y=0}^{L} \frac{Inv_y}{(1+r)^y}$$

where:

- L [years] is the estimated lifetime of the project
- y is a index which represents the year
- $\boldsymbol{Inv_y}$ [€/year] is the yearly estimated investment amount for improvements
- $\boldsymbol{(1+r)^y}$ [-] is the compound interest factor, where r is the annual discount rate

With this formula, not only the initial investment Inv_0 is considered, but all the discounted investments necessary during the life cycle of the project.

5.4.2.2 Payback period

The payback period refers to the amount of time it takes to recover the cost of an investment. It is calculated by comparing the cost of the initial investment with the annual discounted net cash flow:

$$PBP\ [years] = \frac{Inv_0}{\sum_{y=0}^{L} \frac{NCF_y}{(1+r)^y}}$$

Where:

- $\boldsymbol{NCF_y}$ is the Net Cash Flow at year y
- $\boldsymbol{Inv_0}$ [€] is the total initial investment cost discounted at year 0
- $\boldsymbol{(1+r)^y}$ [-] is the compound interest factor, where r is the annual discount rate
- $\boldsymbol{L}$ [years] is the estimated lifetime of the project

The Net Cash Flow can be calculated as:

$$NCF_y\ [€] = +Rev_y + Sav_y - Fuel_y - Elect_y - Op\&Main_y$$

Where:

- $\boldsymbol{Rev_y}$ [€] are the yearly revenues coming from energy selling

- $\boldsymbol{Sav_y}$ [€] are the yearly savings due to the new system or configuration
- $\boldsymbol{Fuel_y}$ [€] is the yearly fuel cost
- $\boldsymbol{Elect_y}$ [€] is the yearly electricity cost
- $\boldsymbol{Op\&Main_y}$ [€] is the yearly operation & maintenance cost

5.4.2.3 Internal return rate

The internal return rate (IRR) estimates the profitability of the investment. It represents the discount rate that makes the net present value (NPV) of the cash flows equal to zero. The NPV is the difference between the present value of cash inflows and the present value of cash outflows over a period of time:

$$IRR\ [\%]\ such\ that\ NPV = \sum_{y=0}^{L} \frac{NCF_y}{(1+IRR)^y} - InvCost = 0$$

Where:

- $\boldsymbol{NPV}$ [€] is the net present value of the project
- $\boldsymbol{NCF_y}$ [€] is the net cash flow at year y
- $\boldsymbol{InvCost}$ [€] is the cost of investment
- $\boldsymbol{L}$ [years] is the estimated lifetime of the project

5.4.2.4 Levelized cost of energy

LCOE in the future scenario can be calculated as:

$$LCOE\left[\frac{€}{kWh}\right] = \frac{\sum_{y=0}^{L} \frac{Inv_y + Fuel_y + Elect_y + Op\&Main_y}{(1+r)^y}}{\sum_{y=0}^{L} \frac{FE_y + IE_y}{(1+r)^y}}$$

Where:

- $\boldsymbol{Inv_y}$ [€] is the yearly investment cost in the future scenario
- $\boldsymbol{Fuel_y}$ [€] is the yearly fuel cost in the future scenario
- $\boldsymbol{Elect_y}$ [€] is the yearly electricity cost in the future scenario
- $\boldsymbol{Op\&Main_y}$ [€] is the yearly operation & maintenance cost in a future scenario
- $\boldsymbol{FE_y + IE_y}$ [kWh] is the sum of final and internally produced energy in the system in a future scenario
- $\boldsymbol{(1+r)^y}$ [-] is the compound interest factor, where r is the annual discount rate
- $\boldsymbol{L}$ [years] is the estimated lifetime of the project

5.4.2.5 Operational expenses

OPEX baseline

The operation expenditure (OPEX) parameter represents the cash expenditure that occurs every year and can be expressed in monetary unit per year. In the baseline case it can be calculated as :

$$OPEX\_B\left[\frac{€}{year}\right] = Fuel_{y,base} + Elect_{y,base} + Op\&Main_{y,base}$$

Where:

- $\boldsymbol{Fuel_{y,base}}$ [€/year] is the yearly fuel cost in the baseline scenario
- $\boldsymbol{Elect_{y,base}}$ [€/year] is the yearly cost of imported electricity in the baseline scenario
- $\boldsymbol{Op\&Main_{y,base}}$ [€/year] is the yearly operation & maintenance cost in the baseline scenario

OPEX future

As in the baseline case, the OPEX in a future scenario can be calculated as:

$$OPEX\_F\left[\frac{€}{year}\right] = Fuel_{y,fut} + Elect_{y,fut} + Op\&Main_{y,fut}$$

Where:

- $\boldsymbol{Fuel_{y}}$ [€/year] is the yearly fuel cost in a future scenario
- $\boldsymbol{Elect_{y}}$ [€/year] is the yearly cost of imported electricity in a future scenario
- $\boldsymbol{Op\&Main_{y}}$ [€/year] is the yearly operation & maintenance cost in a future scenario

OPEX variation

The OPEX variation between the baseline and future scenario, in percentage, can be expressed as:

$$OPEX\_V\,[\%] = \frac{OPEX\_B - OPEX\_F}{OPEX\_B}$$

5.4.3 Informatic KPIs[10]

5.4.3.1 Real time KPI

Real time KPI: Average time taken to process and update energy consumption data in real-time should not exceed a defined time expressed in ms.

[10] Paper: 2019 System level Key Performance Indicators for Building Performance Evaluation.pdf

Description: Measure the system's efficiency in handling and processing data from various sensors and devices to provide real-time insights.

5.4.3.2 System response time KPI

System Response Time KPI: The system will respond to changes in conditions within an average of time expressed minutes.

Description: record and analyze the time taken for the system to respond to changes in conditions, including the time between specific events, such as a change in sensor reading and the corresponding action taken by the control system.

5.4.3.3 Sensor reliability KPI

Sensor Reliability KPI: Sensor failure rate and mean time between failures (MTBF) should not exceed a defined time expressed in ms.

Description: Ensure that sensors used for data collection are reliable and require minimal maintenance.

5.4.3.4 System downtime KPI

System Downtime KPI: The system will maintain a downtime of less than a defined percentage of total operational time.

