Prescient building Operation utilizing Real Time data for Energy Dynamic Optimization

WP9 – Dissemination and communication activities

D9.7 – Educational activity report

Version 2

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PRELUDE KEY FACTS

Project Title	Prescient building Operation utilizing Real Time data for Energy Dynamic Optimization
Starting date	01/12/2020
Duration in months	48
Call (part) identifier	H2020-NMBP-ST-IND-2020-singlestage
Topic	LC-EEB-07-2020 Smart Operation of Proactive Residential Buildings (IA)
Fixed EC Keywords	-
Free Keywords	Free running, model-based predicted control, dynamic building simulation, demand side flexibility, proactive buildings, predictive maintenance, occupancy models, smartness assessment.
Consortium	21 organisations

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

EXECUTIVE SUMMARY

Deliverable D9.7 focuses on the main actions developed in Task 9.5, which are about citizen science and educational activities. The aim is to involve students at different educational stages in disseminating, discussing, interacting, and developing projects about PRELUDE-correlated topics, such as intelligent buildings, smart monitoring and actuating, building energy efficiency, climate correlated design and operational aspects, including climate change, proactive optimisation, Indoor Environmental Quality (IEQ) and Indoor Air Quality (IAQ) issues. These experiences, on the one hand, act as dissemination actions. On the other hand, they act as additional explorative works looking at focused topics and challenges and analysing the potential impact of simplified smart solutions and activities in society.

Task 9.5 works are organised around three main actions:

i. The organisation of a series of international conferences/lectures and workshops, i.e. the "PRELUDE Educational event series", presenting PRELUDE results and theories and discussing them with recognised experts coming from the consortium and outside the PRELUDE partnership;
ii. The management of a series of university student projects, investigating and proposing solutions, e.g. prototypes, software, tools, workflows, about given smart and bioclimatic building open challenges;
iii. The development of a citizen science activity involving six middle and high schools of the Piedmont Region in collective action for monitoring and improving IEQ and especially IAQ levels in classrooms and laboratories. Citizen science includes cloud monitoring systems, the use of LED alerts to suggest window opening at a given CO_2 threshold, direct communications (lectures) to students about IAQ, IEQ and intelligent building topics, and a restitution of their ability to manage self-actuation of their windows to improve IAQ levels.

Concerning the Educational event series, seven conferences plus a final educational workshop have been performed, including 25 speeches and seven general introductions. More than 300 participants were reached in the seven meetings. The final event includes a final restitution of primarily PRELUDE outcomes and the PRELUDE educational activities, plus a workshop about citizen science involving local schools and the Piedmont Regional Educational Division, part of the PRELUDE advisory board, and including nine speakers and an expected number of about 75 participants. Treated topics include proactive building optimisation, free-running buildings, urban climate dimensions, parametric design, retrofitting actions, intelligent building solutions, building monitoring and control logic, digital twins, and climate changes.

Looking at the educational projects, five master's degree theses and five interdisciplinary group projects have been organised involving 22 students from architecture and telecommunication engineering. Treated topics focused on dynamic energy simulation platforms, considering optimisation algorithms for both design choices and building operational management, the development and use of surrogate models, the integration of open weather data sources, the development of parametric building optimisation scripts, the definition of cost-optimal retrofitting scenarios, development of intelligent cloud IoT monitoring and alerting solutions, arriving at testing prototypes considering thermal comfort, multi-comfort IEQ and IAQ domains, weather sensoring kit development, free-running building optimisation via fuzzy logic control systems, and the development of solutions to identify occupancy profiles from actual buildings. Results are presented in the final educational PRELUDE exhibition via posters.

The citizen science experience involved six schools, i.e. three middle schools and three high schools, half of which were in the Turin city area and the others in small cities within the Turin Province. Cloud monitoring IEQ and IAQ systems are installed in all schools, aligning with PRELUDE demo case-used technologies. Defined a first measurement period to set benchmark conditions; lectures are given to students to introduce and discuss smart building, building energy needs, and multi-comfort domains, focusing on Indoor Air Quality challenges and building monitoring and self-actuation actions. Students start the citizen

science action, following the LED alerts activated on specific sensors in classrooms or other school spaces, e.g., laboratories. Finally, the outcomes of different IAQ pollutant levels are analysed, and feedback is given to students and/or teachers to communicate citizen science outcomes. More than 1500 students directly used the measured school spaces, while more than 650 followed a PRELUDE citizen science lecture. In total, 7 gateways, 41 CO_2, 10 TVOC, and 7 PMx sensors, plus a U-value cloud-monitoring kit and additional routers, have been installed. Results underlined the importance of supporting CO2 measurements to improve and control IAQ levels, especially where high classroom densities require high ventilation rates. Positive results are obtained in the majority of cases. However, the need to develop solutions to maintain the attention of the end-users over time is underlined to avoid a progressive decrease in IAQ levels.

All three actions obtained positive results and were appreciated by students and participants, suggesting the need to prosecute these activities in the future to disseminate intelligent and proactive building topics, supporting the next generations in being involved in increasing their confined space comfort conditions, reducing energy needs, and acting to the spread of digital culture.

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ABBREVIATIONS

ACM	Adaptive thermal Comfort Model
AHU	Air Handling Unit
AIM	Asset Information Management
ANN	Artificial Neural Networks
BIM	Building Information Model
COP	Coefficient of Performance
EAHX	Earth-to-Air Heat eXchanger
EPW	EnergyPlus Weather
FLC	Fuzzy Logic Control
GCMs	Global Climate Models
GHG	GreenHouse Gas emissions
GUI	Graphical User Interface
HVAC	Heating, Ventilation, and Air Conditioning
I/O	Input/Output
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
IoT	Internet of Things
EUI	Energy Use Intensity
ICT	Information and Communication Technologies
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
PDEC	Passive Downdraught Evaporative Cooling
PMx	Particulate Matter where x is for different particulate diameters (i.e. 10 and 2.5 μm)
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
PREDYCE	Python Realtime Energy Dynamics and Climate Evaluation tool
S.Y.	School Year
TMY	Typical Meteorological Year
TVOC	Total Volatile Organic Compounds
UHI	Urban Heat Island

1. INTRODUCTION

D9.7 reports the educational activities conducted during T9.5. These activities involved students with their teachers of different grades and ages, including middle school and high school classes (citizen science) and university ones. Furthermore, dissemination events are also organised and opened to society.

The PRELUDE educational works are organised around three main actions:

1. The organisation of an "Educational event series" involving internationally recognised speakers within and outside the consortium to discuss and present in a series of 7 lectures/conferences for university students and open to professionals and interested people. Speakers come from research institutions, universities, and companies covering transdisciplinary visions. The meetings were organised in the hybrid model, being accessible both physically and remotely, while all events were recorded to increase accessibility.
2. The organisation of 10 "Educational projects" involving university students from architectural and ICT engineering backgrounds. Projects included both master's degree theses and student group works supporting PRELUDE correlated topics, pursuing an explorative vision and aiming at disseminating PRELUDE innovations into future professional generations.
3. The organisation of a significant "citizen science" action involving six schools of the Piedmont Region in an IEQ (Indoor Environmental Quality) and IAQ (Indoor Air Quality) shared work. During the citizen science action, IEQ and IAQ sensors were installed in the mentioned schools, measuring relevant KPIs (Key Performance Indicators) that were aligned with the PRELUDE works. Furthermore, thanks to the activation of LED alerts, students and teachers have been involved in self-actuation actions to improve the space IAQ levels. In parallel, a series of lectures have been organised in the schools involved to support citizen science action, motivate students, and show results. The action promotes educational dissemination and increases future generations' consciousness of IEQ/IAQ topics and the intelligent building dimension.

