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Prescient building Operation utilizing Real Time data for Energy Dynamic Optimization

WP7 – DEMONSTRATIONS IN OPERATIONAL ENVIRONMENT

D7.4 – Demo site report #3 Krakow

Version 1.0

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PRELUDE KEY FACTS

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PRELUDE CONSORTIUM PARTNERS

	Participant organisation name	Country
1	AALBORG UNIVERSITET	DK
2	TAMPEREEN KORKEAKOULUSAATIO SR	FI
3	ASOCIACIÓN DE INVESTIGACIÓN METALÚRGICA DEL NOROESTE	ES
4	POLITECNICO DI TORINO	IT
5	FORSCHUNG BURGENLAND GMBH	AT
6	UNISMART - FONDAZIONE UNIVERSITÀ DEGLI STUDI DI PADOVA	IT
7	BRUNEL UNIVERSITY LONDON	UK
8	EMTECH DIASTIMIKI MONOPROSOPI IDIOTIKI ETAIREIA	EL
9	CORE INNOVATION AND TECHNOLOGY OE	EL
10	ESTIA SA	CH
11	EUROCORE CONSULTING	BE
12	IREN SMART SOLUTIONS SPA	IT
13	LIBRA AI TECHNOLOGIES PRIVATE IDIOTIKI KEFALAIOUCHIKI ETAIREIA	EL
14	STAM SRL	IT
15	LA SIA SRL	IT
16	TREE TECHNOLOGY SA	ES
17	1A INGENIEROS S.L.P	ES
18	DIMOS ATHINAION EPICHEIRISI MICHANOGRAFISIS	EL
19	BLOK ARCHITEKCI SPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA	PL
20	CAISSE DE PREVOYANCE DE L'ETAT DE GENEVE	CH
21	INNOVACION Y CONSULTING TECNOLOGICOSL	ES
22	CORE INNOVATION CENTER NPO	GR

EXECUTIVE SUMMARY

This report provides key findings from the demo site project in Krakow for the Prescient building Operation. The project aimed to improve occupant comfort and energy optimization in office buildings. Thermo-modernization was identified as a cost-effective approach, while portable air conditioners and intelligent thermostats were implemented due to resource limitations. Ongoing monitoring, analysis, and user engagement through an application are crucial for achieving energy efficiency goals. The project highlights the need for substantial investment in enhancing user comfort and emphasizes the importance of continuous improvement and user involvement in optimizing energy usage.

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ABBREVIATIONS

BIM	Building Information Modeling
DBRP	Dynamic Building Renovation Plans
IAQ	Indoor Air Quality
PM 2,5	particulate matter with a diameter of 2.5 µm or less
RES	renewable energy source
VOC	Volatile organic compound

1. INTRODUCTION

1.1 Objectives

The objective of this report is to demonstrate the reduction of energy consumption made possible by the implemented PRELUDE technologies (simulations on external shutters, renovation roadmap, and behavioural change and habits based on available app).

1.2 Overview of use case

The initial plan for the PRELUDE project was to use a residential building in Krakow as the demo case. However, due to the lack of consent from the residents, the project had to be re-evaluated, and a new demo case was chosen.

The new demo case is an office building located at Szlak St. in Krakow, which was constructed between 1965 and 1968. This building is representative of the older office buildings still in use, usually located in prime locations in city centers, and it embodies the challenges of reducing energy consumption in such buildings through proper refurbishment.

The office building at Szlak St. has a total area of 5,815.65 m2, with 10 storeys and a total storey area of 480.75 m2. The energy consumption in such buildings is high, with typical energy performance ranges between 250 and 500 kW/m2. Therefore, this group of buildings is particularly interesting for research aimed at reducing energy consumption.

The end-users for this project are the building owners who are investigating possibilities of further modernization, as well as the office users willing to be part of the research. The building owners are interested in participating in project activities and obtaining questionnaires. The renovation roadmap can consider a wide spectrum of technical interventions, such as automatic louver systems, changes in ventilation and air conditioning systems, and the integration of photovoltaic systems.

BLOK, the organization represented in the Consortium through which S-LABS Sp. z o.o. participates in the Advisory Board, is interested in extending their digitization services, and more specifically BIM. The benefits offered by PRELUDE will provide additional motivation for clients to digitize their assets and become more receptive towards innovative technologies. The focus of PRELUDE on techno-economic analysis and features such as the DBRPs will provide clarity of knowledge with regards to leveraging renewable energy source (RES) investments.

The methodology for this project will involve outfitting the office building with sensors to collect data on energy consumption patterns, including individual thermostats, which will provide information on aggregated consumption profiles. The office users will receive alerts and notifications to improve their consumption patterns, and the overall consumption peaks will be assessed in the context of district heating.

2. Requirements of the Use Case

2.1 Description of the buildings and their current state

The building is a 10-storey office building with one underground floor, located in the city center of Kraków, Poland. The building has a total area of 5820 m2, with part of the first floor designated as a sensored area of 155m2. The sensored area includes an open office space, conference room, and social room.

The building is grid-connected, with its electricity supplied by TAURON Group. The building does not have a building automation system, and the ventilation system is a natural ventilation system. There is no cooling system or air conditioning in the building, with only two air conditioning units present on your floor. The water supply is provided by MPW Company, and the district heating system is based on coal, with heat supplied from the switchgear to the radiators on each floor. The building has radiators in all rooms without smart valves.

To improve energy efficiency, a PRELUDE solution with two submeters on the floor and smart valves mounted on the radiators is proposed. Additionally, Lerta and FOS sensors are installed as part of the PRELUDE solution. These sensors can provide valuable data on energy usage, temperature, and humidity, which can be used to optimize energy consumption and improve indoor air quality.

Overall, with these energy supply systems, building automation, ventilation system, water supply, district heating, and sensors, there is potential to reduce energy consumption and improve energy efficiency in the building.

The building has a traditional low technology construction with double-glass plastic windows and traditional gravity ventilation. The heating system is a central heating system from the MPEC, with radiators installed in offices and common spaces on all 10 floors. The building operates during regular office working hours.

It is important to note that there are no existing sensors, no automation, and no smart devices installed in the building.

Figure 1 Photos of the building

Figure 2 Floor plan

2.2 Overview of the local regulations and standards

Sustainable construction is the practice of creative construction and operation work that is environmentally responsible and resource-efficient throughout an organization's life cycle, from initial planning and design to construction, operation, and maintenance. Until now, the focus on sustainability has only been in the user phase. However, as buildings become more energy efficient, the potential for sustainability is expanding using the following phases: from planning to construction. Thus, regulations and standards have started to take those aspects into account.

Sustainable buildings are of immediate interest to owners and investors who want to get more energy-efficient buildings and be guaranteed low repair and operating costs. Certified sustainable buildings allow them to quickly assess the quality and value of a building and its economic competitiveness. The sustainable stage of construction plays a key role in terms of the use of appropriate materials and technologies, as well as whether sustainable processes have taken place and how location costs, which play a major role in sustainability costs, have evolved. Doing so brings additional benefits, as construction companies gain profit growth through changing proprietary business models, allowing them to provide new products and services with increasing accuracy to meet customers' needs for a sustainable building. Construction companies are therefore increasingly being urged to produce a sustainable building, as well as labeling systems that cover all aspects of a building's life cycle and evaluated through rating systems such as **DGNB or BREEM, LEED.**

2.2.I Sustainability

2.2.I.I Development of EU-wide standards by the CEN/TC 350 Technical Committee

The CEN/TC 350 Technical Committee is developing technical standards related to green building in Europe. The CEN/TC 350 guidelines are implemented into national polish building regulations, as well as into voluntary product evaluation and building certification and assessment systems.

The committee is responsible for the development of horizontal standardized methods for the assessment of the sustainability aspects of new and existing construction works (buildings and civil engineering works) in the context of the UN Sustainable Development Goals and of the circular economy.

Standardization work - list of main standards

At the first level of principles defined by CEN/TC 350 is the core standard EN 15643-1 "Sustainable buildings. Sustainability assessment of buildings. Part 1: General provisions." It is linked to the framework level by the following standards on environmental, social, and economic performance:

- EN 15643-2 "Sustainable buildings. Assessment of buildings. Part 2: Provisions for the assessment of environmental performance", EN 15643-3 "Sustainable building facilities. Assessment of buildings. Part 3: Provisions for the assessment of social performance", EN 15643-4 "Sustainable building facilities. Assessment of buildings. Part 4: Provisions for the assessment of economic performance".

The second level is the building level, which is also divided into standards for environmental, social, and economic performance:

- EN 15978 "Sustainable buildings. Assessment of environmental performance of buildings. Calculation method", EN 16309 "Sustainability of building facilities. Assessment of social performance of buildings. Calculation methodology",
- EN 16627 "Sustainability of buildings. Assessment of economic performance of buildings. Calculation methods".

At the third level, there are standards grouped for the assessment of environmental performance., Some aspects of social and economic assessments are however included in the following standards:

- EN 15804 "Sustainability of buildings. Environmental product declarations. Basic principles for categorization of construction products",
- CEN/TR 15941 "Environmental product declarations. Methodology for selection and use of generic data",
- EN 15942 "Sustainable building facilities. Environmental product declarations. Message format: business-to-business".

2.2.I.II <u>PN-EN 15978:2012</u>

This standard UNE EN 15978:2012 Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method is classified in two ICS categories. A calculation method based on life cycle assessment (LCA) for evaluating the environmental performance of a building is provided, and a means of communicating the evaluation results is given. The assessment approach covers all stages of a building's life cycle and is based on data obtained from environmental product declarations (EPDs), their "information modules," (prEN 15804) and when appropriate other information related to the environmental performance of the building as a whole. Included are all building-related construction products, processes, and services throughout the building's life cycle.

2.2.II THE CONSTRUCTION LAW

The Act Journal of Laws Dz.U. 2023.682 - regulates activities related to the design, construction, maintenance and demolition of buildings.

The Construction Law, in particular:

- regulates issues related to the performance of independent technical functions in construction and construction authorizations
- defines the rights and obligations of the participants in the construction process, i.e.: the investor, the designer, the construction manager and the investor supervision inspector;
- defines the activities to be performed before the start of construction work, during construction work and at the end of construction;
- Regulates the requirements for maintenance of construction objects;
- defines the powers and duties of the authorities of architectural and construction administration and construction supervision;
- gives the rules of conduct in the event of a construction disaster
- indicates the principles of criminal and professional liability related to non-compliance with construction regulations;

The latest current consolidated text of **the Act Journal of Laws Dz.U. 2023.682** announced by the announcement of the Speaker of the Sejm of the Republic of Poland on March 10, 2023.

a) Ordinance of the Minister of Transport, Construction and Maritime Economy of July 5, 2013, amending the Ordinance on technical conditions to be met by buildings and their location (Journal of Laws DZ.U. 2013, item 926).
b) Regulation of the Minister of Infrastructure and Development of February 27, 2015, on the methodology for determining the energy performance of a building or part of a building and energy performance certificates (Journal of Laws Dz.U. z 2015, item 376).
c) PN-EN ISO 13790:2009, "Energy performance of buildings. Calculation of energy consumption for heating and ventilation".
d) The basic legal act on building energy performance is the Law on Energy Performance of Buildings – PN - EN 12831:2006, "Heating systems in buildings - Method of calculating the heat load."

It defines:

- The principles of preparing energy performance certificates,
- The principles of control of the heating system and air conditioning system in buildings,
- The rules for keeping a central register of energy performance of buildings,
- How to develop a national action plan to increase the number of buildings with low energy consumption.

2.3 Identification of key requirements for the use case

For the PRELUDE project use case, the key requirements can be categorized into several areas, such as data collection, technology implementation, user engagement, and performance analysis. Here is a list of key requirements we considered for this use case:

1. Data Collection:
a. Install the necessary sensors to measure energy consumption, temperature, humidity, and other relevant parameters.
b. Ensure reliable and secure data transmission from the sensors to the central data management system.
c. Develop a robust data storage and management solution to handle the large volume of data generated by the sensors.
2. Technology Implementation:
a. Integrate smart valves and submeters to monitor and control energy consumption in heating systems.
b. Evaluate and implement potential building automation systems for improved efficiency.
c. Consider upgrading the building's infrastructure, such as windows, insulation, and lighting, to reduce energy consumption.
d. Investigate the feasibility of integrating renewable energy sources, such as photovoltaic systems, to reduce dependency on grid electricity.
3. User Engagement:
a. Develop a user-friendly interface to display real-time energy consumption data and provide alerts and notifications to office users.
b. Implement engagement strategies to raise awareness and motivate office users to reduce their energy consumption.
c. Provide regular updates on the project's progress and impact on energy consumption to maintain user interest and involvement.
4. Performance Analysis:
a. Establish a set of key performance indicators (KPIs) to assess the project's success in reducing energy consumption and improving efficiency.
b. Analyze the collected data to identify trends and patterns in energy consumption and evaluate the effectiveness of implemented measures.
c. Continuously monitor and adjust the implemented strategies based on the insights gained from data analysis to optimize the project's impact.
5. Scalability and Replicability:
a. Ensure that the solutions implemented in the demo case can be scaled and replicated in other buildings facing similar challenges.
b. Develop guidelines and best practices based on the project's findings to assist other building owners and operators in implementing similar energy efficiency measures.