5.4.3.5 Latency KPI

Latency KPI: Average time taken for sensors to transmit data to the central system should be within a defined time expressed in ms.

Description: Measure the efficiency of data transmission to ensure real-time monitoring.

5.4.4 User-related KPIs

5.4.4.1 Comfort KPIs

5.4.4.1.1 Thermal comfort and satisfaction

- **Weighted hours outside the thermal comfort range or Degree Hours Criteria**

Description: This KPI measures the number of hours outside the comfort range weighted by a factor that is a function of the difference in operative temperature between the upper limit of the comfort threshold and the measured operative temperature. The operative temperature is measured in proximity of each occupant or at each desk location. Depending on the demo site, the PMV thermal comfort model or the adaptive thermal comfort model are recommended to define the comfort thresholds [2]. In particular, for the office spaces with mechanical cooling, the use of the PMV is recommended, while with the offices without mechanical cooling (e.g. Delft), the use of the adaptive thermal comfort model is suggested.

Quantifying procedure: The following equation shows the quantifying procedure for this KPI.

$$Degree\ Hours\ of\ thermal\ discomfort: \frac{\sum_{h=1}^{tot} \Delta T * h}{\sum h}$$

Where:

ΔT is the difference in operative temperature between the hourly average indoor operative temperature and the upper or lower comfort threshold.

h is the total amount of hours per difference in indoor operative temperature.

The operative temperature is a simplified thermal parameter that represent the weighted average of the air temperature (t_a) and the mean radiant temperature (t_r) by the respective coefficient of heat transfer, as shown in the following equation.

$$OT = \frac{h_r * t_r + h_c * t_a}{h_r + h_c}$$

Since the operative temperature is a function of both the air temperature and the air velocity, but the proposed monitoring strategy only continuously measures the relative humidity and the air temperature, it is recommended that once per season a detailed thermal comfort monitoring is performed to define the coefficients of heat transfer and the distribution of drafts and surface temperatures in the space in order to identify specific sources of thermal discomfort. In addition, reporting of clothing level is required per season for each of the occupant in the space.

- Level of thermal satisfaction

Description: The thermal satisfaction describes the subjective evaluation of the occupants regarding their satisfaction with the surrounding thermal environments. For this, a direct feedback system (a web-based questionnaire) is used to ask occupants to state their satisfaction with the thermal environment on a Likert scale.

Quantifying procedure: During each season, at least once per season, occupants are invited to answer web-based questionnaires on their satisfaction with the thermal environment. The question is phrased as agreement level with the following sentence: "To what extent do you agree with this sentence: I am satisfied with the thermal environment". Occupants can express their level of agreement on a 5 points Likert scale, ranging from strongly agree to strongly disagree.

These subjective evaluations are then converted in numerical ordinal scales, and the distribution of responses analyzed to compute the mean, the standard deviation and the upper and lower percentiles. Linear mixed model is then used to perform the statistical analysis and identify any statistical significance between the differences of thermal satisfaction pre and post intervention.

- Number of reported thermal discomfort events

Description: Occupants can report thermal discomfort in a point in time by using mobile-based questionnaires. This information is reported on a binary scale ("yes" or "not") by answering the following question: "Do you feel uncomfortable with the thermal environment?". Then a question follows to record information on the motivation behind the visual discomfort event.

Quantifying procedure: the total count of reported thermal discomfort events by the occupants is computed to evaluate whether occupants were reporting thermal discomfort more frequently in the pre and post intervention phase.

- Number of overrides of thermal comfort systems

Description: During the pre and post intervention phases, occupants are allowed to interact or override the automated control of the thermal comfort systems (i.e. air conditioning units, radiators, openable vents etc.). The interaction of occupants with thermal comfort systems is a source of information regarding their dissatisfaction with the current state of the thermal environment and their thermal preferences, since occupants override and interact with thermal comfort systems to adapt and restore their level of satisfaction with the thermal environment. The number and type of interactions are therefore monitored continuously to capture this information.

Quantifying procedure: User interaction with thermal comfort systems is monitored, including time of interaction and control setting selected. The total number of interactions and the direction of interaction (if it is either to warm or cool down the environment) is monitored. Total number of interactions are then clustered per type of thermal discomfort (feeling warm or cold) in order to provide information on whether occupants were feeling warm or cold during the pre and post intervention phase. Occupant interaction is monitored continuously across the demo buildings.

5.4.4.1.2 Visual quality, comfort and satisfaction

- Weighted number of hours outside visual comfort range

Description: at each desk location, visual comfort is continuously measured by measuring horizontal illuminance on the desk. The total number of hours in which the measured horizontal illuminance is outside the comfort range is then computed as a proxy of visual performance in the space. This measurement is performed for each desk.

Quantifying procedure: the Useful Daylight Illuminance is used to assess the quality of the visual environment. Useful daylight Illuminance (UDI) is defined as the fraction of the time in a year when indoor horizontal daylight illuminance at a given point falls in a given range.

$$UDI = \frac{\sum h}{\sum t}$$

Where h is the time outside the comfort range during the occupied hours, defined as [3]:

Lower illuminance limit (lx): 300

Upper illuminance limit (lx): 8000

and t is the total amount of hours in which the space is occupied.

A lower and an upper illuminance limit values are proposed in order to split the analyzed period into three bins: the upper bin is meant to represent the percentage of the time when an oversupply of daylight might lead to visual discomfort or glare, the lower bin represents the percentage of the time when illuminance levels may be too low, and the intermediate bin represents the percentage of the time with appropriate illuminance level. Since, the sensors measure the overall level of illuminance, both including the contribution of the artificial lights and of the daylight, the contribution of the artificial lights will be computed separately and then subtracted from the overall illuminance levels measured. Since horizontal illuminance measurements are performed with low-cost and low-accurate illuminance sensors, therefore it is recommended that detailed daylight assessment is performed in each demo site with off-shelf accurate scientific sensing toolkits for calibration of these sensors.

It is recommended that the UDI measurement is also combined with Luminance and contrast measurements by using calibrated High Dynamic Range Imaging (HDRI) to measure the Daylight Glare Probability in the occupied spaces where excessive brightness and glare is a problem. This can complement the UDI measurements and evaluate the appropriateness of the discomfort thresholds selected. These measurements should be performed once in time during the timeframes that provide the largest risk of glare, which usually is during the winter season when the sun elevation is at the lowest and the sky condition is clear, and from the occupant point of view.