A poster Exhibition has been organised showing point 2 results (2023), followed by a final Educational activity event including a workshop/conference on the main obtained results (20th of November 2024) and a large exhibition (20-22nd November 2024) including the primary outcomes from the three main actions.

This deliverable is organised into 4 Sections:

i. Section 2 is devoted to the Educational event series activities,
ii. Section 3 illustrates the Educational projects thanks to a series of posters,
iii. Section 5 focuses on the citizen science action describing the organisation, the monitoring solutions and the user activities with results, and
iv. Section 6 shortly reports the final event and exhibition results.

A sixth section is finally reporting conclusions.

2. The Educational Event Series

2.1 Introduction and Organisation

The PRELUDE educational and citizen-science dissemination action includes the organisation of an Educational Event Series based on lectures/conferences. They are performed following a hybrid accessibility approach, allowing people to follow both in presence (Turin-based) and remotely via a shared link open to all interested participants. The series started in 2023 and continued till the end of the project, with the 7th lecture/conference held on the 14th of June 2024 and the 8th event: the final educational workshop/conference on the 20th of November 2024. All events are announced via the PRELUDE dissemination channels (e.g. the devoted section of the project internet site) to support mainly remote participation and register participants and via POLITO channels to support remote and physical involvement. All the events also involved local student classes that focused more on ICT engineering and/or architectural backgrounds according to the specific topics being addressed.

Records are made available at the following link.

Figure 1 – QR code for the PRELUDE educational event series YouTube playlist

Speakers are recognised experts in the topics of smart buildings, data-driven analyses, GUI (Graphical User Interface) development, control and proactive-control logic, building digital design, low-energy solutions, climate-correlated design issues, including the urban dimension, and other topics correlated to the PRELUDE project contents and actions. Speakers have academic and/or industrial backgrounds and include consortium partner people. Additionally, selected external speakers are invited to support dissemination and discussions outside the project and enlarge perspectives.

2.2 Overview of the organised events and correlation to PRELUDE topics

A total of 7 lectures/conferences have been organised[1]. Considering all events, we reached more than 300 people in total, with the number of presences (both remote and in-presence) per single event ranging from 22 to 55. The majority of attendees were students, with a little participation of external interested professionals and people. The total number of speeches is 25, plus 7 introductions to the PRELUDE educational series and the events. The list of the events is reported here below – see also the following sub-section for more profound descriptions:

1. "Proactive, forecasting and optimisation approaches for intelligent buildings", 13/01/2023, 9:00-12:00 (52 people, of which 24 were not students);
2. "Free-running, zero energy buildings, and climate-correlated solutions", 31/03/2023, 9:30-12:00 (54 people, of which 3 were not students);
3. "The urban climate dimension: urban heat island and microclimatic issues", 26/05//2023, 13-14:30 (45 people, of which 2 were not students);

[1] The final educational event (the 8th workshop/conference) is described in a devoted section.

4. "Parametric, environmental, and smart solutions for building retrofitting", 12/12/2023, 14:30-16:00 (28 people, of which 2 were not students);
5. "Building monitoring, proactive control logic, and smart solutions", 16/01/2024, 14:30-16:45 (22 people, of which 1 was not a student);
6. "Intelligent building and digital twins: platform, data treatment, lessons learnt", 24/05/2024, 11:00-13:00 (50 people, of which 3 were not students);
7. "Building resilience to climate changes and urban climate issues", 14/06/2024, 11:00-13:00 (55 people, of which 2 were not students).

A final event was also organised for the 20th of November 2024, followed by an exhibition of works (20-22 November 2024) to correlate all the educational activities, including the results of the Educational projects and the citizen science (41 people followed the conference, 9 of which were not students, and 72 people attending the exhibition opening, half of which were not students), with the Prelude project – see Section 5.

2.3 Specific event descriptions

Each event is described here with some details, including the conference flyer and a resume of the interventions.

2.3.I 1st lecture/conference: Proactive, forecasting and optimisation approaches for intelligent buildings

Figure 2 - Flyer of the 1st Edu event series

The first educational event introduced smart building management, control, and modelling issues. It also includes a PRELUDE project presentation by the project general coordinator, prof. Pomianowski. Involved speakers from the PRELUDE's consortium, including POLITO, AAU, TREELOGIC, CORE IC, FB, and STAM, for a total of 8 speakers. The final programme included:

- **9:00** | Giacomo Chiesa **(POLITO)** – *Welcome and introduction to the educational event series;*
- **9:15** | Michal Pomianowski **(AAU)** – *PRELUDE project introduction, aims and challenges;*
- **9:35** | Kais Dai **(TREELOGIC)** – *Scaling-up technologies for multiple models' aggregation;*
- **10:00** | Nikos Sofias **(CORE IC)** – *ML solutions for weather and energy forecasting in energy-efficient buildings;*
- **10:25** | Christian Heschl **(FB)** – *The energy-saving potential of data-driven predictive control;*
- **10:50 |** *small break*
- **11:00** | Giacomo Chiesa & Paolo Grasso **(POLITO)** – *Platform for building energy white box modelling and 24h forecasting;*
- **11:15** | Mattia Repossi & Lorenzo Farina **(STAM)** – *The EnPower platform.*

Shortly, the conference/lecture was on smart building issues, discussing "Proactive, forecasting, and optimisation approaches for intelligent buildings". Held on the 13th of January 2023, the event has been followed in a hybrid mode, both physically at POLITO and remotely online. This conference included six technical presentations focussing on PRELUDE topics and an introduction to the educational event series led by Giacomo Chiesa by POLITO. In particular, Michal Pomianowski by AAU has shortly introduced the PRELUDE projects, Kais Dai by TREELOGIC has discussed scaling-up technologies considering multiple model aggregations supporting a machine learning vision, Nikos Sofias by CORE IC has introduced the use of machine learning algorithms for weather and energy forecasting in the building sector, Christian Heschl by FB has described data-driven predictive control strategies adopted in the Living Lab Energetikum including their energy saving potentials, Giacomo Chiesa and Paolo Grasso (POLITO) have described some free-running application of the PREDYCE tool to support shading and ventilation scheduling optimisation including white-box model forecasting, Mattia Repossi and Lorenzo Farina (STAM) have discussed the EnPower platform and the application of smart building management technologies. An intense debate followed the presentations discussing the replicability of the illustrated approaches, current limitations, and future paths in the intelligent building proactive sector.

Focusing on contents.

In the introduction, Giacomo Chiesa illustrated the PRELUDE educational and citizen science task focusing on the "education event series" activity. Furthermore, he introduced the other speakers and treated topics.