By addressing these key requirements, the PRELUDE project can successfully achieve its goals of improving energy efficiency and reducing energy consumption in the demo office building, while also providing valuable insights that can be applied to other similar buildings.

3. Planning of Project Solutions

3.1 Overview of the proposed solutions for each building

The proposed solution combines various aspects, including building modeling, energy performance analysis, sensor installation, data collection and analysis, and renovation roadmaps. By integrating these components, the solution aims to optimize energy consumption, improve efficiency, and provide valuable insights for future projects.

Moving forward, the project team should continue to collaborate and share data, findings, and best practices. The ongoing work on the **energy model, external shutters simulation, correlation model (BUL)** and **occupancy model (ESTIA)** should be completed and integrated into the overall solution. Additionally, the **renovation roadmap by ESTIA** will help guide the building's modernization process, and the development of the **web app by STAM** will enhance user engagement and provide a user-friendly platform for monitoring and analyzing energy consumption data.

In summary, the proposed solution for the office building in Krakow involves a combination of data collection, technology implementation, building modeling, and user engagement to improve energy efficiency and reduce energy consumption. The project's findings and best practices will provide valuable insights that can be applied to other buildings with similar challenges.

The M&V framework **((Measurement and Verification Framework: LIBRA)** developed in PRELUDE is presented in detail in D4.3 and refers to the M&V methodology developed in Task 4.3 of WP4 (Proactive optimization functions). According to the current plan, there is no intention to implement a PRELUDE solution at the Krakow demo site that would impact thermal energy consumption. Thus, it is not needed to apply the M&V methodology. Instead, LIBRA will develop an adjusted baseline model that conforms to the M&V framework and can be used in the future when interventions occur. To be more specific, this approach will lead to an estimated adjusted baseline model, which can also be used for energy consumption forecasting. If the M&V methodology were to be applied, it would be necessary to define the data points that will be used to calculate the thermal energy consumption.

3.2 Technical specifications of the proposed solutions

Since the building is older, it is equipped with outdated technologies. The heating is distributed through the local heating distributor, MPEC[1] and the building features a central heating system with a single heat meter located in the basement while each room is equipped with radiators. Also, the building does not have a cooling system or external shutters, but it uses natural ventilation. As for electricity, there are electric sub-meters installed to monitor various units such as, e.g., air-conditioning units, lighting, computers.

The different sources (as data points) per apartment and the whole building (central) have been mapped (Figure 3 and Figure 4, respectively) for identifying the data points needed to compute the thermal energy consumption. Although an extended monitoring solution has been implemented in Krakow, there are no relevant data points available for selection from the provided datapoints. Additionally, the applied methodology necessitates weather data, particularly outdoor air temperature, which is acquired from the Meteostat Python library [1].

[1] https://www.mpec.krakow.pl

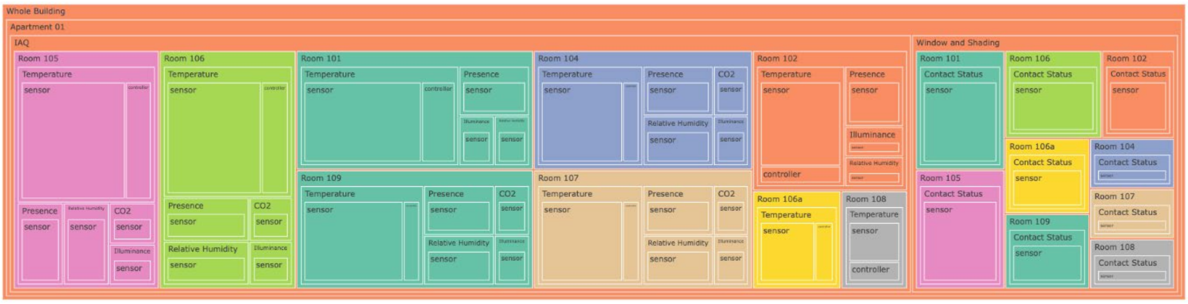


Figure 3: Sensors mapping per room in Krakow.

Figure 4: Centralized Sensors in Krakow

Technical specification of the implemented ICT devices relates to Data Collection process and include sensors, including Lerta and FOS sensors. They are installed throughout the building to monitor energy consumption, temperature, humidity, and other relevant parameters. The data collected by these sensors is securely transmitted to a central data management system for storage and analysis.

Table 1 List of devices installed

	Office set
GateWay	2
Sensor PM2.5/10	9
Window/ door sensor	30
Humidity + temperature Sensor	7
CO2	5
Energy meter	1
Heat meter	1
	1
Smart thermostatic head	12
Smartplug - signal amplifier	5
Motion sensor + lux meter	7
Airly - integration	1

General		
Dimensions (W x H x D)	102 x 102 x 28 mm / 4 x 4 x 1,1 inches	
Color	White (or customer specific)	
Platform	CPU: ARM926EJ-S @ 454 MHz Memory options: 128 MB RAM + 256 MB Flash 256 MB RAM + 512 MB Flash	
Power supply	External netadapter 9V DC, 2 Amp. Optional: Power over Ethernet (PoE)	
Power consumption	Typical: 1.2 W Max. : 2.5 W	
Battery backup OPTIONAL	2-4 hours battery back-up 3.7 V 2000mAh Li-Polymer User exchangable	
Ethernet	10/ 100 Mbit/s	
Expansions	USB port (hidden in compartment) Internal Micro SD card slot	
Environment	IP class: IP20 Operation temperature 0 to +50°C (32 - 122°F) Battery temperature 0 to 40°C (32 - 104°F) Relative humidity 5% - 85%, Non condensing	
Hardware Security OPTIONAL	NXP SE050 Apple MFi (Requires Apple certification of the end product)	
Wireless communication		
Zigbee OPTIONAL	Frequency: 2.4 GHZ Protocol: Zigbee 3.0 Sensitivity Typ: -101 dBm Output power Typ: +18 dBm (+12 dBm EU)	
Wireless M-Bus/ Sub 1 GHz Radio OPTIONAL	Frequency: 868 MHZ (Europe only) Protocol: WMB TI KCI Mode Sensitivity Typ: -100 dBm Alternative: Other Sub 1 GHZ protocols	
Z-Wave OPTIONAL (Requires Z-Wave certified end product)	Frequency: 868/916 MHz, etc. (depending on region) Protocol: Z-Wave Plus Sensitivity: -103 dBm Output power: +4 dBm	
WLAN OPTIONAL	Frequency: 2.4 GHZ Protocol IEEE: 802.11 b/g/n (Access Point and/or Station) Sensitivity Typ: -98 dBm Ouput power Typ: +20 dBm	
Wireless Module	DevCom module space for custom module	
Bluetooth OPTIONAL	Protocol: 5.1 Sensitivity Typ: -94 dBm Transmit power Typ: +12 dBm	
BLE Pro OPTIONAL	Protocol: 5.1 Sensitivity: -95dBm (-103 dBm @ 125 KB/s) Transmit power: +19dBm	
Cellular Module OPTIONAL	Internal Modem options: LTE Cat1 (EU) / LTE Cat1 (US) - LTE Cat-M1 / NB-IoT Antenna options: Internal antenna, external antenna, or both	
SIM card OPTIONAL	Micro SIM (single or dual) Embedded SIM (eSIM) Micro + Embedded SIM	
Certifications		
Radio	EN 300 328 EN 300 220-1 EN 300 220-2 EN 301 511	EN 301 908-1 EN 301 908-13 RED CE
Safety	EN 62368-1:2014 + A11:2017 EN 62311:2008	
EMC	EN 301 489-1 EN 301 489-17 EN 301 489-3 EN 55032:2015 + A11:2020	EN 55035:2017 + A11:2020 EN IEC 61000-3-2:2019 EN 61000-3-3:2013 + A1:2019 EN 301 489-52
FCC	SAR Evaluation: 47 CFR Part 1.1307 47 CFR Part 1.1310 47 CFR Part 2.1091	Radio Spectrum: 47 CFR Part 15, Subpart C 15.247 47 CFR Part 15, Subpart B 47 CFR Part 15, Subpart C 15.249
IC	RSS102 Issue 5 March 2015 RSS-247 Issue 2, February 2017 RSS-Gen Issue 5, March 2019 Amendment 1	ICES-003:Issue 6 RSS-210 Issue 10 Dec 2019
Operating System	Linux	

Figure 5 Gateway

Smart Plug Mini - Technical specifications

Model numbers: SPLZB-131 (Schuko), SPLZB-132, (FR), SPLZB-134 (UK)

General

Dimensions (Ø x H)	Ø41 X 45 mm (Type G 48 X 48 X 32 mm)
Color	White
Plug types	Schuko, French, British
Weight	Type E, F: 45.1 g (with packaging: 75.9 g), Type G: 71.1 g (with packaging: 101 g)
Power supply	230V +/-10%
Power consumption	0.4 W
Radio	Sensitivity: -101 dBm @ 1% PER Output power: +8 dBm
Environment	IP class: IP40 Operation temperature 0 to +50°C Relative humidity 5% - 85%, non condensing

Functions

Power meter	Voltage range:	207 to 253 VAC
	Accuracy:	Typ +/- 1 %
	Reported resolution:	1W
Remote control	Max. switch voltage:	250 VAC
	Max. load:	16 A
	Max. continuous load:	10 A (Type G 13 A)
	Overload and over temperature protection	

Communication

Wireless protocol	Zigbee Home Automation 1.2, Zigbee router

Certifications

Conforming to CE, RED, Low Voltage and RoHS directives

Zigbee Home Automation 1.2 certified

zigbee certified product

Figure 6 Smart plugs

Window Sensor - Technical specifications

Model numbers: WISZB-120 (Full version), WISZB-121 (Basic version)

General	
Dimensions (W x H x D)	76 x 26 x 17 mm (sensor part) 30 x 12 x 9 mm (magnetic part)
Color	White
Weight	28.8 g (with packaging: 93.1 g)
Power supply	Battery: 2 x AAA, exchangeable Battery life: 9 years of battery life, when reporting every 2 min Battery level and low battery warning can be reported
Radio	Sensitivity: -98 dBm Output power: +6 dBm
Environment	IP class: IP40 Operation temperature 0 to +50˚C Relative humidity 5% - 85%, non condensing
Functions	
Temperature sensor	Range: 0 to +50˚C Resolution: 0.1˚C (accuracy Typ ±0.5˚C and Max ±2˚C) Sample time: config.: 2 s -65,000 s Reporting: configurable
Detection	Magnetic: 0.1-1.0 cm
Communication	
Wireless protocol	Zigbee Home Automation Zigbee end-device
Certifications	Conforming to CE, FCC, IC, ISED, RED and RoHS directives Zigbee Home Automation 1.2 certified

Figure 7 Window sensor

Humidity Sensor - Technical specifications

Model number: HMSZB-110

General	
Dimensions (W x H)	70 x 70 x 21 mm / 2.76 x 2.76 x 0.83 inches
Weight	27.2 g / 0.96 oz (with packaging: 114.9 g / 4.05 oz)
Colour	White
Power supply	Battery: 2 x AA, exchangeable Battery life: 5 years, reporting every 5 minutes Battery level and low battery warning can be reported
Radio	Sensitivity: -92 dBm Output power: +3 dBm
Environment	IP class: IP20 Operation temperature 0 to +50˚C / 32-122˚F Relative humidity 5% - 85%, non condensing
Functions	
Temperature sensor	Range: 0 to +50˚C / 32-122˚F Resolution: 0.1˚C / 0.18˚F (accuracy Typ ±0.5˚C / 1˚F and Max ±2˚C / 4˚F) Sample time: config.: 2 s -65,000 s Reporting: configurable
Humidity sensor	Range: 0 to 100% rH Resolution: 1% rH (accuracy ± 3,5% rH, 20 - +80% rH)
Communication	
Wireless protocol	Zigbee Home Automation Zigbee end-device
Certifications	Conforming to CE, FCC, IC, ISED, RED and RoHS directives Zigbee Home Automation 1.2 certified

zigbee certified product

Figure 8 Humidity sensor

Motion Sensor Mini - Technical specifications

Model numbers: MOSZB-140 (Full version), MOSZB-141 (Basic version)