- Level of visual satisfaction with daylight availability, glare mitigation and outdoor view

Description: The visual satisfaction describes the subjective evaluation of the occupants regarding their satisfaction with the surrounding visual environments. For this, a direct feedback system (a web-based questionnaire) is used to ask occupants to state their satisfaction with the visual environment, specifically regarding their satisfaction with glare mitigation, daylight availability, outdoor view access and clarity, and privacy.

Quantifying procedure: During each season, at least once per season, occupants are invited to answer web-based questionnaires on their satisfaction with the visual environment. The question is phrased as agreement level with the following sentence: "To what extent do you agree with this sentence: (i) I am satisfied with the daylight availability in the space"; (ii) I am satisfied with the glare mitigation in the space", (iii) I am satisfied with the access to the outdoor view; "I am satisfied with the view clarity through the window"; (iv) I am satisfied with the level of privacy from the window. Occupants can express their level of agreement on a 5 points Likert scale, ranging from strongly agree to strongly disagree.

These subjective evaluations are then converted in numerical ordinal scales, and the distribution of responses analyzed to compute the mean, the standard deviation and the upper and lower percentiles. Linear mixed model is then used to perform the statistical analysis and identify any statistical significance between the differences of visual satisfaction pre and post intervention.

- Number of reported visual discomfort events

Description: Occupants can report visual discomfort due to glare, lack of daylight or dissatisfactory view access, clarity or privacy, in a point in time by using mobile-based questionnaires. This information is reported on a binary scale ("yes" or "not") by answering the following question: "Do you feel uncomfortable with the visual environment?". Then a question follows to record information on the motivation behind the visual discomfort event.

Quantifying procedure: the total count of reported visual discomfort events by the occupants is computed to evaluate whether occupants were reporting visual discomfort more frequently in the pre and post intervention phase. This information is reported per visual domain (glare, daylight, view, privacy).

- Number of overrides of daylight or light systems

Description: During the pre and post intervention phases, occupants are allowed to interact or override the automated control of the daylight control or light systems (i.e. artificial lights at the ceiling, task lightings and shading devices). The interaction of occupants with daylight and light systems is a source of information regarding their dissatisfaction with the current state of the visual environment and their visual preferences, since occupants override and interact with daylight and light systems to adapt and restore their level of satisfaction with the visual environment. The number and type of interactions are therefore monitored continuously to capture this information.

Quantifying procedure: User interaction with daylight and light control systems is monitored, including time of interaction and control setting selected. The total number of interactions and the direction of interaction (if it is either to increase (day)light or decrease it) is monitored. Total number of interactions are then clustered per type of visual discomfort in order to provide information on whether occupants were feeling excessive brightness, insufficient daylight or light levels or view during the pre and post intervention phase. Occupant interaction is monitored continuously across the demo buildings.

5.4.4.1.3 Acoustic quality, comfort and satisfaction

- Equivalent Noise Levels

Description: the equivalent continuous sound pressure level, weighted with the curve A, is used over the time period of the occupied hours to describe the environmental noise in space. This metric is not continuously monitored in the SMARTeeSTORY system and therefore it will be only measured sporadically during the pre and post intervention phases.

Quantifying procedure: calibrated noise level meters are used to monitor during a full day the average equivalent noise level.

- Level of acoustic satisfaction

Description: The acoustic satisfaction describes the subjective evaluation of the occupants regarding their satisfaction with the surrounding acoustic environments. For this, a direct feedback system (a web-based questionnaire) is used to ask occupants to state their satisfaction with the visual environment, specifically regarding their satisfaction with glare mitigation, daylight availability and outdoor view access and clarity.

Quantifying procedure: During each season, at least once per season, occupants are invited to answer web-based questionnaires on their satisfaction with the acoustic environment. Two different aspects of the acoustic environment are considered: (i) the appropriateness of surrounding sounds; (ii) the satisfaction with noise levels. The question is phrased as agreement level with the following sentence: "To what extent do you agree with this sentence: (i) I am satisfied with the noise levels in the space"; (ii) I am satisfied with the sound appropriateness in the space". Occupants can express their level of agreement on a 5 points Likert scale, ranging from strongly agree to strongly disagree.

These subjective evaluations are then converted in numerical ordinal scales, and the distribution of responses analyzed to compute the mean, the standard deviation and the upper and lower percentiles. Linear mixed model is then used to perform the statistical analysis and identify any statistical significance between the differences of acoustic satisfaction pre and post intervention.

- Number of reported acoustic discomfort events

Description: Occupants can report visual discomfort due the acoustic environment, in a point in time by using mobile-based questionnaires. This information is reported on a binary scale ("yes" or "not") by answering the following question: "Do you feel uncomfortable with the acoustic environment?". Then a question follows to record information on the motivation behind the acoustic discomfort event. In particular, SMARTeeSTORY will assess the acoustic discomfort related to the noise produced by automation systems, which is often one of the main reasons of dissatisfaction of user with automated control systems.

Quantifying procedure: the total count of reported acoustic discomfort events by the occupants is computed to evaluate whether occupants were reporting acoustic discomfort more frequently in the pre and post intervention phase.

- **Number of overrides with building systems related to the acoustic environment**

Description: During the pre and post intervention phases, occupants are allowed to interact or override the automated control of mechanical ventilation systems, blinds, and windows. The interaction of occupants with systems that can allow noise to enter or produced noise themselves is a source of information regarding their dissatisfaction with the current state of the acoustic environment, since occupants override and interact with these systems to adapt and restore their level of acoustic satisfaction. The number and type of interactions are therefore monitored continuously to capture this information.

Quantifying procedure: User interaction with systems that influence the acoustic environment is monitored, including time of interaction and control setting selected. The total number of interactions and the direction of interaction (if it is either to increase exposure to noise or mitigate it) is monitored. Total number of interactions are then clustered per type of acoustic discomfort or type of noise (e.g., people speaking, outdoor noise etc.) in order to provide information on whether occupants were feeling acoustic discomfort during the pre and post intervention phase. Occupant interaction is monitored continuously across the demo buildings.