Michal Pomianowski described the PRELUDE project - Prescient building Operation utilising Real-Time data for Energy Dynamic Optimization – as a project that aims to support advanced innovative, smart, and low-cost solutions that support intelligent buildings and proactive optimisation services. Among the others, the project pursues the minimisation of energy uses, the maximisation of self-consumption and renewable sources balance, and the improvement of comfort conditions supporting the maximisation of free-running building potentials. This presentation focused on the overall PRELUDE project presentation, its aims, and challenges, reminding that the project concept is developing a modular PRELUDE platform built and integrated around the middleware solution FusiX. Several PRELUDE modules are based on historical data availability to analyse and proactively forecast weather, energy, and comfort.

Kais Dai focused on the TREE project's proposed solutions to efficiently aggregate models in multiple buildings' scenarios (i.e., neighbourhood, district, city) towards generating knowledge and intelligence at the different scales based on the aggregation of the individual ones (i.e., taking the predictive models and optimisation features to the neighbourhood/district/city scale). Several techniques have been proposed to achieve this goal, such as consumption profile clustering, ensemble models and federated learning. All these models perform 24-hour-ahead forecasting of the district heating energy consumption. In this lecture, Kais described how TREE solution has applied these methods and explored the pros and cons of each one.

Nikos Sofias introduced some of the topics CORE-IC treated during PRELUDE. In particular, he described data-driven methodologies (Machine Learning) for local climate Weather and Energy Forecasting. This process includes energy-efficient buildings as pilots in different European climate zones. Successfully forecasting Energy consumption and production plays a crucial role in residential building's energy management, planning, and functionality optimisation. The context of the presentation also illustrated the fundamentals of data analysis and time-series forecasting tools. Results from PRELUDE project real demo cases, considering the 24-hour ahead weather and energy forecasts, were also presented in this speech.

Christian Heschl, director of the study program building technology and building management at the University of Applied Science FH Burgenland and in charge of the centre of building technology at the FB research centre. His presentation focused on energy-saving potentials reached by applying data-driven predictive control logic to the Forschung Burgenland (FB) living lab Energetikum. Firstly, an introduction to data-driven predictive control approaches was given and supported by the description of the Energetikum systems. Secondly, data-driven space models were introduced, followed, and thirdly, by a discussion about linear state space models. Finally, the speech focused on the approaches needed to implement data-driven predictive control algorithms in actual buildings by defining and detailing energy-saving potentials driven by this approach.

Giacomo Chiesa and Paolo Grasso presented some new functionalities and usage scenarios added to the POLITO's PREDYCE tool during the PRELUDE project. They focused on describing a Python library acting as a dynamic simulation platform connecting EnergyPlus with monitored data. PREDYCE supports sensitivity analyses and massive simulation studies, directly comparing KPIs calculated from simulation and real-time monitored data. Considering forecasted weather conditions and building characteristics, a new usage scenario was presented to optimise the next day's shading and ventilative cooling activation schedules. According to building smartness levels, outputs are conceived to be sent to mechanical actuators via BMS or end-users for self-actuation. The presentation showed the 24-hour forecasting architecture and discussed sample results on a PRELUDE demo flat simulated under typical weather. Comparisons between optimised conditions and standard shading/ventilation controlling action were given to better describe the approach.

Mattia Repossi and Lorenzo Farina detailed the STAM's EnPower platform visions for the PRELUDE project. The AI supports users in controlling and optimising HVAC, adopting a holistic approach that considers Thermal Comfort and IAQ in real time with constant synchronisation with the connected home devices integrated within a modular, collaborative platform. This goal is achieved by load distribution optimisation, which considers economic, environmental, technical, and user-related data to forecast the optimal schedule for the times ahead. Therefore, the typical starting point is the optimal exploitation of the contractual conditions concerning the canonical tariff bands. This is associated with the smoothing of the power peaks, giving the user the possibility to decide whether to request a reduction in the contractual power, with the consequent economic advantages, in the face of imposing a technical limit on the quantity of loads electricity that can be powered at the same time and therefore to the reduction of comfort. A homogeneous distribution of the withdrawal demand allows the electricity provider to manage the user more efficiently, reducing network problems such as overloads and overvoltage.

2.3.II 2nd lecture/conference: Free-running, zero energy buildings, and climate-correlated solutions

Figure 3 - Flyer of the 2nd Edu event series

The second lecture/conference was focused on climate-building correlations, free-running and low-energy technologies, and bioclimatic building visions. Involved speakers are part of the PRELUDE's consortium, including POLITO and BUL, and external experts, for a total of 5 speakers. The final programme included:

- **9:30** | Giacomo Chiesa (**POLITO**) – *Welcome and introduction to the educational event series and the PRELUDE project;*
- **9:45** | Milica Mitrovic & Laura Carnieletto (**UNIPD**) – *UniZEB, a Living Lab on Zero Energy Building of the University of Padua;*
- **10:50** | *small break*
- **11:00** | May Zune (**BUL**) – *Indoor environment prediction using climate correlation models;*
- **11:20** | Giacomo Chiesa & Francesca Fasano (**POLITO**) – *Platform for studying the geo-climatic potential of low energy technologies, including KPIs;*
- **11:45** | *Q&A Session.*

Shortly, the second event of this series was a conference/lecture on low-energy and bioclimatic buildings, discussing "Free-running, zero energy buildings and climate correlate solutions". Held on the 31st of March 2023, the event has been followed in a hybrid mode, both physically at POLITO and remotely online. This conference included three technical presentations focussing on PRELUDE-connected topics, including an external presentation and an introduction to the educational event series led by Giacomo Chiesa by POLITO. In particular, Milica Mitrovic and Laura Carnieletto from Padua University described their experience designing and building the UniZEB building, a zero-energy building living lab at the UNIPD, detailing the long work done with student workshops. This external experts' speech opened the discussion within the audience and the PRELUDE partners about zero- and net-energy-building correlated topics. May Zune by BUL has introduced and discussed the PRELUDE indoor/outdoor correlation module, supporting indoor environmental predictions based on climate correlations. She also included sample applications on PRELUDE demo sites. Giacomo Chiesa and Francesca Fasano (POLITO) have described the very beginning initial development of a new PREDYCE tool usage scenario, supporting geo-climatic studies in the climate change dimension to support local policies and designers in identifying the low-energy bioclimatic potential of different natural technologies. After the presentations, a vibrant debate was conducted to discuss the replicability of the illustrated samples, their connections with architectural topics, and their educational aspects.

Focusing on contents.

The introductive speech illustrated the PRELUDE educational citizen-science works, focusing on the action of the education event series. This part also introduced the PRELUDE project, its main topics, and its objectives.

Milica Mitrovic (Padua University) and Laura Carnieletto (Ca' Foscari and Padua University) illustrated in detail the long and challenging development of the UniZEB building project. This building is a multidisciplinary students' laboratory at the University of Padua. The project aimed to build a Living Lab and a Zero Energy Building based on a long-term activity involving students and professors pursuing a citizen science vision. The speech focused on developing the first physical building prototype (UniZEB), which Scuola Edile of Padua hosted. UniZEB was born in 2015 thanks to a bottom-up initiative, and today, it involves more than 40 companies and different local institutions.

May Zune, a Research Fellow at BUL with a PhD in Building Technology, presented the "Climate Correlation Models" developed in the PRELUDE project that encourage building occupants' decision-making processes in predicting Indoor Environmental Prediction. The presentation was aligned with PRELUDE's innovation and solution to realise natural ventilation and passive cooling to maintain comfort and indoor air quality. This new method provides evidence to apply both in smart home devices and simplified calculation without a high degree of building physics knowledge, so it is a user-focused approach. In the presentation, simulation results were also shown.