General

Dimensions (W x H x D)	70 x 70 x 21 mm / 2,76 x 2,76 x 0,83 inches
Weight	31.4 g / 1.11 oz (with packaging full version: 162.1 g / 5.72 oz)
Color	White
Power supply	Battery: 2 x AA, exchangeable Battery life: 3 years, reporting every 2 minutes Battery level and low battery warning can be reported
Radio	Sensitivity: -92 dBm Output power: +3 dBm
Environment	IP class: IP30 Operation temperature 0 to +50°C / 32 - 122 °F Relative humidity 5% - 85%, non condensing

Functions

Occupancy & alarm sensor	Sensitivity range: 9 m (30 ft) View angle: 45° up/down, left/right Off-time: configurable 2 s - 65,000 s Two trigger levels: one for occupancy and one for alarm
Light sensor	Resolution: dark, light, bright Sample time: config.: 2 s -65,000 s Reporting: configurable
Temperature sensor	Range: 0 to +50°C / 32 - 122 °F Resolution: 0.1°C / 0,18°F (accuracy Typ ±0.5°C / 1°F and Max ±2°C / 4°F) Sample time: config.: 2 s -65,000 s Reporting: configurable

Communication

Wireless protocol	Zigbee Home Automation, Zigbee end-device

Certifications

Conforming to CE, FCC, IC, ISED, RED, RoHS and REACH directives

Zigbee Home Automation 1.2 certified

zigbee certified product

Figure 9 Motions sensors

External Meter Interface - Technical specifications

Model number: ZHEMI-101

General	
Dimensions (W x H x D)	115 x 35 x 70 mm
Color	Black
Weight	113.4 g (with packaging: 246.6 g)
Power supply	Battery: 3 x AA alkaline batteries, exchangeable Battery life: 2 years, updating every 5 seconds, at room temperature Battery level and low battery warning can be reported
RF performance	Sensitivity -98 dBm Output power +8 dBm
Environment	Operation temperature -20 to +60°C IP class: IP22 Relative humidity 5% - 85%, non condensing
Functions	
Meter reading	By exchangeable probes, supporting pulse and IR communication
Interfaces	Supports LED, IR, pulse (configurable pulse range from 50 to 10 000 pulses per kWh) Pulse, S0, and P1 on demand (MOQ 5000)
Communication	
Wireless protocol	Zigbee Home Automation
Certifications	Conforming to CE, RED and RoHS directives Zigbee Home Automation 1.2 certified

Figure 10 Energy meters

Danfoss Ally™ Power Module 24V:	
Power supply	Input: 24V~ or 24V ⎓ SELV +/-25%
	Output: 3V ⎓ -5%/+25%
Power cable	2 m 0.75 mm^2 H05VVH2-F
Ambient temperature range	0 to 40 °C
Transportation temperature range	-20 to 65 °C
Safety classification	Type 1
Pollution degree 2	PD2
Overvoltage category I	OVI 1,5 kV
Color	RAL 9016
Weight	100 g
IP class	20 (not to be used in hazardous installations or in places where it will be exposed to water)
Approvals, markings etc.	CE UKCA

Figure 11 Smart valves

3.3 Implementation plan

1) Building Audit and Energy Performance Analysis:
    a. Conduct a thorough audit of the building to assess its current energy performance and identify areas for improvement.
    b. Engage an external company to perform an energy performance analysis and provide recommendations for energy efficiency measures.
2) Building Modeling and Data Collection:
    a. Create a 3D model of the building in Revit BIM and distribute it to some Prelude partners.
    b. Collect historical data from the administration and distribute it to some Prelude partners.
    c. Gather and distribute electricity consumption (2020-2022) and heat consumption (2017-2022) data.
3) Sensor Installation and Integration:
    a. Install sensors (temperature, humidity, motion, window/door, and CO2) and electric smart valves in the building by Lerta.
    b. Mount electrical submeters by Lerta.
    c. Collect data from the sensors and integrate it with FUSIX (except for CO2).
    d. Set up the Lerta Dashboard for easy access to charts and data visualization.
4) Additional Sensor Installation and Data Collection:
    a. Mount FOS sensors by AIMEN.
    b. Install additional A/C units for PRELUDE scenarios.
    c. Collect data from the A/C units provided by S-LABS.

5) Data Analysis and Recommendations:
    a. Analyze the collected data, including data from sensors, submeters, historical records, and A/C units.
    b. Identify trends, patterns, and areas for improvement based on the data analysis.
    c. Develop recommendations for energy efficiency measures, taking into account the findings from the building audit, energy performance analysis, and data analysis.
6) Implementation and Monitoring:
    a. Implement the recommended energy efficiency measures based on the findings from the previous tasks.
    b. Continuously monitor the performance of the implemented measures using the installed sensors and submeters.
    c. Adjust the implemented strategies based on the insights gained from ongoing monitoring and analysis to optimize the project's impact.

Based on the current plan, there are no immediate intentions to implement a PRELUDE solution that would directly impact thermal energy consumption. Consequently, the analysis conducted is primarily focused on creating an adjusted baseline model that aligns with the M&V framework and will serve as a valuable resource for future interventions or for forecasting energy consumption.

To estimate the total thermal energy consumption, the gas billings provided by the demo site owner will be used as input source. However, since the gas billing data is applicable to the entire building, an approximation will be made to determine the energy usage specifically for the first floor. In Figure 13, the monthly gas consumption data from 2017 to 2022 is depicted in correlation with the temperature displayed in Figure 12. However, the year 2018 will be excluded from the analysis due to significant deviations observed in comparison to other years, rendering it unrepresentative. The remaining years will be utilized to develop the adjusted baseline model.

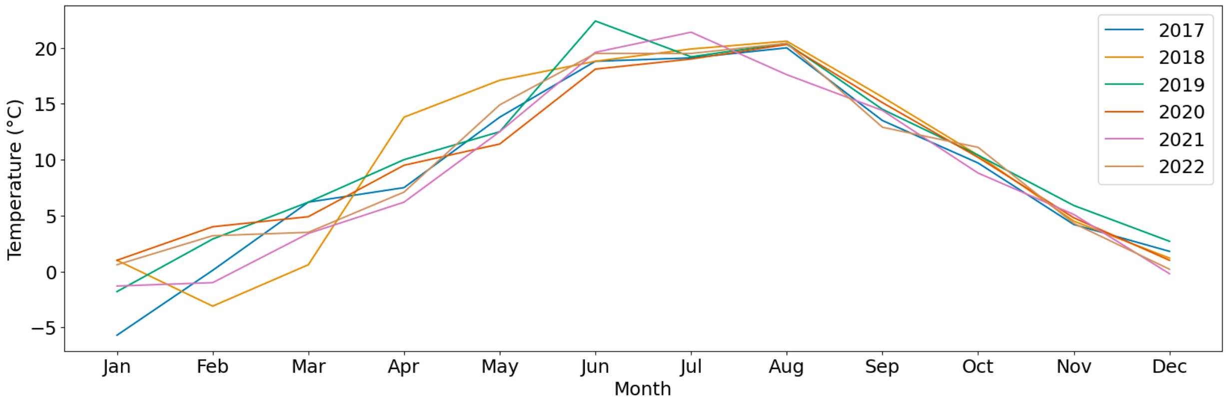


Figure 12: The average monthly temperature in Krakow for the years 2017 till 2022

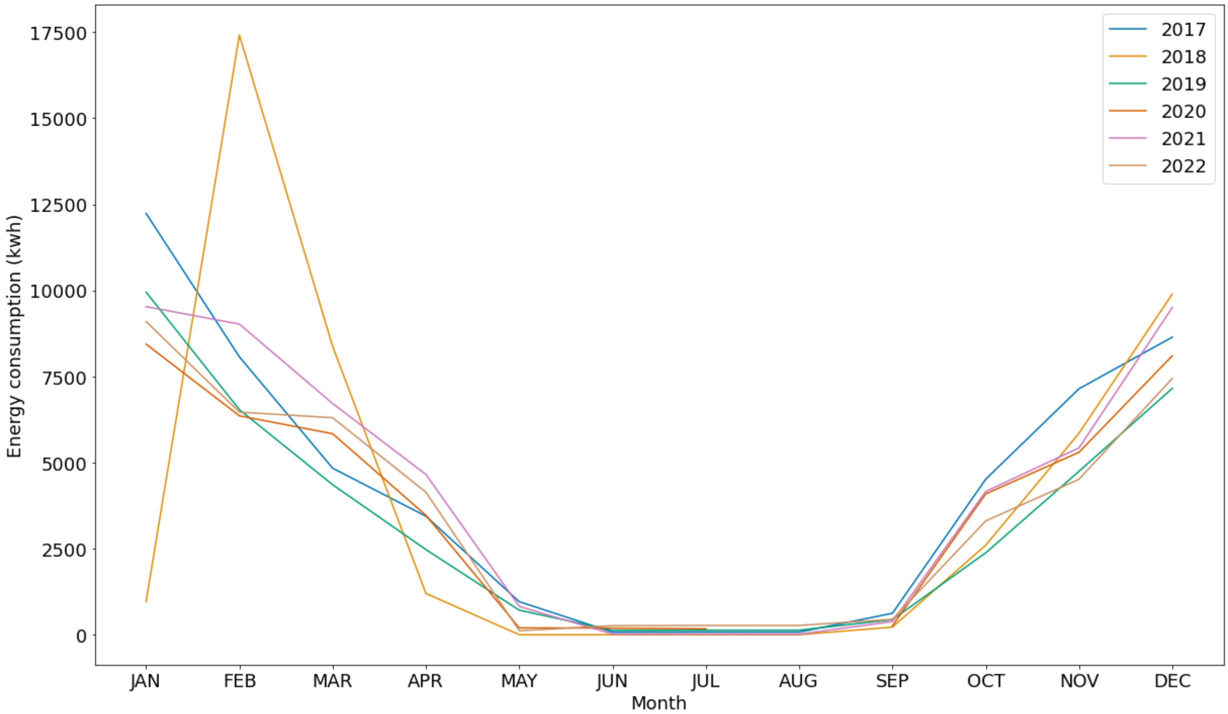


Figure 13: The monthly gas consumption for the Krakow demo site for the years 2017 till 2022

4. Implementation of Project Solutions

4.1 Installation and integration of sensors and monitoring systems

Table 2 Status and Progress of Prelude Project Tasks

TASK	STATUS	Appendix
Audit of the building	DONE	
3d model built up in Revit BIM – distributed to some Prelude partners	DONE	May 2022
Energy performance – done by external company	DONE	October 2022
Historical data from administration - collected and distributed to some Prelude partners	DELIVERED	January 2023
Electricity consumption (2020-2022), Heat consumption (2017-2022)	GATHERED AND DISTRIBUTED	January 2023
Sensors (temperature, humidity, motion, window/door and co2) and electric smart valves mounted by Lerta	MOUNTED	May 2022
Electrical sub meters mounted by Lerta	MOUNTED	May 2022
Data collected by Lerta and integrated with FUSIX (except from CO2)	DONE AND DELIVERED	June 2022
Lerta Dashboard working - we can easily see charts and read data.	DONE AND DISTRIBUTED	June 2022

FOS sensors mounted by AIMEN	DONE	October 2022
Additional A/C units mounted for PRELUDE scenarios	DONE	January 2023
Data collection from A/C units provided by S-LABS	DISTRIBUTED	February 2023

- Sensors and Electrical sub meters mounted by Lerta:

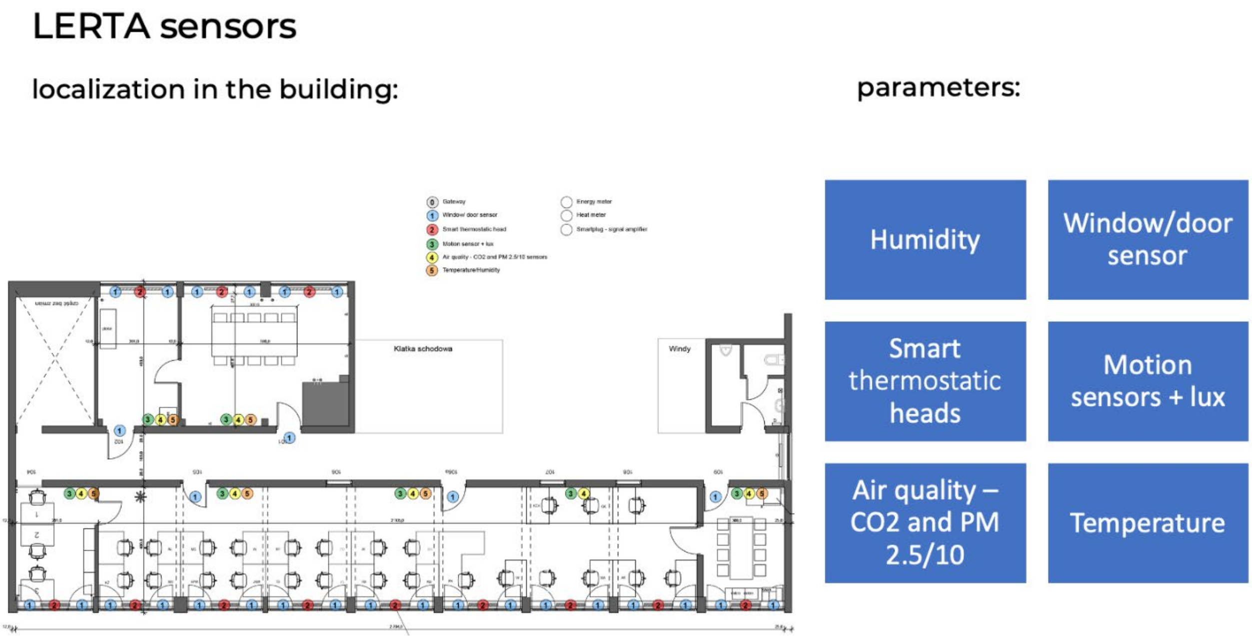


Figure 14 Sensors and Electrical sub meters mounted by Lerta: The sensors mapping

Figure 15 Photographs of installed sensors

Figure 16 Photographs of installed devices

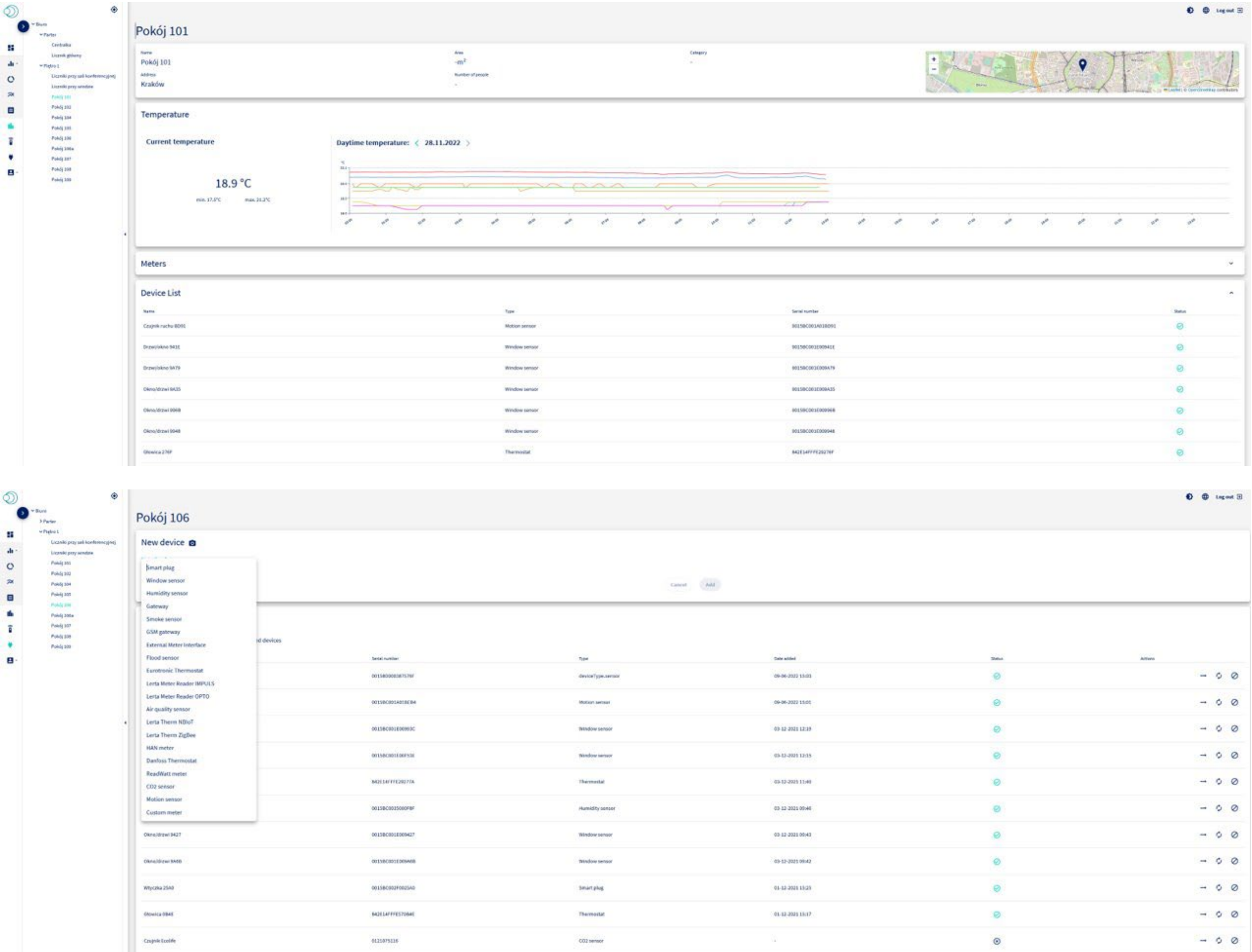


Figure 17 Lerta Dashboard working - we can easily see charts and read data

- FOS sensors mounted by AIMEN

The proposed monitoring solution uses Fiber Optic Sensors (FOS) to effectively monitor the indoor environmental conditions of the office, enabling the collection of real-time data for predictive maintenance modules. The monitoring system leverages the inherent sensing capabilities of fiber optics, offering a multiparametric and intrinsic approach to monitoring. To meet the monitoring requirements of the Krakow demo case, a FOS monitoring solution has been employed based on Brillouin Distributed Fiber Optic Sensors (DFOS). The solution installed at the office of BLOK is based on the developments made during tasks related to WP2, WP4, WP5, and WP7, whose activities are described in detail in the corresponding deliverables. There are explained the developments of the fiber sensors, the technology used to develop the indoor climate monitoring solution, the use of FOS for monitoring passive elements like concrete or bricks, and the upscaling of the FOS monitoring solution to adapt it to buildings.

As explained in other reports, FOS monitoring solutions are present in different scenarios, including the construction sector, where a single fiber optic can monitor thousands of points in a building. However, their usage is primarily focused on structural health monitoring, such as load measurements, crack growth monitoring, and fire detection. Their potential for monitoring environmental parameters like temperature and humidity is not extensively explored, despite their advantages over other sensors like IoT devices. In the context of PRELUDE project, two types of FOS have been tested: punctual Fiber Bragg Gratings (FBGs) and distributed sensors based on Brillouin technology. However, for the use in the Krakow office case study, it is more interesting to use only the distributed solution.

The objective of the monitoring system installed in the Krakow demo case is to gather measurements on indoor climate parameters, particularly temperature variations inside the different zones of the office, to support algorithms and predictive models in the FUSiX system. Optical fibers offer unmatched properties for indoor monitoring, such as small size, immunity to electromagnetic interference (EMI), multiparametric and multiplexing capabilities, and the ability to cover critical points with a single fiber. The monitoring architecture consists primarily of distributed sensors, providing multipoint solutions along the fiber optic. With this setup, temperature measurements can be obtained with a spatial resolution of 0.2-5m, enabling thousands of measurement points from a single optical fiber.

Distributed fiber sensors rely on scattering phenomena in optical fibers, which can be generated through Rayleigh, Brillouin, and Raman effects, leading to different types of distributed sensors with unique properties for various applications. Rayleigh sensors excel in acoustic vibration sensitivity, making them suitable for earthquake monitoring and intrusion surveillance. Brillouin sensors are highly sensitive to strain and temperature, making them ideal for structural health monitoring where both magnitudes need to be measured. Unlike Fiber Bragg Gratings (FBGs) that measure at a single point, distributed sensors utilize the entire fiber as the sensor, offering thousands of measurement points based on spatial resolution and fiber length. Another advantage is that distributed sensors do not require modifications to the fiber for strain and temperature measurements.

To enhance Brillouin sensors, different techniques based on time, frequency, or correlation domains have been proposed, with Brillouin Optical Time Domain Analysis (BOTDA) being the most widely used method. BOTDA sensors rely on stimulated Brillouin scattering, where a probe wave is amplified through coherent addition with a reflected pump wave generated by an acoustic wave. The fiber's composition, temperature, and strain determine the frequency of maximum Brillouin amplification, known as the Brillouin Frequency Shift (BFS), enabling the measurement of temperature and strain.

In BOTDA, a continuous wave serves as the probe, while a pulse acts as the pump traveling in the opposite direction, allowing time-of-flight measurements. The pump pulse amplifies the probe wave along the fiber, and at the opposite end, the probe wave carries spatial information about Brillouin gain. By processing this signal, the maximum gain frequency, proportional to the measured strain and temperature, can be determined. BOTDA sensing requires more complex interrogators compared to other sensing solutions, resulting in higher cost and complexity, also the data processing is more complex than other due to the presence of the distance variable. However, the distributed nature of monitoring data and the simplicity and low cost of the sensor network, consisting of a single-mode optical fiber, are advantageous.

Installation and commissioning of FOS in the demo site

Several meetings were conducted between BLOK and AIMEN to determine the optimal monitoring approach for designing the Fiber Optic Sensor (FOS) network at the KRAKOW demo case. The purpose was to identify the areas that would yield maximum benefits from implementing the FOS system solutions. Following these discussions, an agreement was reached to monitor the temperature distribution in part of the floor, walls, and ceiling of the two rooms that there is in the BLOK´s office.

The development of the monitoring solution involves the use of distributed fiber sensors to measure the temperature distribution within both rooms. The first stage of the installation is the analysis of plans and photos, like the one in Figure 18, provided by BLOK to AIMEN. This initial assessment provides an approximate understanding of how the sensors will be implemented in different rooms and allows for calculations regarding the estimated materials required for the installation process.

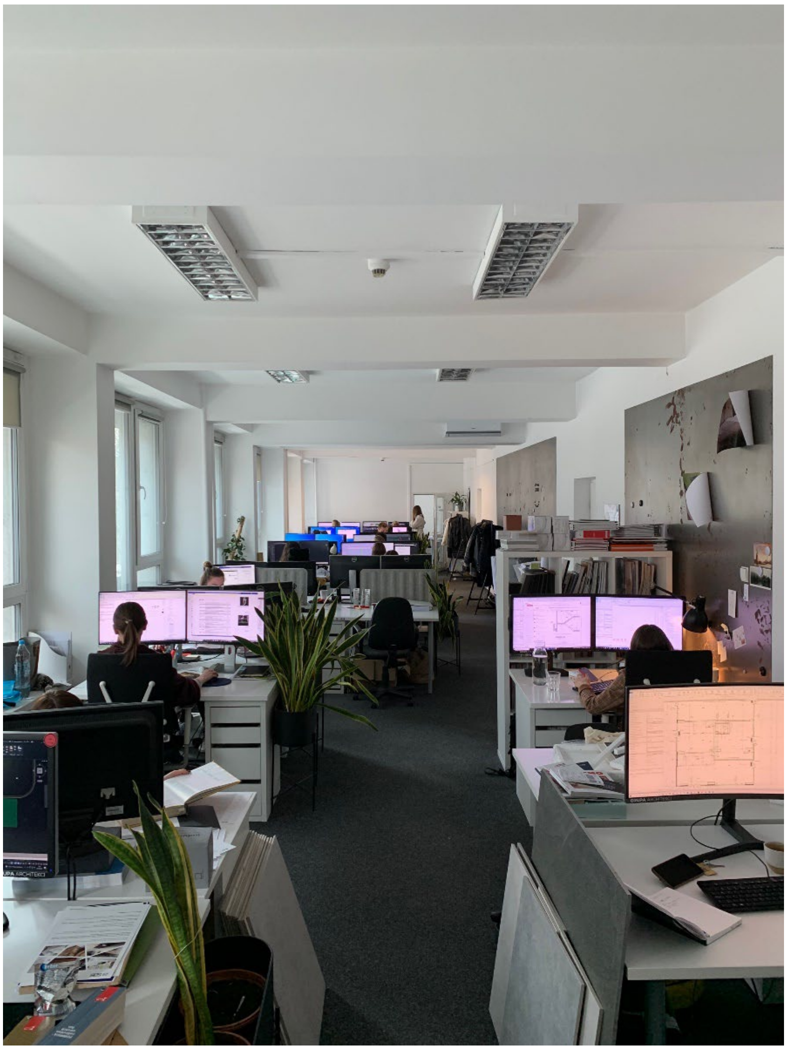


Figure 18. Image of the office

After analyzing both the photos and the plans, it was decided to install two distributed sensors that would cover the largest possible area of the offices, one monitoring the entire edge of the room near the floor and part of the walls, and another fiber or sensor that runs along the edge of the ceiling and crosses from side to side leaning on the beams that the office itself has, passing by the air conditioning elements. The following images, Figure 19 and Figure 20, schematically show the distribution of both fibers in the office. The first one shows the route of the fiber that was installed near the floor in blue, meanwhile the second one shows the fiber near the ceiling painted in red.