5.4.4.2 Health and well-being

- **Time with pollutants concentration levels above recommended standards**

Description: The following contaminants are considered for evaluating the quality of the indoor air: volatile organic compounds (VOC), carbon dioxide (CO_2) indoor particulate matter with a diameter of 10 microns or less (PM10) or 2.5 microns or less (PM2.5). The concentration levels of these contaminants are a proxy for the quality of the indoor health, which can have a detrimental impact on human health when the concentration of these contaminants is above the recommended levels.

The CO_2 is not a proxy for indoor air quality, but a reliable proxy for occupancy and level of exhausted air and lack of oxygen. The PM2.5 and the PM10 are instead the best indicators for indoor air quality or in other words freshness and cleanliness of the air. VOCs are instead a good indication for contaminants that are emitted by chemical products, such the one contained in new furniture or other building components.

Quantifying procedure: The World Health Organization recommends the following thresholds of contaminants in indoor spaces:

- VOCs levels: 0.3 mg/m^3,
- CO_2 levels: 900 ppm (better below 600 ppm)
- PM2.5: 15 µg/m^3, 5 µg/m^3 a year - smaller particles below 2.5 micron are the most dangerous for health since are the one that can enter inside the lung and even into your blood.
- PM10: 45 µg/m^3 a day, 15 µg/m^3 a year -coarser particles that tend to irritate eyes, nose, throat, they are typically produced by roads, farms, dry riverbeds, construction sites and

combustion.

These contaminants and the levels of CO_2 are measured by sensors at each desk or room level. The average levels per hour are then considered and compared to the recommended threshold.

Then, the fraction of the time in a year when indoor pollutants exceed recommended levels at a given point falls in a given range. This indicator is computed for each of the contaminants:

$$IAQ = \frac{\sum h}{\sum t}$$

Where h is the time outside the recommended range for health during the occupied hours, defined by the WHO [4], and t is the total amount of hours in which the space is occupied. Finally, the mean and standard deviations of the overall concentration of indoor pollutants is also evaluated to compare scenarios and test the significant difference between pre and post intervention.

- Level of satisfaction with air quality

Description: The satisfaction with the air quality describes the subjective evaluation of the occupants regarding their satisfaction with the surrounding air quality. For this, a direct feedback system (a web-based questionnaire) is used to ask occupants to state their satisfaction with the indoor air quality.

Quantifying procedure: During each season, at least once per season, occupants are invited to answer web-based questionnaires on their satisfaction with the indoor air quality. The question is phrased as agreement level with the following sentence: "To what extent do you agree with this sentence: (i) I find the indoor air quality in the office satisfactory". Occupants can express their level of agreement on a 5 points Likert scale, ranging from strongly agree to strongly disagree.

These subjective evaluations are then converted in numerical ordinal scales, and the distribution of responses analyzed to compute the mean, the standard deviation and the upper and lower percentiles. Linear mixed model is then used to perform the statistical analysis and identify any statistical significance between the differences of indoor air satisfaction pre and post intervention.

- Number of overrides with building systems related to the indoor air quality

Description: During the pre and post intervention phases, occupants are allowed to interact or override the automated control of mechanical ventilation systems and windows. The interaction of occupants with systems that can influence the indoor air quality is a source of information regarding on their dissatisfaction with the current state of the air quality. The number and type of interactions are therefore monitored continuously to capture this information.

Quantifying procedure: User interaction with systems that influence the indoor air quality is monitored, including time of interaction and control setting selected. The total number of interactions and the direction of interaction is monitored. Total number of interactions are then clustered in order to provide information on whether occupants were feeling dissatisfied with indoor air. Occupant interaction is monitored continuously across the demo buildings.

5.4.4.3 Convenience

- Level of satisfaction with the convenience of the building

Description: The satisfaction with the convenience of the smart automated controls describes the subjective evaluation of the occupants regarding their satisfaction with: (i) the overall automation system; (ii) their perceived level of personal control; (iii) the interface for personal control; (iv) the frequency and interfaces for providing feedback or input to the automated control. The first and second item "satisfaction with the perceived personal control" and the "satisfaction with the automated control" are addressed separately for each dynamic building component, namely: heating, cooling, ventilation, window vents, shading devices and lights. For this, a direct feedback system (a web-based questionnaire) is used to ask occupants to state their satisfaction with the indoor air quality.

Quantifying procedure: During each season, at least once per season, occupants are invited to answer web-based questionnaires on their satisfaction with the indoor air quality. The question is phrased as agreement level. Occupants can express their level of agreement on a 5 points Likert scale, ranging from strongly agree to strongly disagree.

These subjective evaluations are then converted in numerical ordinal scales, and the distribution of responses analyzed to compute the mean, the standard deviation and the upper and lower percentiles. Linear mixed model is then used to perform the statistical analysis and identify any statistical significance between the differences of satisfaction with the convenience in the pre and post intervention.

This KPI is addressed to both type of users: the facility managers and the end users of the space.

Convenience will also be assessed by the frequency of overrides from the previous comfort domains, since the interaction with the system can also inform on the overall convenience of the smart building control.

5.4.4.4 Information

- Level of satisfaction with the level of information from the building management systems

Description: The satisfaction with the information from the building management system describes the subjective evaluation of the occupants regarding their satisfaction with the interface and content of the information received by the building. For this, a direct feedback system (a web-based questionnaire) is used to ask occupants to state their satisfaction with the indoor air quality.

Quantifying procedure: During each season, at least once per season, occupants are invited to answer web-based questionnaires on their satisfaction with the indoor air quality. The question is phrased as agreement level with the following sentence: "To what extent do you agree with this sentence: (i) I find the information received on the performance and operation of the building satisfactory"; (ii) I find the interface for receiving information on the building operation and performance satisfactory; (iii) I find the frequency of information received satisfactory. Occupants can express their level of agreement on a 5 points Likert scale, ranging from strongly agree to strongly disagree.

These subjective evaluations are then converted in numerical ordinal scales, and the distribution of responses analyzed to compute the mean, the standard deviation, and the upper and lower percentiles. Linear mixed model is then used to perform the statistical analysis and identify any statistical significance between the differences of satisfaction with information in the pre and post intervention.

This KPI is addressed to both type of users: the facility managers and the end users of the space.