The presentation by Giacomo Chiesa and Francesca Fasano (POLITO) introduced the new PREDYCE energy dynamic simulation platform able to manage massive simulations in EnergyPlus and real-time monitored data supporting the calculation of different KPIs to support usage scenarios. The PREDYCE tool, developed in Python, is co-supported by two EU H2020 Projects (EDYCE and PRELUDE). During the presentation, they treated PRELUDE's correlated issues, focusing on the under-development platform's ability to support climate change and geo-climatic studies to analyse the local potential of low-energy technologies and systems concerning passive cooling. This specific usage scenario is under development for the PRELUDE project. The presentation introduced the methodological framework, a preliminary sample application, and the next steps in development.

2.3.III 3rd lecture/conference: The urban climate dimension: urban heat island and microclimatic issues

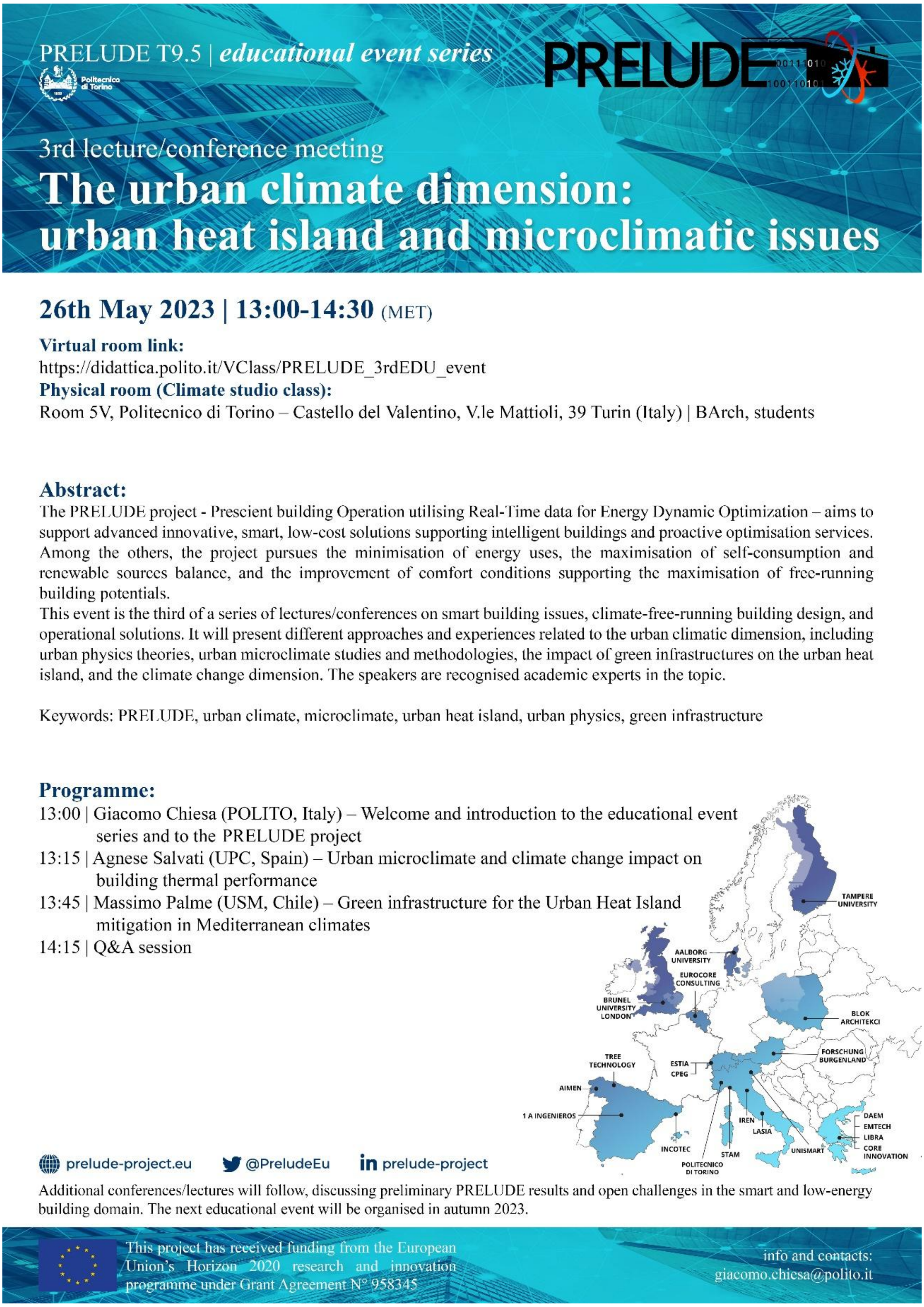


Figure 4 - Flyer of the 3rd Edu event series

The third lecture/conference focused on climate issues correlated to the urban dimension, connecting building performances with urban contexts and urban climate and climate change issues. It introduced the urban physics theory, urban microclimate studies and applied methodologies, impacts of natural-based solutions and other mitigation techniques, including urban heat island phenomena. Involved speakers are external experts, for a total of 2 speakers from Spain and Chile, plus the POLITO introduction. The final programme included:

- **13:00** | Giacomo Chiesa (**POLITO**) – Welcome and introduction to the educational event series and to the PRELUDE project
- **13:15** | Agnese Salvati (**UPC**, Universitat Politècnica de Catalunya, Spain) – Urban microclimate and climate change impact on building thermal performance
- **13:45** | Massimo Palme (**USM**, Universitat Técnica Federico Santa Maria, Chile) – Green infrastructure for the Urban Heat Island mitigation in Mediterranean climates
- **14:15** | Q&A Session

Shortly, the third conference meeting was held on the 26th of May 2023 in dual mode, both physically at the Valentino Castle (POLITO) and remotely online. This event focused on urban heat island and urban climate topics, detailing innovative microclimate study experiences and methodologies thanks to the presence of recognised invited experts. The conference included an introduction to the educational event series led by Giacomo Chiesa by POLITO and two invited speeches. In particular, Agnese Salvati, lecturer at the Universitat Politècnica de Catalunya, Spain, detailed her research on urban microclimate and climate change impacts on building performances in the urban environment. Differently, Massimo Palme, an associate professor at the Universidad Técnica Federico Santa María, Chile[2], had a lecture on green infrastructure for mitigating the Urban heat island effect in Mediterranean climates. After the presentations, a debate was established among the audience about urban climatic issues.

Focusing on contents.

The introduction by Giacomo Chiesa focused on the PRELUDE educational citizen-science activities, focusing in particular on the education event series. Additionally, the PRELUDE project, its main topics, and its objectives were also introduced.

Agnese Salvati is an expert in energy and environmental performance of the built environment at different scales, particularly regarding the urban dimension. Her speech described the interdependencies between urban morphology, building energy performance and urban climate, including the urban heat island phenomena (UHI) and countermeasures. The presentation focused on current studies on the topic and included results from different research combining urban climate and climate change dimensions. The UHI phenomenon is initially presented, introducing and discussing the variations between rural and urban microclimatic conditions. Urban microclimate amplifies the negative effect of climate changes in city spaces, requiring additional countermeasures, as underlined in previous EU projects, such as the ReCO$_2$ST project. Results from demo applications were discussed with innovative methodological approaches for morphing weather files and analysing the urban microclimatic environment, including climate changes and sample applications in different London urban contexts.