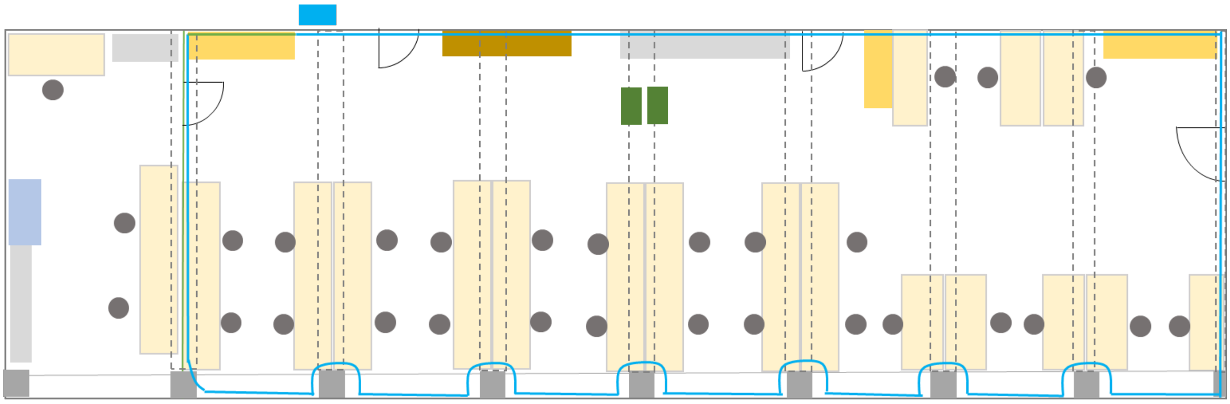


Figure 19. Route of the fiber installed near the floor.

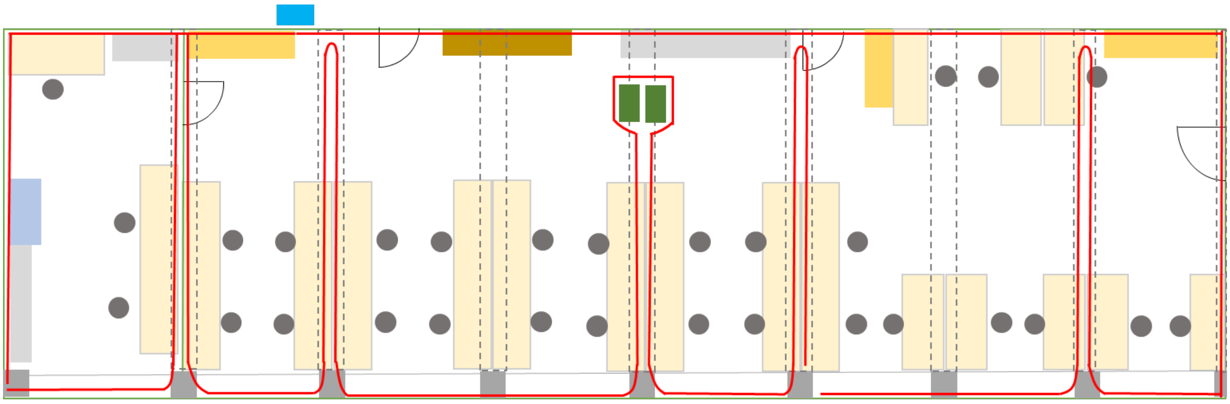


Figure 20. Route of the fiber installed near the ceiling.

The fibers used to measure temperature were planned to be installed on the edge of the floor and ceiling, they do not undergo significant mechanical deformations or displacement, as could happen if the fiber is directly on the ground which may be affected by people walking over it. As a result, these fibers do not require encapsulation in metallic tubes and can be directly fixed onto the surface of the respective elements. When it comes to the walls, the fiber is attached using plastic staples commonly used for electric cables. The provided image demonstrates an example of the fiber securely fixed to one of the walls in the office. The fibers follow a designated path, aiming to cover the perimeter of the office, and then return to its initial point, where they are spliced to create a single distributed sensor. This allows temperature values to be obtained at different positions within the same wall. The fiber fixed to the ceiling follows a route that around the entire office and sometimes across the ceiling horizontally using the beams as a reference. Figure 21 and Figure 22 show two images of the office where it is possible to see the installation of the fiber for temperature measurement.

Figure 21. General view of the office with the fiber installed

Figure 22. Detail of the fiber installed in a corner of the office

Around 350m of fiber optics were used to carry out the installation, although part of this only serves as a link between the interrogator who is in another room and the office to be monitored, being the sensing part close to 200m. Because the spatial resolution used by the interrogator is 0.2m, around 2000 measurement points are obtained.

As mentioned before, the sensing fiber is connected to the distributed interrogator unit which is depicted in Figure 23.

Figure 23. Distributed interrogator installed in BLOK.

Regarding the results obtained, the following figures exemplify the results obtained using this technology. Figure 24 shows the measured results obtained by the distributed interrogator during some consecutive measurements where each color represents a different timestamp. The graph displays the frequency evolution versus fiber distance. It is noticeable that there are slight variations among different distance points. Overall, the trend remains more or less consistent across all the different color lines.

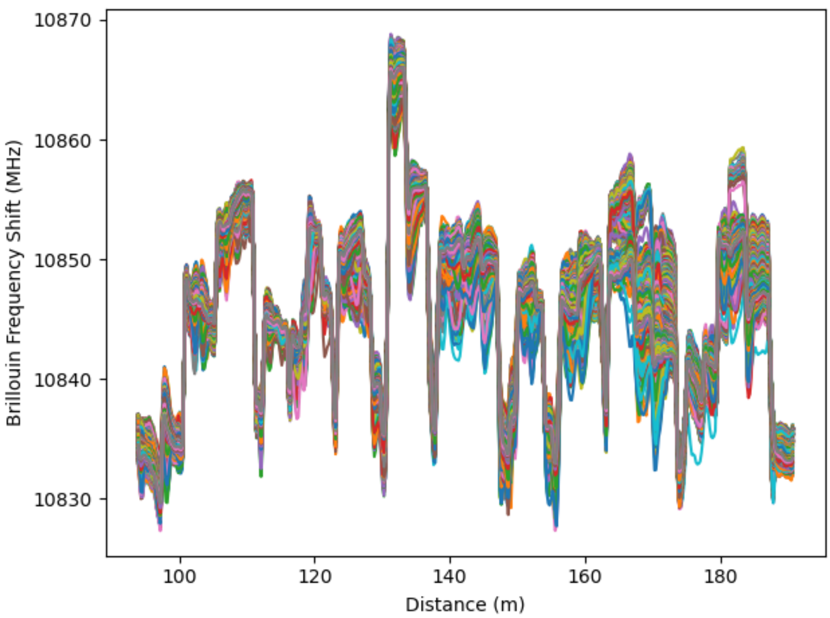


Figure 24. Raw data obtained for the fiber sensor

If this obtained raw information is processed, both the absolute temperature and the temperature variation with respect to a reference point can be calculated. The following two figures show these two types of results, where one, Figure 25, shows a 2D image associating each point of the fiber and the time instant with the temperature variation obtained, and the other, Figure 26, represents the temperature measured at different points in the office during the first 10 days of monitoring.

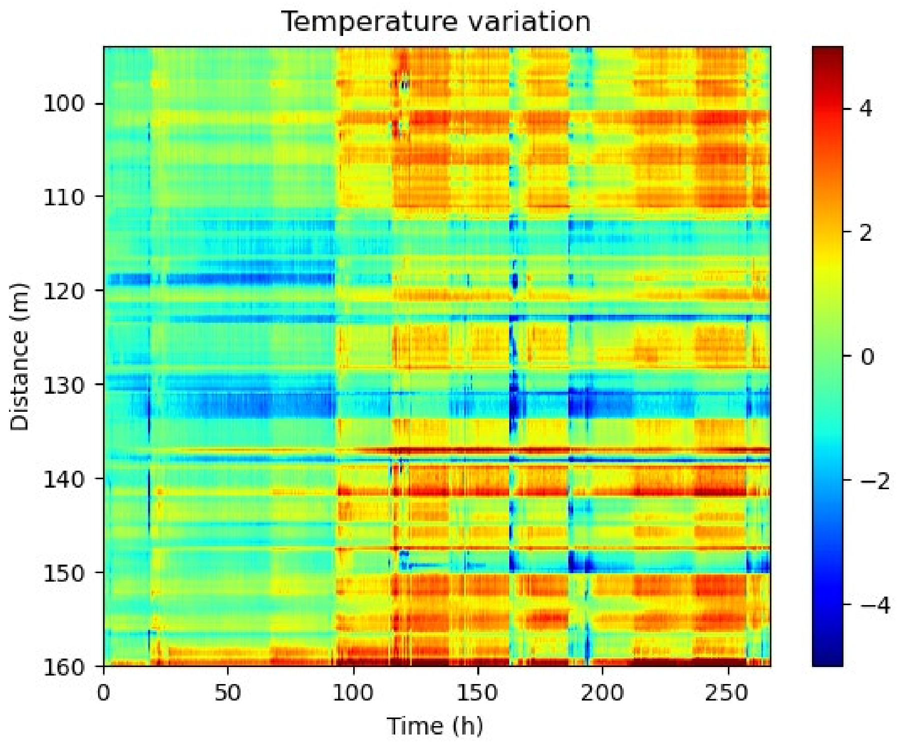


Figure 25 Image representation of the temperature variation of the fiber

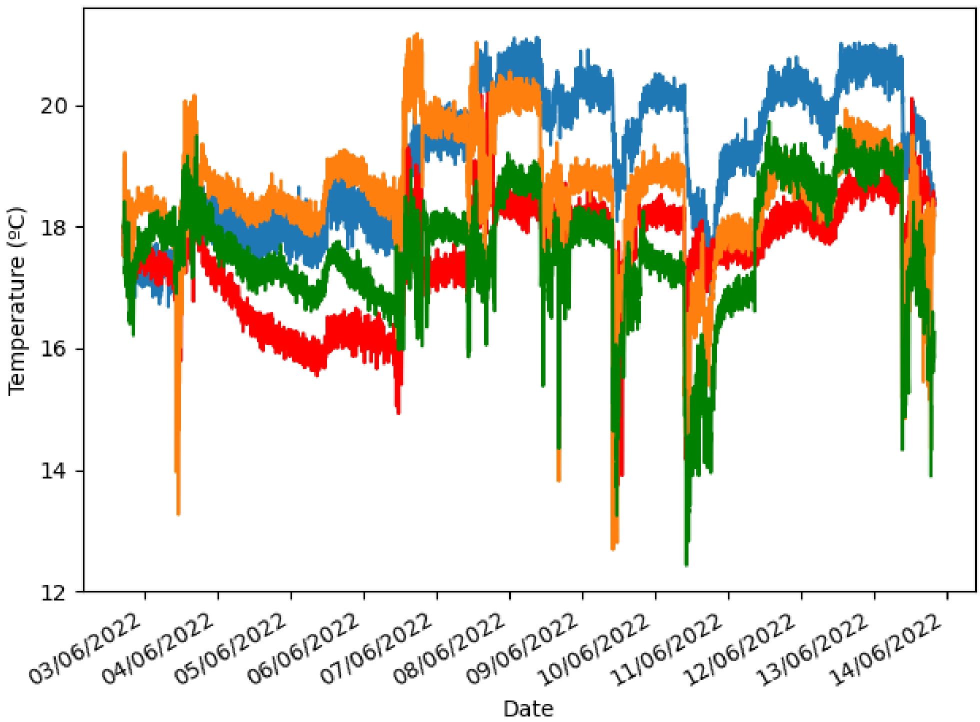


Figure 26. Temperature measurement at different fiber locations.