5.5 Impacts of increasing the level of SRIs on KPIs

SRI by itself gives the idea of how interventions on digitalization can improve the smart readiness level of a building but gives no idea about how the interventions quantitatively impact on economic, comfort, environmental and energy KPIs, implicitly assuming that better performances can derive from its upgrade. Therefore, a theoretical analysis about the impacts that an increased level of SRI can bring to historical buildings in terms of economic, comfort, energy and environmental benefits will be performed and applying the methodology explained in the following chapters. The results of this analysis will be then validated with the results coming from the monitoring campaign after the installation of the SMARTeeSTORY solutions.

5.5.1 Link between SRIs and KPIs

In order to identify the relation between the SRIs and the KPIs, the SRI calculation method has been taken as reference to generate some preliminary considerations.

The SRI value is a percentage value obtained from the ratio between the sum of products between impact scores (ISs) and weights, both related to the three main categories of the impact criteria (i.e., Energy saving and operation, respond to user need, and Respond to the needs of the grid), with the maximum reachable score. Each impact criteria macro category affects for 1/3 the final SRI value. The impact criteria (i.e., Energy efficiency, Maintenance and fault prediction, Comfort, Convenience, Health, well-being, and accessibility, Information to occupants, and Energy flexibility and storage) are the areas that are affect by the SRSs improvements. The impact criteria are linked to the impact scores, that are defined in turn as the product between the score associated to the SRSs level and other weights, depending on geographical position (i.e., EU climate zones), user type (i.e., residential or no residential building), and further building properties (i.e., energy performance of the buildings in the different EU countries included in each EU climate zone related to building envelope properties). Moreover, the impact scores are evaluated for each domain (i.e., Heating, DHW, Cooling, Ventilation, Lighting, Dynamic building envelope, Electricity, Electric vehicle charging, and monitoring and control). In Table 22 an example of dimensionless impact scores values have been reported.

Table 22. Example of impact scores for the SRI calculation

	Energy saving and operation		Respond to user need				Respond to the needs of the grid
Domain	Energy efficiency	Maintenance and fault prediction	Comfort	Convenience	Health, well-being, and accessibility	Information to occupants	Energy flexibility and storage
Heating	100%	0%	100%	75%	100%	50%	100%
Domestic hot water	100%	0%	0%	0%	0%	50%	100%
Cooling	100%	0%	100%	100%	100%	100%	0%
Ventilation	89%	0%	100%	100%	100%	100%	100%
Lighting	100%	0%	100%	100%	100%	0%	0%
Dynamic building envelope	100%	0%	80%	100%	75%	0%	0%
Electricity	80%	100%	0%	80%	0%	67%	100%
Electric vehicle charging	0%	25%	0%	100%	0%	0%	67%
Monitoring and control	100%	0%	100%	75%	100%	50%	100%

Considering the method used for the SRI calculation reported above, the decision to correlate the impact scores variations with the consequent KPIs variation has been taken. First, in order to be able to define a relevant relation, a preliminary identification of the impact criteria affecting the specific KPIs category (economic, environmental, comfort or energy) has been performed. The resulting links are summarized in Table 23.

Table 23. General summary of link between impact criteria and KPIs.

	Energy and Environmetal KPIs	Indoor environment KPIs	User-related KPIs	Economic KPIs
Energy savings on site				
Maintenance & fault prediction				
information to occupants				
Wellbeing and health				
Comfort				
Convenience				
Flexibility for the grid and storage				

Going into the details of the relation between each KPI and the impact criteria (and scores linked to the SRSs), the specific descriptions have been reported in the following bullet points list and from Table 24 to Table 27. In these figures the highlighted cells assumed two different shadows: darker if the variation of the KPI on the column will be directly evaluated starting from the variation of the impact scores related to the impact criteria on the rows, and lighter if the variation of the KPI on the column will be evaluated starting from the variation of other KPIs belonging to the same category and applying the already defined formula.

- Energy KPIs (Table 24):
  - Useful energy: from the preliminary analysis the SRS included in the impact criteria Energy saving on site and the Information to occupants has been identified as affecting this KPI. Moreover, this KPI has been evaluated as influenced by a specific list of SRSs, that have been considered as the ones apporting chances in the amount of requested energy and not the generation

efficiency. The code used in the SRI calculation of the SRSs corresponding to the previous description are: H-1a, H-1d, H3, DHW-3, C-1a, C-1d, C-1f, C-3, V-1a, V-1c, V-2c, V-2d, V-3, V-6, L-1a, L-2, DE-1, DE-2, DE-4, E-12, EV-15, MC-3, MC-4, MC-9, MC-13, MC-28, MC-29, MC-30.

- Final energy consumption (FEC): from the preliminary analysis the SRS included in the impact criteria Energy saving on site, the Information to occupants and the Flexibility for the grid and storage has been identified as affecting this KPI. Moreover, the variation in the useful energy, that is taken into account for the evaluation of the FEC, will be already evaluated from the impact scores variation related to the SRSs listed in the previous point, while other SRSs have been considered as affecting the generation efficiency. The code used in the SRI calculation of the SRSs identified as affecting the energy efficiency value are the following: H-1c, H-1f, H-2b, H-2d, H3, H-4, DHW-1a, DHW-1b, DHW-1d, DHW-2b, DHW-3, V-6, C-1c, C-1g, C-2a, C-2b, C-3, C-4, DE-4, E-2, E-3, E-4, E-5, E-8, E-11, E-12, EV-16, MC-3, MC-13, MC-25, MC-28, MC-29, MC-30.
- Primary energy consumption (PEC): from the preliminary analysis the SRS included in the impact criteria Energy saving on site, the Information to occupants and the Flexibility for the grid and storage has been identified as affecting this KPI. The value of the PEC variation will be evaluated starting from the FEC variation and applying the primary energy factor (that is constant).
- RES exploitation level: from the preliminary analysis the SRS included in the impact criteria Energy saving on site, the Information to occupants and the Flexibility for the gid and storage has been identified as affecting this KPI. This KPI has been evaluated as affected by all the SRSs included in the evaluation of the impact scores related to these criteria.