Massimo Palme focused on climate change adaptation in the urban climate context, including natural-based solutions and their mitigation and resilience effects. The presentation introduces the correlations between the urban characters, local climate and microclimate environments and which UHI mitigation strategies may be applied to the different contexts. Different international case studies are discussed in three Mediterranean sites (Spain, Chile, and Italy), including adopting different investigation tools. Among the mitigation strategies to reduce the urban heat island, nature-based solutions are discussed, including green roofs, envelope treatments and tree installation.

[2] Visiting researcher in Italy (La Sapienza University 2015-2022, Catania University 2019), Japan (Kobe University - JSPS Fellow 2020) and Ecuador (National Institute of Energy Efficiency and Renewable Energy 2015-16).

2.3.IV 4th lecture/conference: Parametric, environmental, and smart solutions for building retrofitting

Figure 5 - Flyer of the 4th Edu event series

The fourth lecture/conference discussed building retrofitting, focusing on different experiences and application domains. The conference addressed the aspects of energy efficiency, including adopting a new dynamic energy simulation platform for sensitivity analyses, upgrading a professional tool supporting professional decisions, and cost-optimization and LCA (Life Cycle Assessment) aspects. Digital and data analysis and database aspects were also treated during presentations. Involved speakers are part of the PRELUDE's consortium, including POLITO, BUL, and ESTIA experts, for a total of 3 speeches plus the introduction. The final programme included:

- **14:30** | Giacomo Chiesa (**POLITO**, Italy) – Welcome and introduction to the educational event series and to the PRELUDE project;
- **14:40** | Nathalie Dumas (**ESTIA**, Switzerland) – the EPIQR+ method and its platform to efficiently diagnose renovation costs and related CO2 emissions;
- **15:05** | Valentina Stojceska (**BUL**, GB) – Building a greener future: improving Environmental sustainability through retrofitting and renewable energy integration;
- **15:30** | Giacomo Chiesa, Francesca Fasano, Davide Mecca Cici (**POLITO**, Italy) – PREDYCE cost-optimal analyses – energy dynamic simulation supporting sensitivity analyses and optimisation;
- **15:50** | *Q&A*

Shortly after, the fourth lecture/conference meeting, held on the 12th of December 2023 in a hybrid mode, physically at the PoliTO Main campus and online, discussed the parametric, environmental, and smart solutions for building retrofitting. The event hosted an introduction to the education event series by Giacomo Chiesa (POLITO, Turin, Italy) and three presentations by PRELUDE partners. In particular, Nathalie Dumas (ESTIA, Lausanne Switzerland) presented the new EPIQR+ web interface supporting professionals during the complex activity of diagnosis via a systematic approach to identify building degradations and identification of retrofitting solutions considering a fast approach to costs and the newly developed CO_{2-eq} calculations. Valentina Stojceska (Brunel University, London, UK) focused on improving environmental sustainability through retrofitting and renewable energy integration, presenting LCA-LCC's vision for building retrofitting. The POLITO team (Turin, Italy) discussed the possibility of running sensitivity cost-optimal analyses via the PREDYCE EnergyPlus interface, including costs and massive simulations applied to the Turin PRELUDE demo case.

Focusing on contents.

The introduction by Giacomo Chiesa briefly described the different PRELUDE educational citizen-science activities. A focus on the education event series was given, detailing and introducing the speeches of the current events. Additionally, the PRELUDE project and its objectives were also introduced.

The first speaker was Nathalie Dumas, an ESTIA engineer whose interests are focused on the energy and environmental performance of the built environment, the building scale, and both professional and industrial research and innovation issues. Her presentation focused on the EPIQR+ platform[3], a user-friendly simulation tool to support community and retrofitting actions, comparing design solutions and supporting the identification of shared decisions. A new version of the tool has been developed within the PRELUDE project with a fast interface, including a web application, that includes, in addition to simple energy and intervention costs analyses, also CO_2-correlated indices to identify the grey energy of the different intervention scenarios.

Valentina Stojceska, a Reader at Brunel University, London, College of Engineering, Design and Physical Sciences, is leading the second speech. Her intervention focused on building environmental sustainability, considering building retrofitting and environmental assessment, including LCA studies, and also included

[3] https://www.epiqrplus.com/ (last view July 2024)

a case study building in Geneva. She fixed the great responsibility of the building sector in energy consumption and greenhouse gas emissions (GHG). She reminded the EU of the zero-emission building roadmap, including a description of the most diffused GHG mission-efficient retrofitting choices. The ongoing challenges and issues for building retrofitting are also introduced, together with the LCA framework and correlated system boundaries of buildings. The mentioned LCA analysis is hence applied to a caste study, represented by the PRELUDE Geneva demo building, underlining the impact of the building refurbishment on different environmental indicators, including global warming and ecotoxicity.

The latter presentation, by Giacomo Chiesa and Francesca Fasano, focused on adapting the newly developed PREDYCE (Python Realtime Energy Dynamics and Climate Evaluation tool) dynamic simulation platform to support cost-optimal analyses. The new approach includes cost variables correlated to retrofitting actions expanding, in a beta version, the sensitivity analysis scenario. The approach allows us to correlate retrofitting parametric actions, e.g. adding wall insulation with different thicknesses, changing the system COPs, changing window systems, and adding shading solutions, with a parametric cost database, assuming the regional building intervention price list. In addition, post-elaboration analyses are conducted by translating results into readable graphs, such as the heat map ones correlating input variation with outcome KPIs. Some calculations correlated to cost-optimal, and ROI analyses need to be performed post-elaboration, but preliminary results show good potential for future expansions.

2.3.V 5th lecture/conference: Building monitoring, proactive control logic, and smart solutions

Figure 6 - Flyer of the 5th Edu event series

The fifth educational event was about building monitoring and smart solutions. Involved speakers come from the PRELUDE's consortium, including ESTIA, AAU, UNIPD, and FB, as well as from outside the consortium, thanks to a presentation from an ENEA speaker. The final programme is organised as described below.

- **14:30** | Giacomo Chiesa **(POLITO)** – *Welcome and introduction to the educational event series and to the PRELUDE project;*
- **14:40** | Michele Zinzi (**ENEA**, Italy) – *Integrating smart technologies in the ENEA Living Lab: examples from field studies;*
- **15:00** | Tristan de Kerchove (**ESTIA**, Switzerland) – *High energy performance building: a challenge for monitoring and control;*
- **15:20** | Martin Frandsen (**AAU**, Denmark) – *Monitoring of NZEB buildings – lessons learned from two-direction communication from and to the buildings;*
- **15:40 |** *small break*
- **15:50** | Angelo Zarrella & Enrico Prataviera (**UNIPD**, Italy) – *Sensitivity analysis on the best heating setpoint strategy for retrofitted residential buildings: a case study of with radiator systems;*
- **16:10** | Peter Klanatsky (**FB**, Austria) – *Long-term test results of data-driven predictive control;*
- **16:30** | *Q&A session.*

This conference/lecture event focused on "building monitoring, proactive control logic, and smart solutions, including lessons learnt by in-field studies considering several demo cases and two living lab facilities. Preliminary PRELUDE and demo building results are also introduced. Held on the 16th of January 2024, the event has been organised in a hybrid mode, both physically at POLITO main campus and remotely online. This conference included five technical presentations and an introduction to the educational event series led by Giacomo Chiesa by POLITO. In particular, Michele Zinzi by ENEA (the Italian National Energy Agency) has detailed a living-lab field study on the integration of smart technologies in an office building, Tristan de Kerchove by ESTIA has discussed current challenges for high-performative building monitoring and control, Martin Frandsen by AAU focused on NZEB building monitoring, including lesson learned from building cloud bi-directional connections, Enrico Prataviera by UNIPS concentrated on the optimisation of setpoints of radiator systems via a sensitivity analyses on a residential demo building, while Peter Klanatsky by FB, focused on the long-term results of data-driven control logics in the Energetikum living lab.