The figures demonstrate that the fiber optic sensors installed in BLOK´s office are measuring properly, providing reliable measurements. These measured data can be effectively utilized to support the various models implemented within the PRELUDE project. Despite these good results, it has been verified that for certain locations, the measurements have errors due to the interaction of people with the fiber, causing deformations that disturb the interpretation of the measurements, and may cause the fibers to break as already It happened once, and that caused the AIMEN technicians to have to go to the demo to inspect and repair the installation. Taking this into account, the use of another type of fiber that is much more robust and that is only sensitive to temperature is being evaluated.

4.2 Testing and calibration of systems

From May to July 2022, the project team focused on the testing and calibration of the sensors and Lerta systems. During this period, the sensors were mounted, and their performance was closely monitored to ensure accurate data collection and reliable operation. However, some challenges were encountered during the testing and calibration process.

One challenge was the distance between the gateway and the energy meters, which led to weak signal strength. To overcome this issue, signal amplifiers were installed to boost the connection between the gateway and the energy meters. This helped to improve the reliability and stability of the communication between the devices.

Another significant challenge faced during the testing and calibration phase was the connection with the smart meters. Due to cybersecurity threats, the district heating supplier MPEC denied permission to connect to their meter, which meant that the project team was unable to collect heat consumption data directly from the supplier's meter. This posed a considerable limitation to the project, as the heat consumption data is crucial for understanding the building's energy performance and identifying potential areas for improvement.

To address this issue, the project team explored alternative ways to collect heat consumption data. One potential solution could involve installing separate heat meters in the building, which would allow for independent data collection without compromising the heat supplier's cybersecurity. Alternatively, the team could collaborate with the heat supplier to identify secure data sharing methods that would satisfy the supplier's cybersecurity concerns.

To make up for the missing data, Blok has delivered historical data from the invoices which are reliable and don’t require to extend budget covering renovation and new meter installation.

In summary, the testing and calibration of the sensors and Lerta systems took place from May to July 2022, during which several challenges were encountered. The project team successfully addressed the issue of weak signal strength by installing signal amplifiers. However, the inability to connect to the heat supplier's meter remains a challenge that requires further exploration and potential alternative solutions to ensure comprehensive data collection and analysis.

Regarding the Krakow pilot, STAM did not implement their module. The web-app development is an open point, since EMTECH is designing the PRELUDE portal for this purpose. BLOK is open to implement the proposed solution when ready.

4.3 User engagement strategies: Indoor-outdoor correlation module for the Krakow pilot building

The indoor-outdoor correlation module predicts hourly internal environmental conditions from ambient climatic conditions by investigating the relationships between indoor and outdoor conditions in a building for its thermal comfort, indoor air quality and lighting. In Deliverable 3.4, the development of the indoor-outdoor correlation module was presented, demonstrating how the indoor operative temperature, airflow and illuminance can be predicted if the outdoor dry bulb temperature, wind speed and solar radiation are known. A specific model was developed for the Krakow pilot office building. The pilot building is equipped with temperature and CO2 sensors and therefore is possible to compare the predictions of the climate correlation module with measurements. This section presents the correlation equations and some prediction results. The scenarios investigated and the envelope properties used for the EnergyPlus simulations are presented in *Table 3*.

Table 3: Scenarios simulated, building envelope properties and settings

Cases	**Window opening mode**	**Building envelope U value (W/m^2-K)**	**Internal Gain**
Base 1	always closed	0.505 for the external wall, 1.471 for the internal partition, 2.092 for the internal floor, 2.511 for external glazing, and 25 people with internal gain from the appliance.	Occupied 25 people and internal gain from appliances.
Base 2	open (assume 2 hours daily in winter and occupied hours in summer)		
	window closed (the other hours)		
Base 2N	open (winter: 1 hour morning, 1 hour evening) (summer: from 20:00 to 08:00)		

The correlations derived are shown in Table 4 and Table 5.

Table 4: Correlation Equations for Thermal Comfort and Ventilation

Scenario code	Correlation Parameters		Coefficient of determination (R^2)		Correlation Equation for Thermal Comfort and Ventilation	
	x = Outdoor	y = indoor	Window Close	Window Open	Window Close	Window Open
Base 1	DBT	OT	0.7773	n/a	$y = 0.0063x^2 + 0.9309x + 20.318$	n/a
	WS	ACH	0.0051		$y = 4E\text{-}05x^2 + 0.0001x + 0.0457$	
	IVT	ACH	0.2367		$y = -226398x^2 + 226.56x + 0.0057$	
Base 2	DBT	OT	0.7990	0.9042	$y = 0.0047x^2 + 0.8807x + 17.15$	$y = 0.0027x^2 + 0.8927x + 12.622$
	WS	ACH	0.0105	n/a	$y = 5E\text{-}05x^2 + 0.0002x + 0.0365$	n/a
	IVT	ACH	0.1990	0.9155	$y = -137870x^2 + 166.84x + 0.0102$	$y = -6E+07x^2 + 43321x + 8.5437$
Base 2N (Summer only)	DBT	OT	0.7494	0.9198	$y = -0.0025x^2 + 0.8661x + 13.007$	$y = -0.0018x^2 + 0.9828x + 8.0797$
	WS	ACH	0.0293	n/a	$y = -5E\text{-}06x^2 + 0.0012x + 0.0291$	n/a
	IVT	ACH	0.1130	0.9417	$y = -464366x^2 + 218.3x + 0.0104$	$y = -1E+08x^2 + 72146x + 5.1086$
DBT: Dry bulb temperature (C) ; WS = Wind speed (m/s); IVT = Invesed of indoor and outdoor temperature differences						
OT = Indoor operative temperature (C); ACH = Air change per hour (ach)						

Table 5: Correlation Equations for Daylighting

Krakow Scenario	Time	Correlation Equation for Daylighting (x = global solar radiation (W/m2); y = zone illuminance (lux))	
		North	South
No Shading	05:00	$y = -0.001x^2 + 1.2092x + 1.4237$	$y = -0.0011x^2 + 0.7927x + 2.4338$
	06:00	$y = -0.0013x^2 + 1.3129x + 5.7776$	$y = -0.0013x^2 + 1.1023x + 7.595$
	07:00	$y = -0.0015x^2 + 1.4489x + 10.015$	$y = -0.0017x^2 + 1.6277x + 10.925$
	08:00	$y = -0.0013x^2 + 1.4108x + 16.325$	$y = -0.0021x^2 + 2.2999x + 2.1558$
	09:00	$y = -0.001x^2 + 1.2325x + 38.166$	$y = -0.0025x^2 + 3.1304x - 24.812$
	10:00	$y = -0.0009x^2 + 1.112x + 57.293$	$y = -0.0029x^2 + 4.0177x - 36.704$
	11:00	$y = -0.0008x^2 + 1.094x + 60.166$	$y = -0.003x^2 + 4.3351x - 51.914$
	12:00	$y = -0.0008x^2 + 1.0854x + 62.672$	$y = -0.0029x^2 + 4.3328x - 67.263$
	13:00	$y = -0.0009x^2 + 1.166x + 48.383$	$y = -0.0029x^2 + 4.2522x - 40.447$
	14:00	$y = -0.001x^2 + 1.213x + 51.941$	$y = -0.0031x^2 + 4.1265x - 66.162$
	15:00	$y = -0.0011x^2 + 1.27x + 38.032$	$y = -0.0024x^2 + 2.965x - 15.814$
	16:00	$y = -0.0015x^2 + 1.4955x + 17.032$	$y = -0.0021x^2 + 2.262x + 5.5088$
	17:00	$y = -0.0014x^2 + 1.3893x + 16.64$	$y = -0.0016x^2 + 1.508x + 15.736$
	18:00	$y = -0.0011x^2 + 1.1995x + 12.179$	$y = -0.0012x^2 + 1.01x + 11.731$
	19:00	$y = -0.0014x^2 + 1.3278x + 2.8659$	$y = -0.0013x^2 + 0.8263x + 3.4524$
With Internal Blind	05:00	$y = -3E-05x^2 + 0.1007x + 0.0658$	$y = -9E-05x^2 + 0.0653x + 0.2145$
	06:00	$y = -5E-05x^2 + 0.0994x + 0.4889$	$y = -9E-05x^2 + 0.0892x + 0.6397$
	07:00	$y = -9E-05x^2 + 0.1119x + 1.0032$	$y = -0.0001x^2 + 0.1316x + 0.8227$
	08:00	$y = -8E-05x^2 + 0.1143x + 1.9921$	$y = -0.0001x^2 + 0.192x - 0.4398$
	09:00	$y = -6E-05x^2 + 0.107x + 4.5213$	$y = -0.0001x^2 + 0.2535x - 3.0473$
	10:00	$y = -6E-05x^2 + 0.1078x + 6.148$	$y = -0.0001x^2 + 0.3035x - 7.1679$
	11:00	$y = -6E-05x^2 + 0.1163x + 5.867$	$y = -0.0001x^2 + 0.3004x - 7.0108$
	12:00	$y = -6E-05x^2 + 0.1196x + 5.8667$	$y = -8E-05x^2 + 0.2914x - 6.7535$
	13:00	$y = -7E-05x^2 + 0.1216x + 5.0575$	$y = -9E-05x^2 + 0.2888x - 5.7867$
	14:00	$y = -7E-05x^2 + 0.115x + 5.875$	$y = -0.0001x^2 + 0.289x - 6.4261$
	15:00	$y = -7E-05x^2 + 0.1109x + 4.2828$	$y = -0.0001x^2 + 0.2472x - 2.4979$
	16:00	$y = -9E-05x^2 + 0.1234x + 1.8371$	$y = -0.0001x^2 + 0.1896x + 0.0103$
	17:00	$y = -8E-05x^2 + 0.106x + 1.5051$	$y = -0.0001x^2 + 0.1212x + 1.2514$
	18:00	$y = -3E-05x^2 + 0.0878x + 1.0084$	$y = -7E-05x^2 + 0.0802x + 1.0131$
	19:00	$y = -2E-06x^2 + 0.106x + 0.2052$	$y = -0.0001x^2 + 0.067x + 0.3119$

The correlation equations predictions for typical summer and winter days about thermal comfort are shown in Figure 27 and Figure 28. The internal conditions of thermal comfort are above acceptable standards during the summer. Opening windows during the day reduces internal temperature even though they remain high. Opening windows during the night to exploit night cooling further reduces internal temperatures. It should be noted that there are high internal heat gains in the building if fully occupied and this can explain the high internal temperatures. If the occupancy factor is lower, comfort might be established.

Figure 29 and Figure 30 present the IAQ in the office (CO_2 concentration due to metabolic CO_2 gains). Status of the windows is crucial to maintain IAQ. However, this must be balanced with energy efficiency during winter and external pollution ingression during the summer.

Figure 31 presents the internal illuminance due to daylighting. Windows are oriented north and south. The predictions indicate that good natural illuminance could be achieved in winter without blinds, although blinds are needed during the summer especially for the south oriented windows. Such as