- Environmental KPIs (Table 24):
    - GHG emissions: likewise, the PEC, from the preliminary analysis the SRS included in the impact criteria Energy saving on site, the Information to occupants and the Flexibility for the gid and storage. The value of the GHG emissions variation will be evaluated starting from the PEC variation and applying the emission factor (that is constant).
    - Fossil fuel consumption (FFC): likewise, the previous KPI, from the preliminary analysis the SRS included in the impact criteria Energy saving on site, the Information to occupants and the Flexibility for the grid and storage has been identified as affecting this KPI. The value of the FFC variation will be evaluated starting from the FEC and considering the fraction of energy generated using fossil fuels.

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Table 24. Link between impact criteria and Energy and Environmental KPIs

	Energy KPIs				Environmental KPIs	
	Produced energy consumption	Final energy consumption	Primary energy consumption	RES exploitation level	GHG emissions	Fossil fuel consumption
Energy savings on site						
Maintenance & fault prediction						
information to occupants						
Wellbeing and health						
Comfort						
Convenience						
Flexibility for the grid and storage						

- Indoor Environment KPIs (Table 25): from the preliminary analysis the SRS included in "Respond to user need" impact criteria macro category (i.e., Information to occupants, Wellbeing and health, Comfort and Convenience) has been identified as affecting this KPIs category. The KPIs affected by the SRS belonging to these impact criteria are:
  - Indoor air temperature
  - Indoor relative humidity
  - Indoor CO2 concentration
  - Indoor PM10 concentration
  - Horizontal lux at desk level.

Table 25. Link between impact criteria and Indoor environment KPIs

	Indoor environmet KPIs				
	Indoor air temperature	Indoor relative humidity	Indoor CO2 concentration	Indoor PM10 concentration	Lux at desk level
Energy savings on site					
Maintenance & fault prediction					
information to occupants					
Wellbeing and health					
Comfort					
Convenience					
Flexibility for the grid and storage					

- User-related KPIs: from the preliminary analysis the SRS included in the impact criteria "Respond to user need" impact criteria macro category (i.e., Information to occupants, Wellbeing and health, Comfort and Convenience) has been identified as affecting this KPIs category. The KPIs affected by the SRS belonging to these impact criteria are:
  - The ones affected by the SRS belonging to the "Comfort" impact criteria (Table 26) are:
    - Weighted percentage of hours outside the thermal comfort range
    - Weighted percentage of hours outside the visual comfort range
    - Hours of unobstructed window view
    - Hours outside recommended levels of noise
    - Level of thermal satisfaction

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- Number of reported thermal discomfort events
- Level of visual satisfaction with daylight availability, glare mitigation and outdoor view
- Number of reported visual discomfort events
- Level of acoustic satisfaction
- Number of user overrides of thermal comfort systems
- Number of user overrides of daylights and light systems.

Table 26. Link between "Comfort" impact criteria and User-related KPIs

	User-related KPIs										
	Weighted percentage of hours outside the thermal comfort range	Weighted percentage of hours outside the visual comfort range	Hours of unobstructured window view	Hours outside recommended levels of noise	Level of thermal satisfaction	Number of reported thermal discomfort events	Level of visual satisfaction with daylight availability, glare mitigation and outdoor view	Number of reported visual discomfort events	Level of acoustic satisfaction	Number of user overrides of thermal comfrot systems	Number of user overrides of daylight and light systems
Energy savings on site											
Maintenance & fault prediction											
Information to occupants											
Wellbeing and health											
Comfort											
Convenience											
Flexibility for the grid and storage											

- The ones affected by the SRS belonging to the "Wellbeing and health" impact criteria (Table 27) are:
  - Time with pollutants concentration levels above recommended standards
  - Satisfaction with air quality
  - Number of overrides of building systems related to the indoor air quality.

Table 27. Link between" Wellbeing and health" impact criteria and User-related KPIs

	User-related KPIs		
	Time with pollutants concentriation levels above recommended standards	Satisfaction with air quality	Number of overrides of building system realted to the indoor air quality
Energy savings on site			
Maintenance & fault prediction			
information to occupants			
Wellbeing and health			
Comfort			
Convenience			
Flexibility for the grid and storage			

- The ones affected by the SRS belonging to the "Convenience" impact criteria (Table 28) are:
  - Satisfaction with the overall automation system
  - Satisfaction with interfaces for personal control
  - Satisfaction with the frequency and interfaces for providing feedback.

Table 28. Link between" Convenience" impact criteria and User-related KPIs

	User-related KPIs		
	Satisfaction with overall automation system	Satisfaction with interfaces for personal control	Satisfaction with the frequency and interfaces for providing feedback
Energy savings on site			
Maintenance & fault prediction			
information to occupants			
Wellbeing and health			
Comfort			
Convenience			
Flexibility for the grid and storage			

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   - The ones affected by the SRS belonging to the "Information to occupants" impact criteria (Table 29) are:
      - Satisfaction with the level of information received on the performance and operation of the building
      - Satisfaction with the interfaces for receiving information on the building operation and performance
      - Satisfaction with the frequency of the information received.

Table 29. Link between" Information to occupants" impact criteria and User-related KPIs

	User-related KPIs		
	Satisfaction with the level of information received on the performance and operation of the building	Satisfaction with the interfaces for receiving informations on the building operations and performance	Satisfaction with the frequancu of the information recieved
Energy savings on site			
Maintenance & fault prediction			
information to occupants			
Wellbeing and health			
Comfort			
Convenience			
Flexibility for the grid and storage			

- Economic KPIs (Table 30):
   - Total initial investment (CAPEX): considering that the investment costs of all the devices of each SRS affect the capital expenditure, this KPI has been considered as linked to all the SRSs included in all impact criteria.
   - Payback period (PBP): considering that the PBP will be calculated starting from the evaluated CAPEX and money savings values, this KPI has been considered as linked to all the SRSs included in all impact criteria.
   - Internal rate of return (IRR): considering that the IRR will be calculated starting from the evaluated money savings values, this KPI has been considered as linked to all the SRSs included in all impact criteria.
   - Levelized cost of energy (LCOE): considering that the LCOE will be calculated starting from the evaluated FEC, CAPEX and OPEX values, this KPI has been considered as linked to all the SRSs included in all impact criteria.
   - Operational costs (OPEX): considering that the OPEX calculation is affected by energy costs, depending on energy demand and generation efficiency, and maintenance costs, this KPI has been considered as linked to all the SRSs included in all impact criteria except for the ones affecting only the user comfort (i.e., Wellbeing and health, Comfort and Convenience).
   - Operational costs variation for battery, BIPV and EV: considering that the OPEX variation due to implementation of SRSs related to battery, BIPV and EV, this KPI will be calculated starting from the evaluated overall OPEX variation, this KPI has been considered as linked to the SRSs included in the same impact criteria

affecting also the OPEX KPI.