Focusing on contents.

Giacomo Chiesa illustrated in its introduction the PRELUDE educational and citizen science works, primarily focusing on the "education event series" reminding previous events. Furthermore, he introduced the speakers and the treated topics.

Michele Zinzi, a researcher at ENEA and national ExCo member of the IEA EBC, described a living-lab experience conducted during different previous projects focusing on the integration of smart technologies in a real living lab office building – the ENEA Casaccia one sited near Rome – and reporting correlated lessons learned. The speech described the ENEA living lab – currently covering about seven rooms and 100 m2 of a 3-floor office building – and its main technological features, including the progressive installation of new smart solutions. Results from a study on performance gaps were also reported. The developed SBEM (smart building energy management) is described, and the recently installed GUI supporting monitoring (energy and environmental) and actuation is shown. Focusing on the performance-gap analysis, this considers the energy performance gap between simulated and measured data. Adopting a verified model, different input model variations are considered to detail the impact on the divergencies by the parallel measured data, by also considering different control rules and building management variations. Results suggested how smart technologies coupled with energy-efficient building technologies are relevant in reducing energy uses; smart technology applicability is potentially possible in all building components and services, while one of the current barriers is correlated to the different protocols, systems and standards increasing the complexity in integrating solutions.

In his speech, Tristan de Kerchove by ESTIA focused on the challenges in energy monitoring of buildings, taking advantage of the Geneva real demo case building of PRELUDE. The building is a complex residential building that was recently retrofitted. It is described together with its systems and installed monitoring solutions. In addition to energy issues, IAQ key performance indicators are also considered, allowing the inclusion of indoor environmental quality analyses. Looking at the cons of having extensive monitoring solutions, the presentations underlined that they may require higher maintenance and that a large number of data may support many potential analyses. Still, several data may be questionable, and high coordination is needed among technical people. Nevertheless, these systems' usability may drastically improve from practice, and predictive maintenance may help cover data gaps and support a fast intervention when necessary. The lessons learned are the importance of the proper design of these technologies during the refurbishment project, the need to limit data bridges, inform as early as possible tenants in order to avoid conflicts, anticipate the needed analyses to prevent time losses, and that monitoring probes and communications need to be often verified to prevent issues.

Martin Frandsen, by AAU, presented the establishment of a two-directional communication to monitor and control the Ry Danish PRELUDE demo building. Considering the PRELUDE proactive goal, not only monitoring is needed, but logging also allows the management of data. After having described the different PRELUDE technologies to be correlated to the building monitoring and management system and the communication workflow, the presentation focused on the different measured data points, including energy uses and IEQ indicators. The solutions also control ventilation and shading systems, in addition to PV and heating solutions. Lessons learnt focused on i. where positioning in spaces the different IEQ sensors to reduce multi-factor influences; ii. the identification and access to the monitoring systems, underlining the current complexity and the high time consumption needed to integrate data and solutions; iii. the current limitation of older smart home systems in remote controlling while allowing data logging, and the fact that the integration of different solutions may not be possible, requiring new industrial solutions; and iv. the need to properly design the systems on the base of every single real building, supporting multi-feed-back visions, including inspections, installation, refinement, rechecking, and constant verifications of time series to avoid issues.

The speech of Enrico Prataviera by UNIPD introduced a parametric analysis on the optimisation of setpoint strategies to control residential radiation systems. The energy flexibility and smart readiness of a building are introduced underlining the importance of flexibility in current building management considering active demand response in the building heating season. Furthermore, the presentation focused on the results of parametric control analysis to support via EnergyPlus simulations the anticipated control of radiator thermo valves acting on local setpoints. The proposed approach variates the set-point and set-back temperatures, together with the ramp and the delay times to optimise the energy and thermal comfort simulation outcomes. The approach showed a visible improvement in comfort without increasing energy needs. Conclusions underlined how the increase in comfort is not supporting a reduction in energy uses, although strategies may increase comfort using the same energy when the pre-heating phase and ramp set-point are currently optimised, shifting and reducing energy peaks.

Peter Klanatsky by FB presented what data-driven predictive control approaches are and their importance. Additionally, He described a data-driven predictive control approach application in the Energetikum office living lab, showing the data and technological structures and the obtained energy savings in a long-term test. The data-predictive control logic is an innovative approach that does not require a detailed building model but allows for saving peak energy and shifting loads, optimising run and turn-off times, avoiding active heating and cooling during neutral periods, optimise plant sizing and hourly loads and exploiting solar gains better. In the demo building, grey-box models are developed and coupled with past and forecasted data to support mixed-integer linear programming optimisation. Savings are very consistent, both in reducing the heating and cooling periods and in reducing the daily energy uses during activation.

2.3.VI 6th lecture/conference: intelligent building and digital twins: platform, data treatment, lessons learnt

PRELUDE T9.5 | *educational event series*

Politecnico di Torino

PRELUDE

6th lecture/conference meeting

Intelligent building and digital twins: platform, data treatment, lessons learnt

24th May 2024 | 11:00-13:00 (MET)

Virtual room link:
https://didattica.polito.it/VClass/PRELUDE_6thEDU_event
Physical room (Climate studio class):
Room 5V, Politecnico di Torino – Castello del Valentino, Viale Mattioli, 39 Turin (Italy) | BArch, students

Abstract:
The PRELUDE project - Prescient building Operation utilising Real-Time data for Energy Dynamic Optimization – aims to support advanced innovative, smart, low-cost solutions supporting intelligent buildings and proactive optimisation services. Among the others, the project pursues the minimisation of energy uses, the maximisation of self-consumption and renewable sources balance, and the improvement of comfort conditions supporting the maximisation of free-running building potentials. This event is the sixth of a series of lectures/conferences on smart building issues, climate-free-running building design, and operational solutions. This lecture/conference focuses on energy and comfort in building management platforms, discussing some of the novelties introduced and tested during the PRELUDE project. Contents focus on lessons learnt, including predictive maintenance, BIM and digital twins, user comfort optimisation, user energy profile optimisation, energy and comfort monitoring platforms, middleware and data treatment issues. Results include demo buildings in different countries and discussion of platforms, systems, and GUIs. Speakers are recognised professional experts in the topic.