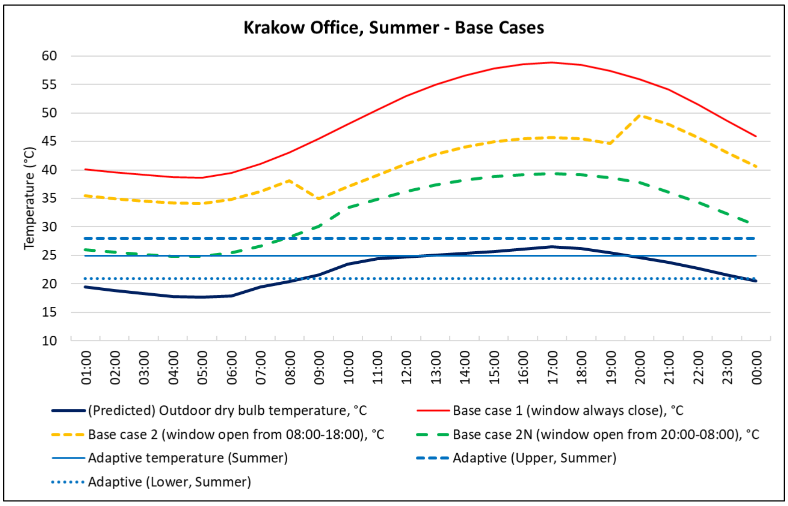


Figure 27: Predicted thermal comfort during a summer day

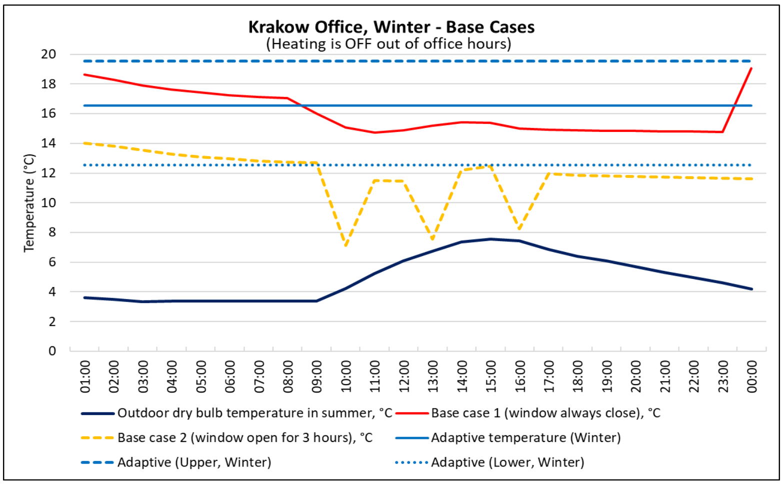


Figure 28: Predicted thermal comfort during a winter day

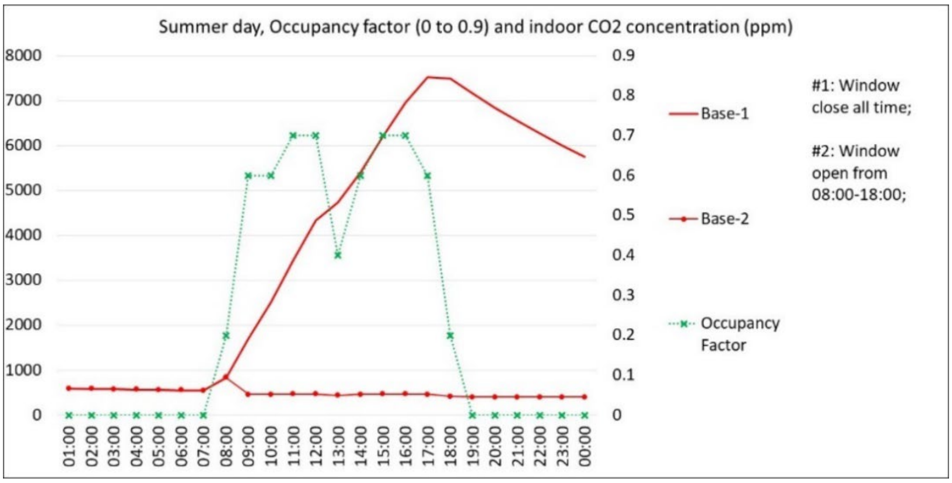


Figure 29: CO2 prediction during a summer day

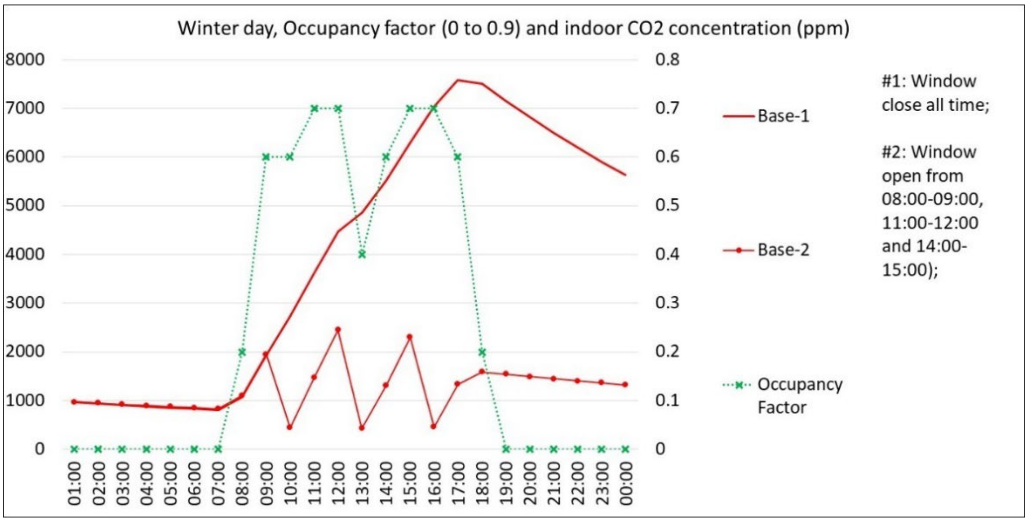
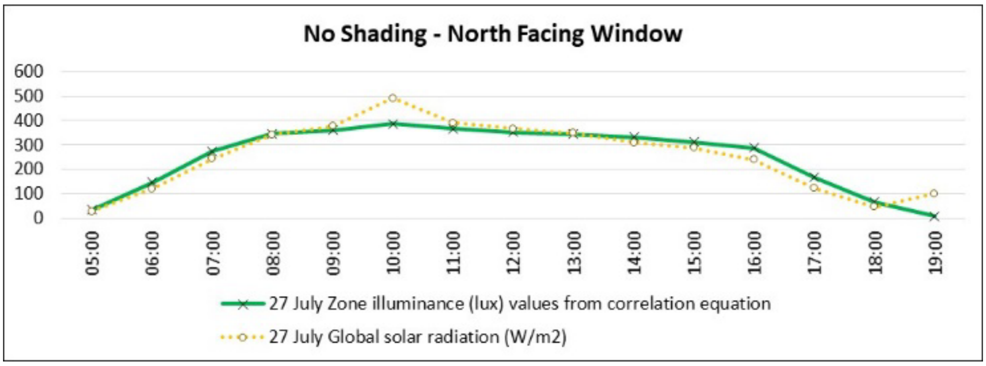
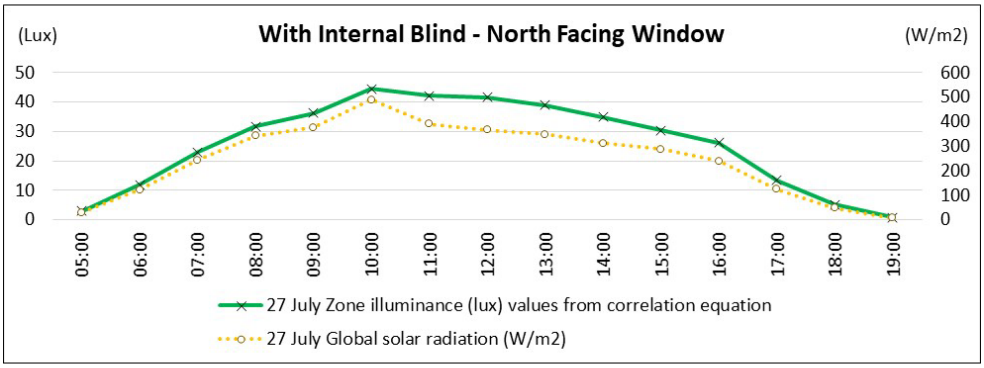
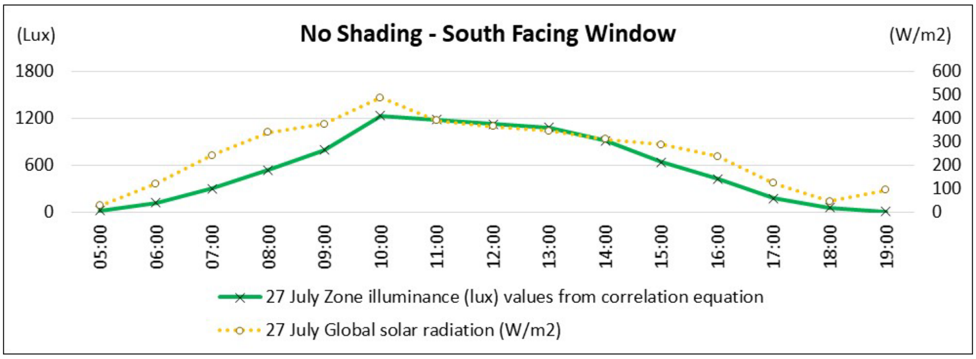
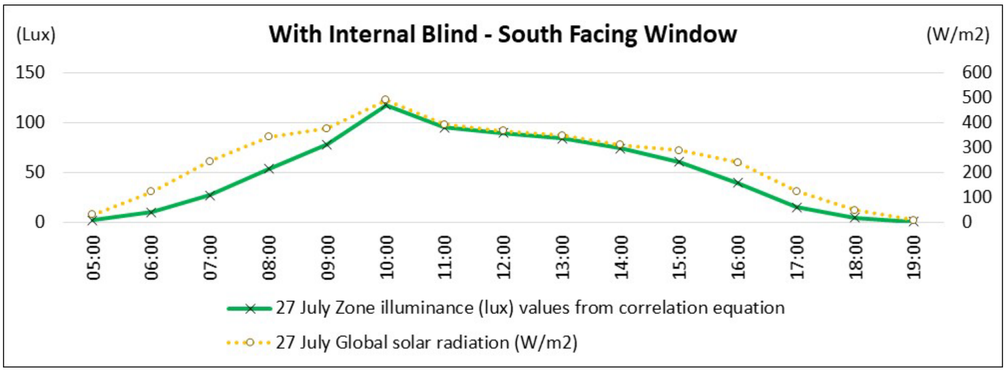


Figure 30: CO2 prediction during a winter day









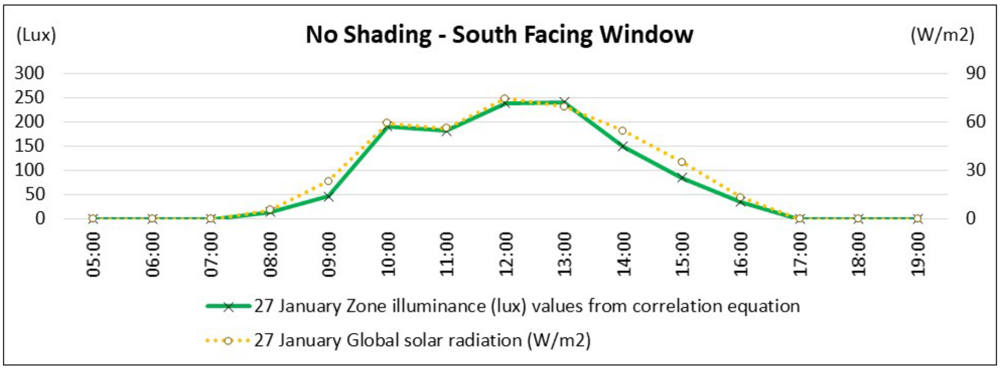


Figure 31: Daylighting internal conditions

Future work:

1. Future work includes the comparison of the indoor-outdoor correlation module predictions with measurements in the office to validate the model. In addition, other internal pollutants such as moisture, VOC and PM2.5 will be predicted by the correlation module based on emission levels in the office and achieved air flow rate.
2. The predictions of the indoor-outdoor correlation module will be communicated to the occupants of the office with instructions on how to use windows/blinds and when. Short experiments will be carried out. BUL will predict occupants' actions for 2-3 days; these will be communicated to the occupants for their action. Internal environment measurements from the building will be analysed by BUL to evaluate whether the internal environment has been improved by the prescribed actions of the indoor-outdoor correlation module.

4.4 Analysis of collected data

BLOK's role is to provide the necessary infrastructure, such as office space and sensor installations, to support the implementation of the technology-driven solutions. However, it is important to note that BLOK does not possess the resources or tools to conduct detailed data analysis from the gathered sensor data or analyze the outcomes of implemented scenarios within our office building.

The data collected from the sensors is managed and stored in the FusiX system, which is operated and analyzed by our technological partners. They possess the expertise and specialized tools required for in-depth data analysis, interpretation, and further optimization of the implemented solutions.

Our focus is to ensure a seamless integration of the technology within our architectural designs, creating a harmonious and efficient environment for our occupants. By collaborating with our technological partners, we can leverage their expertise in data analysis to enhance the overall performance and user experience of the building.

In summary, BLOK's role in the Prelude project is centered around providing the necessary physical infrastructure, while the data analysis and interpretation are the responsibilities of our technology partners. This division of labor allows us to focus on our core competencies in architectural design while leveraging the expertise of our partners in the field of data analysis and optimization.

5. Results and Impacts

5.1 Performance assessment of the implemented solutions

To evaluate the performance of the adjusted baseline model for the demo case, two metrics will be employed: the Coefficient of Variation of Root Mean Square Error (CV-RMSE) and the Normalised Mean Bias Error (NMBE). These metrics together provide valuable insights into the model's performance. The model demonstrates superior performance when the CV-RMSE value is minimized, as it measures the introduced uncertainty. However, the NMBE serves as a supplementary metric for model evaluation, but it is not utilized for model selection. This is because positive bias can counterbalance negative bias, and the primary objective is to minimize uncertainty throughout the modelling process.