Table 30. Link between impact criteria and Economic KPIs

	Economic KPI					
	Total initial investment (CAPEX)	Payback period	Internal return rate	Levelized cost of energy	OPEX (operational expenditure)	OPEX variation for battery, BIPV and EV
Energy savings on						
Maintenance & fault						
information to occupants						
Wellbeing and health						
Comfort						
Convenience						
Flexibility for the grid and storage						

5.5.2 Theoretical analysis

Starting from the previously defined preliminary link between the SRS (and so their impact scores) included in the different impact criteria and the KPIs, the methodology that will be used to generate a regression between these parameters allowing to estimate the KPIs in the post-intervention scenario before the monitoring campaign has been defined and will be presented in this chapter.

The regression that will be defined will link the KPI value, or the value of a specific term of the equation used to evaluate the KPI, and the sum of the impact scores derived from the SRS affecting this parameter. The points that will be used to generate the regression can be depict in a simplified version (i.e., mono dimensional correlation) on the plot in Figure 21 and they will be generated from the measurements of the monitoring campaign that will be carry on before the interventions implementation and from the simulation of the post-intervention scenario by means of the physical models that will be developed within T3.1 for the energy performance evaluation and for the control algorithms testing phase. Considering this approach for each KPI, or KPI equation term, there should be three points for the pre-intervention scenario and three points for the post-intervention scenarios (Figure 21) taking into account the chance to evaluate these parameters in the three demos for which the SRSs levels are known. However, some KPIs, or equation terms, will be evaluated for less than the three demos, depending on their specific configuration (e.g., a specific domain is missing, such as the DHW domain in Granada and Delft), and so lower possible maximum order of the built regression can be reached. After the post-intervention monitoring campaign other points could be generated, allowing to verify the reliability of the correlation. In chapter 5.5.1 the preliminary identified link between the impact scores, that should be summed in order to became reported on the horizontal axis, and the KPI value has already been presented; however, the definitive link will be described once the regression will be generated during the KPIs calculation that will be carry out during T5.5.

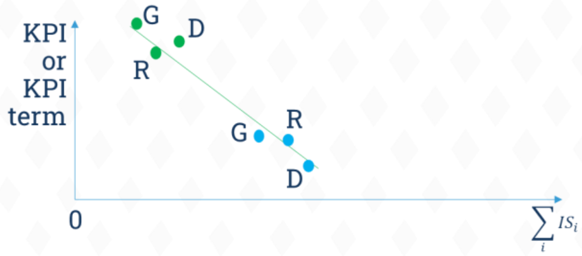

Figure 21. Example of available points (D: Delft, G: Granada, R: Riga – green points: baseline – blue points: future scenario) and polynomial correlation (linear) between KPI (or KPI term) and impact scores

The polynomial correlations will be generated applying regression techniques, such as the least square method or the RMSE minimization, by means of tools such as Python or Matlab. The order of the polynomial correlation will depend on the number of available points and on the evaluation of the benefit that a higher order will bring to the reduction of the error with the data known before the post-intervention monitoring phase. For now, the regression method has been identified as applicable for defining the correlation between the value of the sum of the ISs and:

- Energy KPIs:
    - The useful energy
    - The FEC
    - The RES exploitation level.
- Indoor environment KPIs:
    - Indoor air temperature
    - Indoor relative humidity
    - Indoor CO_2 concentration
    - Indoor PM10 concentration
    - Lux at desk level.
- User-related KPIs:
    - Weighted percentage of hours outside the thermal comfort range
    - Weighted percentage of hours outside the visual comfort range
    - Hours of unobstructed window view
    - Hours outside recommended levels of noise
    - Level of thermal satisfaction
    - Number of reported thermal discomfort events
    - Level of visual satisfaction with daylight availability, glare mitigation and outdoor view
    - Number of reported visual discomfort events
    - Level of acoustic satisfaction
    - Number of user overrides of thermal comfort systems
    - Time with pollutants concentration levels above recommended standards
    - Satisfaction with air quality

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    - Number of overrides of building systems related to the indoor air quality
    - Number of user overrides of daylights and light systems
    - Satisfaction with the level of information received on the performance and operation of the building
    - Satisfaction with the interfaces for receiving information on the building operation and performance
    - Satisfaction with the frequency of the information received.
- Economic KPIs:
    - CAPEX
    - Maintenance costs
    - Energy costs.

The parameters listed above have been differentiated in tables from Table 24 to Table 30 highlighting the cells in darker shades of colors. Instead, the other ones, in lighter shades, will be evaluated not downstream the definition of a dedicated regression, but applying the equations using the updated data derived from the forecast of the post-intervention scenario parameters values (e.g., the maintenance and the energy cost, in addition the CAPEX, to evaluate the PBP).

More complex regressions could be generated considering the influence of each SRS, and the related ISs, on the KPI, or the KPI term, generating multidimensional correlations. However, in this way, an increase of the number of points needed to build the regression is mandatory. A higher number of points could be reached by having more demos to study, performing a literature review, or increasing the scenario to be simulated with the physical models. In addition to the impossibility to increase the number of studied demos within the SMARTeeSTORY project, also the other two solutions present some complications. The literature review causes an effort increase and the need to find the data needed for the evaluation of the specific KPIs, selected within T1.1.3 activity and presented in the previous chapters, in addition to the detailed information for the identification of the SRSs levels, useful for the evaluation of the related ISs. Also, the simulation of different post-intervention scenarios on the same demo physical model lead to an effort increase due to the need to modify the devices included in the models following the set SRSs levels and to adapt the related control logic. Due to the need to increase the effort for their development, these activities have been discarded and a simple regression will be generated initially taking into account the available data.