Keywords: PRELUDE, predictive maintenance, BIM, middleware, BMS, comfort optimisation, lessons learnt, IEQ

Programme:

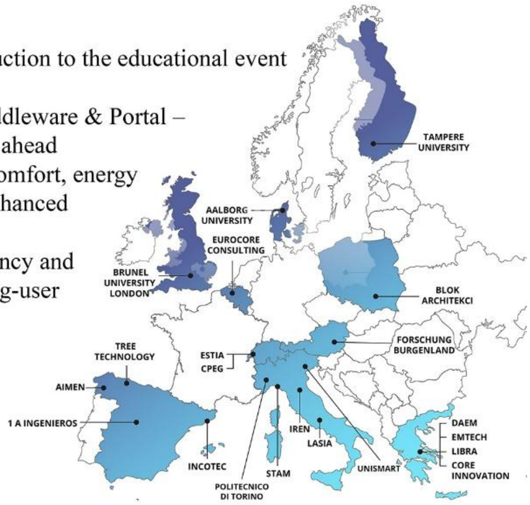
11:00 | Giacomo Chiesa (POLITO, Italy) – Welcome and introduction to the educational event series and to the PRELUDE project

11:10 | Vagelis Alifragkis (EMTECH, Greece) – PRELUDE Middleware & Portal – Stitching everything together. Lessons learnt and the road ahead

11:45 | Marco Barbagelata & Lorenzo Farina (STAM, Italy) – Comfort, energy efficiency and maintenance: novel digital platforms for enhanced building-user interaction (part 1)

12:20 | Rosaria Aversa (LA SIA, Italy) – Comfort, energy efficiency and maintenance: novel digital platforms for enhanced building-user interaction (part 2)

12:55 | Q&A session



prelude-project.eu @PreludeEu prelude-project

The next conferences/lectures of the educational event series will be organised in late spring 2024 focusing on climate resilience in the built environment.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement N° 958345

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Figure 7 - Flayer of the 6th Edu event series

The sixth PRELUDE educational event continued presentation and discussion about PRELUDE's lessons learnt. This specific conference discussed smart building and digital twin topics, including data storage, treatment and elaboration. The event also included a short presentation of the project and the educational activities. The speakers involved are experts within PRELUDE's industrial partners, including EMTECH, STAM, and LA SIA. The programme is structured as follows:

- **11:00** | Giacomo Chiesa **(POLITO)** – *Welcome and introduction to the educational event series and the PRELUDE project;*
- **11:10** | Vagelis Alifragkis (**EMTECH**, Greece) – *PRELUDE Middleware & Portal – Stitching everything together. Lessons learnt and the road ahead;*
- **11:45** | Mattia Repossi & Lorenzo Farina (**STAM**, Italy) – *Comfort, energy efficiency and maintenance: novel digital platforms for enhanced building-user interaction (part 1);*
- **12:20** | Rosaria Aversa & Amilcare Paolella (**LA SIA**, Italy) – *Comfort, energy efficiency and maintenance: novel digital platforms for enhanced building-user interaction (part 2);*
- **12:55** | *Q&A session.*

Shortly, this conference/lecture was on intelligent building and digital twin technologies, discussing lessons learnt correlated to data production, storage, elaboration, and usage in different company-based contexts. Speeches focused on energy and comfort in building management platforms, discussing some of the PRELUDE's introduced and tested novelties. Among the topics addressed, it is possible to mention predictive maintenance, BIM, advanced digital twin generation and their applications, user comfort and energy profile monitoring and optimisation, middleware organisation and multi-sources data treatment issues. Results correlate with PRELUDE's demo buildings and project platforms, including graphical user interfaces.

Focusing on contents.

Firstly, Giacomo Chiesa described the PRELUDE educational and citizen-science task with particular regard to the Educational Event Series. This speech also introduced the PRELUDE project objectives and detailed the following speeches and speakers.

Vagelis Alifragkis by EMTECH presented the developed PRELUDE middleware devoted to connecting different data sources and PRELUDE modules to allow interoperability and integration among the various project technologies and applications. From a software point of view, the PRELUDE project connects tenants with buildings by supporting user information, combining building monitoring, technology providers, and building control and actuation. The project's Middleware, based on the FusiX platform, supports these connections and supports I/O flows. The platform acts as a generic framework for developing DSS applications and enables interoperability and data resource management, storage, security, and homogeneity. The architecture is scalable and cloud-based, supports external tool simulations, and has an independent GUI and several services. Additionally, He introduced the recently developed PRELUDE portal, enabling access to measured data and supporting early elaborations. The speech focused on lessons learned, positive aspects, and open questions. During the speech, a newly under-development monitoring solution by EMTECH, i.e. COMFORT, is also presented, taking inspiration from PRELUDE.

After an introduction to the STAM company, Marco Barbagelata and Lorenzo Farina by STAM introduced their En-Power platform, which supports different layers of operation in building, from design to operational phases, including predictive maintenance and energy optimisation. Focusing on the latter topic, the PRELUDE energy efficiency optimiser technology is presented. It supports the correlation between indoor comfort and energy efficiency while exploiting renewable sources. The scope is helping the users to reduce consumption and save energy costs, e.g. by improving the operational time of the different facilities. Furthermore, the presentation focuses on a new predictive maintenance facility whose approach is based on anomaly detection models and their training. These technologies are tested during the PRELUDE project in demos, including the LLE living lab facility (Austria). Considering the latter, a grey-box approach is adopted for the Energy Optimiser, focusing on an αRC model to define the building characteristics from basic measurements to predict the internal temperatures. Considering the Predictive maintenance, the test applies to air handling units (UHA), defining an anomaly detection model with a train and test approach on existing monitored data. Similarly, applications arrive with good results in the Ry demo building (Denmark), considering PV panels, heat pumps and electric cars. In this demo, the αRC model is not strong enough, suggesting black-box approaches like neural networks. For predictive maintenance, the test is trained for AHU on past data to verify the ability to detect a broken fan that arrived in 2022.

Rosaria Aversa and Amilcare Paolella by LA SIA focus on BIM processes and AIM (Asset Information Management) platform applications, including scan-to-BIM and digital twin development. After a presentation of the LA SIA company, the speech describes advanced BIM approaches and innovations, including the use of proprietary technologies and tools, including drone and laser scanner applications. BIM is used in several phases, including design, construction and maintenance. A series of sample applications of AIM platforms are presented, showing integrations among building and system models, AIM management, supporting data loading and visualisation, managing and monitoring and including static and dynamic data treatment via IoT. The AIM LA SIA platform can help navigate various buildings and modelling versions via its interface, allowing to pursue an integrated approach. Each modelled element, from building to system ones, can be interrogated to retrieve information by adopting filters. With this approach, a maintenance user may check via tablet or smartphone the Digital Twin platform without being a BIM expert, current information and upgrade them when needed. The platform also suggests current and future maintenance interventions to correctly plan and manage the building. The same also allows to see historical or real-time measured information. Finally, the speech introduces a real example of a BIM workflow process considering a very complex and large case, the City of Sport in Rome by Calatrava. The construction site is unfinished, requiring an attentive series of BIM processes: scan-to-model survey, including the definition of modelling specification and rules and the geometric acquisition via more than 1000 stations, laser scanners and drones, documentary research, structural investigation, and maintenance plan development.