5.2 Energy savings, reduction of gas emissions, economic analysis and cost-effectiveness

LIBRA finding is that, considering the current implementation of the PRELUDE solutions, by using the M&V methodology, it is not possible to assess any energy savings. The steps outlined in D4.3 following the installation of ECMs cannot be applied. However, an adjusted baseline model will be developed based on the current state of the demo site, which will serve for energy forecasting purposes. This approach is a necessary initial step for potential saving quantification and performance evaluation, which will be implemented if and when an ECM is introduced in the future. Therefore, it should be emphasized that if any additional ECMs are installed, the M&V methodology will be appropriately adapted to accurately evaluate the resulting energy savings.

5.3 Economic analysis and cost-effectiveness

In the Prelude project, the analysis of economic factors and cost-effectiveness lies within the domain of our partners with expertise in financial and economic assessments. They possess the necessary tools and knowledge to evaluate the financial implications of the implemented technologies and provide insights into the long-term cost efficiency and return on investment.

In summary, while BLOK is committed to delivering architectural excellence and facilitating the implementation of technological solutions, the analysis of economic factors and cost-effectiveness is outside our scope. We rely on the expertise of our partners to provide accurate assessments in these areas, ensuring that the project achieves both architectural and financial success.

CONCLUSIONS

This report is summarizing the findings and conclusions of the demo site in Krakow for the Prescient building Operation utilizing Real-Time data for Energy Dynamic Optimization project. It highlighted the significant investment required to improve the comfort of occupants in office buildings of this nature. Among the available options, thermo-modernization emerged as the most cost-effective approach to enhance comfort without compromising energy consumption.

Due to limitations in building modifications and available resources, the implementation focused on portable air conditioners and intelligent thermostats. Although data collection has been completed by relocating the demo and adjusting sensor installations, the evaluation of specific scenarios to assess their effectiveness is pending. This stage of the project revealed that the technical analysis of sensor data and the economic analysis were beyond BLOK's capacity, primarily due to limited resources and data access.

However, with the development of the application, there is an opportunity to engage office users and empower them to actively participate in optimizing energy usage. By leveraging the application's features, it is anticipated that occupants will contribute to achieving the desired energy efficiency goals. The report underscores the importance of ongoing monitoring, analysis, and continuous improvement to maximize energy efficiency in office buildings, with a particular focus on user engagement and leveraging available technological solutions.

In conclusion, the project highlights the necessity of substantial investment in enhancing user comfort in office buildings of this nature. Thermo-modernization emerged as the most cost-effective approach, considering the constraints on building modifications and available resources. The project's findings underscore the importance of ongoing monitoring and user engagement to optimize energy usage and achieve sustainability goals. The application developed as part of the project presents an opportunity to empower occupants and maximize energy efficiency in office buildings, thereby contributing to a more sustainable future.

APPENDIX A

a) ONLINE SOURCES

[1] "Python Library | Meteostat Developers." https://dev.meteostat.net/python/#installation (accessed Mar. 13, 2023).

APPENDIX B

Attached documents reporting EPIQR+ results:

- 230526_Krakow demo-case_Optimization scenario EPIQRweb results.pdf
- 230526_Krakow demo-case_Reference scenario EPIQRweb results.pdf

Work cost Estimation

Optimization

Cost index : 56.00

Optimization

Summary of cost

Wa Facades and balcony	**173 700**
Wi Windows and doors	**168 600**
Ro Roofs	**0**
Ss Common and secondary surfaces	**624 600**
El Electricity	**73 400**
He Heating	**800**
Ve Ventilation and Air conditioning	**36 900**
Sa Sanitary	**0**
Mi Security, transport, miscellaneous	**0**
Works cost (without fees and without VAT)	**1 078 000**
Architect's fees (without VAT) calculated on the basis of % of the works cost	**108 000**
Sub-total of works and fees (without VAT)	**1 186 000**
Misc. and unexpected's fees (without VAT) calculated on the basis of % of the sub-total	**0**
VAT on the basis of % of the sub-total and misc. and unexpected	**273 000**
Total cost for renovation (with VAT)	**1 458 000**

Work cost Estimation

Optimization

Cost index : 56.00

Wa		Facades and balcony		0	173 700
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1		External wall - Rendering	0		0
2.2		Facade decorations - XXth century buildings	0		0
3.2	50%	External wall thermal insulation - Facade external thermal insulation	0		0 173 700
4.1		Façade scaffoldings - Scaffolding and building site	0		0
5.1		Balconies and galleries - Concrete / masonry railing	0		0

Wi		Windows and doors		0.40	168 600
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.2		Windows - Aluminum or PVC windows	0		0
3.5		External doors - Automatic doors	0		0
2.5	70%	Shutters and solar protection - External blinds	3	■■■	120 400
2.6	30%	Shutters and solar protection - Internal solar protection	3		0 48 100

Ro		Roofs		0	0
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.5		Roof covering - Flat roof without access (to residents)	0		0
4.1		Roof sheet metal work - Pitched roof	0		0
6.1		Lightning protection - Roof with sides	0		0
3.3		Roof thermal insulation - Flat Roof	0		0

Ss	Common and secondary surfaces	0.00	624 600

%	Element-Type	Degradation	Intervention	Cost excl. taxes
3.2	Floor thermal insulation - Thermal insulation basement-ground floor	○○③	■■■	36 500
5.1	Sourroundings - Surroundings - Simple developed areas	①○○	■□□	3 500
1.1	Main distribution - Interior distribution - housing	①○○	■□□	302 000
1.2	Main distribution - Exterior distribution - passageway	①○○	■□□	282 600

El	Electricity		0.00	73 400
%	Element-Type	Degradation	Intervention	Cost excl. taxes
5.1	Lighting appliances - Lighting Fixtures	①○○	■□□	2 100
6.1	Individual electricity production - Photovoltaic panels	○○③	■■■	59 400
1.1	Electrical power supply and main electrical panel - Without induction current compansation	①○○	■□□	3 900
2.1	Pannels and secondary electrical distribution - Low power distribution pannels	①○○	■□□	7 900
4.1	Lighting wiring and plugs - Power supply for outlets and lights	○⓪○	□□□	0
4.2	Lighting wiring and plugs - Wiring sockets and fixtures - dwellings	○⓪○	□□□	0
3.2	Emergency lighting - Centralised power supply	○⓪○	□□□	0

He	Heating		0	800
%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.6	Heating central production plant - Substation without heat production	○⓪○	□□□	0
2.2	Sanitary hot water production - Local electric boilers	○⓪○	□□□	0
3.1	Heating distribution network - Apparent heat distribution	○⓪○	□□□	0
4.1	Heating and cooling terminal units - Radiators	○⓪○	□□□	0
5.1	Heating control - Centralized control	○⓪○	■■■	0
	Implementation of an energy optimization contract with sensors			800

Ve	Ventilation and Air conditioning		0	36 900

	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1		Ventilation system without air handling - Natural ventilation (opening windows)	◯⓪◯	☐☐☐	0
		Installation of exhaust ventilation			36 900

Sa		**Sanitary**		**0**	**0**
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1		Water connection and metering - Connection and water distribution battery	◯⓪◯	☐☐☐	0
2.1		Sewage pipes - Wastewater pipes	◯⓪◯	☐☐☐	0
3.1		Sanitary water distribution - Cold water and hot water pipes	◯⓪◯	☐☐☐	0

Mi		**Security, transport, miscellaneous**		**0**	**0**
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1		Lifts - Lift	◯⓪◯	☐☐☐	0

Works cost (without fees and without VAT)	**1 078 000**
Architect's fees (without VAT) calculated on the basis of % of the works cost	**108 000**
Sub-total of works and fees (without VAT)	**1 186 000**
Misc. and unexpected's fees (without VAT) calculated on the basis of % of the sub-total	**0**
VAT on the basis of % of the sub-total and misc. and unexpected	**273 000**
Total cost for renovation (with VAT)	**1 458 000**

Work cost Estimation

Reference scenario

Cost index : 56.00

Reference scenario

Summary of cost

Wa Facades and balcony	**0**
Wi Windows and doors	**24 200**
Ro Roofs	**0**
Ss Common and secondary surfaces	**588 100**
El Electricity	**13 900**
He Heating	**0**
Ve Ventilation and Air conditioning	**0**
Sa Sanitary	**0**
Mi Security, transport, miscellaneous	**0**
Works cost (without fees and without VAT)	**626 000**
Architect's fees (without VAT) calculated on the basis of % of the works cost	**63 000**
Sub-total of works and fees (without VAT)	**689 000**
Misc. and unexpected's fees (without VAT) calculated on the basis of % of the sub-total	**0**
VAT on the basis of % of the sub-total and misc. and unexpected	**158 000**
Total cost for renovation (with VAT)	**847 000**

Work cost Estimation

Reference scenario

Cost index : 56.00

Wa		Facades and balcony		0	0
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1		External wall - Rendering	○⓪○	☐☐☐	0
2.2		Facade decorations - XXth century buildings	○⓪○	☐☐☐	0
3.2	50%	External wall thermal insulation - Facade external thermal insulation	○⓪○	☐☐☐	0
4.1		Façade scaffoldings - Scaffolding and building site	○⓪○	☐☐☐	0
5.1		Balconies and galleries - Concrete / masonry railing	○⓪○	☐☐☐	0

Wi		Windows and doors		0.00	24 200
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.2		Windows - Aluminum or PVC windows	○⓪○	☐☐☐	0
3.5		External doors - Automatic doors	○⓪○	☐☐☐	0
2.5	70%	Shutters and solar protection - External blinds	○○❸	☐☐☐	0
2.6	30%	Shutters and solar protection - Internal solar protection	○○❸	■■■	24 200

Ro		Roofs		0	0
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.5		Roof covering - Flat roof without access (to residents)	○⓪○	☐☐☐	0
4.1		Roof sheet metal work - Pitched roof	○⓪○	☐☐☐	0
6.1		Lightning protection - Roof with sides	○⓪○	☐☐☐	0
3.3		Roof thermal insulation - Flat Roof	○⓪○	☐☐☐	0

Ss		Common and secondary surfaces		0	588 100
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
3.2		Floor thermal insulation - Thermal insulation basement-ground floor	○○❸	☐☐☐	0

5.1	Sourroundings - Surroundings - Simple developed areas	1	■□□	3 500
1.1	Main distribution - Interior distribution - housing	1	■□□	302 000
1.2	Main distribution - Exterior distribution - passageway	1	■□□	282 600

El	Electricity		0	13 900
%	Element-Type	Degradation	Intervention	Cost excl. taxes
5.1	Lighting appliances - Lighting Fixtures	1	■□□	2 100
6.1	Individual electricity production - Photovoltaic panels	3	□□□	0
1.1	Electrical power supply and main electrical panel - Without induction current compansation	1	■□□	3 900
2.1	Pannels and secondary electrical distribution - Low power distribution pannels	1	■□□	7 900
4.1	Lighting wiring and plugs - Power supply for outlets and lights	0	□□□	0
4.2	Lighting wiring and plugs - Wiring sockets and fixtures - dwellings	0	□□□	0
3.2	Emergency lighting - Centralised power supply	0	□□□	0

He	Heating		0	0
%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.6	Heating central production plant - Substation without heat production	0	□□□	0
2.2	Sanitary hot water production - Local electric boilers	0	□□□	0
3.1	Heating distribution network - Apparent heat distribution	0	□□□	0
4.1	Heating and cooling terminal units - Radiators	0	□□□	0

Ve	Ventilation and Air conditioning		0	0
%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1	Ventilation system without air handling - Natural ventilation (opening windows)	0	□□□	0

Sa	Sanitary		0	0

	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1		Water connection and metering - Connection and water distribution battery	◯⓪◯	☐☐☐	0
2.1		Sewage pipes - Wastewater pipes	◯⓪◯	☐☐☐	0
3.1		Sanitary water distribution - Cold water and hot water pipes	◯⓪◯	☐☐☐	0

Mi		**Security, transport, miscellaneous**		**0**	**0**
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1		Lifts - Lift	◯⓪◯	☐☐☐	0

Works cost (without fees and without VAT)	**626 000**
Architect's fees (without VAT) calculated on the basis of % of the works cost	**63 000**
Sub-total of works and fees (without VAT)	**689 000**
Misc. and unexpected's fees (without VAT) calculated on the basis of % of the sub-total	**0**
VAT on the basis of % of the sub-total and misc. and unexpected	**158 000**
Total cost for renovation (with VAT)	**847 000**