In addition to this, the proposed methodology will allow to estimate the impact of the single SRSs or the single domain on the KPIs values. This could be possible considering that there is the chance to correlate the variation of the impact scores associated to a specific set of SRSs with the variation of the KPI value using the following formula:

$$\Delta_{KPI,spec} = \Delta_{KPI} * \frac{\sum_i \Delta_{IS,i}}{\sum_j \Delta_{IS,j}}$$

Where:

- $\Delta_{IS,i}$ is the impact score variation of the specific SRSs included in the set for which we would like to evaluate the influence
- Δ_{KPI} is the global variation of the KPI value or of the value of the term used in the KPI equation

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- $\Delta_{IS,j}$ is the impact score variation of the SRSs that affect the KPI value or the value of the term used in the KPI equation.
- $\Delta_{KPI,spec}$ is the global variation of the KPI value or of the value of the term used in the KPI equation due to the specific SRSs set.

6 Conclusions

Along this document, digitalization and user requirements for historic buildings has been stablished, together to definition and calculation of KPIs in the scope of SMARTeeSTORY project. After the review of regulations and policies about constraints and protective measures adopted to preserve historical buildings, it is concluded that the requirements for digitalization and adaptation of historic buildings to current energy efficient needs would be all those requirements common to regular buildings besides façade renovation and RES installation, namely non-intrusive energy optimization via cost-effective digitalization that reduce energy consumption and increase occupant comfort while preserving the Historical Integrity.

In addition to this, the SRI values for each SMARTeeSTORY demo site have been evaluated using the calculation Method B to define a baseline for the interventions that will be developed within the project.

On the other side, user requirements, encompassing both end users and facility managers, were assessed through a participatory approach. While initial workshops focused on enhancing user awareness, engagement, and understanding of smart building features, co-design workshops are scheduled for the implementation phase to guide interface and control strategy design. End users emphasized the need for a personalized micro-climate, while facility managers stressed the importance of a scalable, user-friendly system utilizing AI and data for performance optimization and prediction, consistent with SMARTeeSTORY principles. User-related KPIs were identified based on the impact domains of the SRI—Comfort, Health, well-being, Convenience, and Information. These KPIs are measured using a mixed-method methodology, combining subjective perceptual data collection methods with behavioural data and information on indoor environmental quality.

Moreover, the identification of the KPIs, and the related equations to assess them, have been performed in order to define a framework to evaluate, during the demonstration phase, the impact of the SRI value variation, and the related digitalization improvement, on economic, informatic, environmental, user-related and energy performances.

Firstly, the identification of the KPIS have been performed. Five different categories have been distinguished: Energy and Environmental, Indoor Environment, Economic, Informatic, and User-related. After the identification of the KPIs, an analysis has been performed to define their applicability to each demo site based on the SRSs that are feasible to implement. In addition to this, the preliminary methods for quantifying each KPI, measuring or calculating the needed parameters, have been reported. This activity will be the basis for the KPIs value calculation, that will be performed in T5.5, and contributes to define the sensors list, in addition to identify the plant sections on which apply them, for the different demo sites.

Finally, a methodology to evaluate the impact of the SRI difference between the baseline and the future scenario on the KIPs values have been developed. An analysis has been carried out to identify firstly the link between the KPIs categories and the Impact Criteria used in the SRI calculation methods, and then to list the specific SRSs affecting each KPI. The connections so defined are the basis for the definition of the dependencies to be considered for the calculation of the regression that will be developed to forecast the effect of the SRSs implementation on economic, environmental, user-related and energy performances. The data needed to define the regression will come from the pre and post interventions monitoring campaigns, in addition to simulations performed using the physical models that will be generated from T3.1.

7 References

[1] UNESCO, 'CONVENTION CONCERNING THE PROTECTION OF THE WORLD CULTURAL AND NATURAL HERITAGE'.

[2] 'Council conclusions on the Work Plan for Culture 2019-2022'.

[3] 'European Cultural Heritage Green Paper', Europa Nostra. Accessed: Aug. 03, 2023. [Online]. Available: https://www.europanostra.org/our-work/policy/european-cultural-heritage-green-paper/

[4] E. Standards, 'EN 16883 - Conservation of cultural heritage - Guidelines for improving the energy performance of historic buildings', https://www.en-standard.eu. Accessed: Jul. 12, 2023. [Online]. Available: https://www.en-standard.eu/csn-en-16883-conservation-of-cultural-heritage-guidelines-for-improving-the-energy-performance-of-historic-buildings/

[5] 'Council of Europe Convention on Offences relating to Cultural Property - Culture and Cultural Heritage - www.coe.int', Culture and Cultural Heritage. Accessed: Aug. 04, 2023. [Online]. Available: https://www.coe.int/en/web/culture-and-heritage/convention-on-offences-relating-to-cultural-property

[6] E. C. European Parliament, *Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC*. Edward Elgar Publishing, 2022. doi: 10.4337/9781800372092.00015.

[7] E. C. European Parliament, 'Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings'.

[8] P. J. O'keefe, 'The European Convention on the Protection of the Archaeological Heritage', *Antiquity*, vol. 67, no. 255, pp. 406–413, Jun. 1993, doi: 10.1017/S0003598X00045506.

[9] 'European Cultural Convention (Paris, 1954) - Culture and Cultural Heritage - www.coe.int', Culture and Cultural Heritage. Accessed: Aug. 04, 2023. [Online]. Available: https://www.coe.int/en/web/culture-and-heritage/european-cultural-convention

[10] 'Par kultūras pieminekļu aizsardzību', LIKUMI.LV. Accessed: Aug. 07, 2023. [Online]. Available: https://likumi.lv/doc.php?id=72551

[11] 'Rīgas vēsturiskā centra saglabāšanas un aizsardzības likums', LIKUMI.LV. Accessed: Oct. 06, 2023. [Online]. Available: https://likumi.lv/doc.php?id=76001

[12] 'Rīgas vēsturiskā centra saglabāšanas un aizsardzības noteikumi', LIKUMI.LV. Accessed: Oct. 06, 2023. [Online]. Available: https://likumi.lv/doc.php?id=85432

[13] 'Spēkā esošais teritorijas plānojums Rīgas vēsturiskajā centrā un tā aizsardzības zonā', RDPAD. Accessed: Oct. 06, 2023. [Online]. Available: https://www.rdpad.lv/par-rvc/speka-esosie-planojumi-rvc-un-ta-aizsardzibas-zona/speka-esosais-teritorijas-planojums-rvc-un-ta-aizsardzibas-zona/

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