2.3.VII 7th lecture/conference: Building resilience to climate changes and urban climate issues

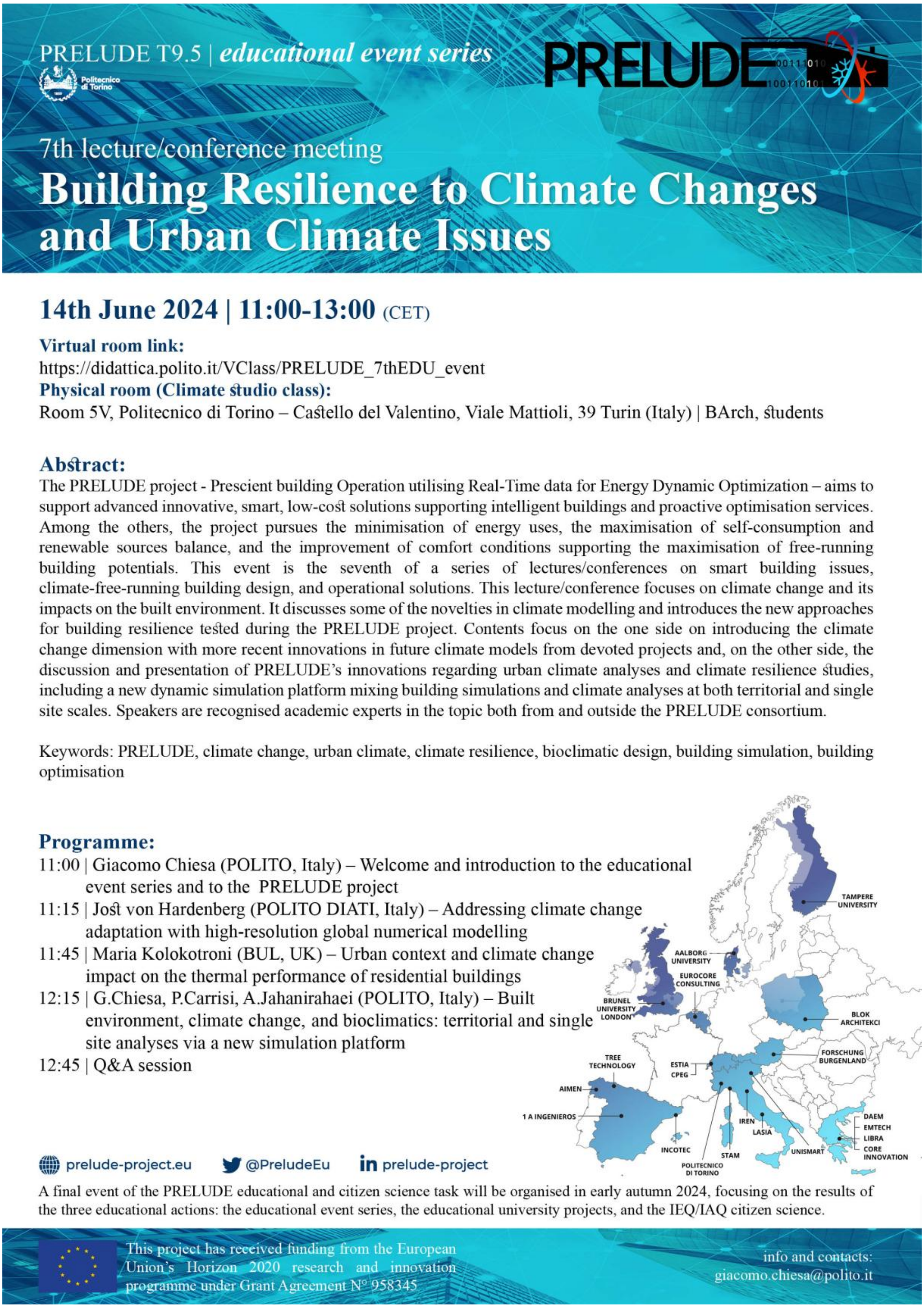


Figure 8 - Flayer of the 7th Edu event series

The seventh educational event was the last lecture/conference of the Educational Event Series. It was devoted to discussing climate change issues in the built environment, focusing on both climate change and urban climate dimensions. Speakers are recognised academic experts, including POLITO and BUL from the PRELUDE's consortium, who are discussing building and city-correlated issues, and a climatologist from POLITO-DIATI introduced climate change and climate modelling aspects at different scales. The programme is presented here:

- **11:00** | Giacomo Chiesa **(POLITO)** – *Welcome and introduction to the educational event series and the PRELUDE project;*
- **11:15** | Jost von Hardenberg (**POLITO DIATI**, Italy) – *Addressing climate change adaptation with high-resolution global numerical modelling;*
- **11:45** | Maria Kolokotroni (**BUL**, UK) – *Urban context and climate change impact on the thermal performance of residential buildings;*
- **12:15** | Giacomo Chiesa, Paolo Carrisi, Ali Jahanirahaei (**POLITO**, Italy) – *Built environment, climate change, and bioclimatics: territorial and single site analyses via a new simulation platform;*
- **12:45** | *Q&A Session.*

This seventh event focuses on climate change and its impacts on the built environment. It discusses some of the novelties in climate modelling and introduces the new approach for building resilience tested during the PRELUDE project. Contents introduce the climate change dimensions, including recent innovations in future climate models. Additionally, they are presented and discussed PRELUDE's outcomes correlated to climate and urban climate resilience. Correlated upgrades to the PREDYCE dynamic simulation platform are discussed to support both territorial and single-building climate analyses.

Focusing on contents.

In the introduction speech, Giacomo Chiesa illustrated the PRELUDE educational and citizen science task, focusing on the "education event series". Furthermore, he presented the other speakers and described the treated topics.

Jost von Hardenberg (POLITO DIATI) introduced the climate change phenomenon, the development of global numerical modelling and the study of results based on numerical climate models and their projections. In addition, the speech also discusses the current and under-development state of the art in terms of modern numerical climate models acting as digital twins of our climate system. Climate models clearly do not represent particular days (they do not do weather forecasting) but the type and variability of possible days. von Hardenberg reminded the historical paths of the development of forecasting numerical models applied to weather forecasting before, and climate after. The global earth-system model considers many components, including oceans, land surface, and atmospheric variables. The increasing complexity and resolutions in modern global climate models (GCMs) are discussed, describing the passage from 500km of spatial resolution and limited variables in 1990 to less than 87km in 2013-21. Nevertheless, higher resolutions are needed when specific analyses are required, e.g. including cities, and may be covered by regional climate models. The EC Earth system model is mentioned. Furthermore, examples of applications of future climate change projects are shown, including the recent CMIP6 global models and some samples from regional models like EUROCORDEX. Finally, recent ongoing works to bring global climate models to km-scale resolutions are discussed, with an introduction to Destination Earth, an EU-funded initiative.

In her speech, Maria Kolokotroni (BUL, UK) presented the PRELUDE correlated works, including the urban dimension in climate change impact analyses focused on thermal performance and ventilation in residential buildings. An approach to include the urban climate dimension in building energy performance analysis is presented and applied to Athens, focusing on the local PRELUDE demo case. The Athens pilot building is a densely built area with limited vegetation. Dynamic energy analyses are typically based on Typical Weather Files (TMY), generally obtained from an Airport meteorological station, although the urban dimension is missing. The proposed methodology includes a previous approach that can morph rural TMY into urban ones by considering the local morphology and its impacts on temperature, humidity, solar obstructions, and the wind. Comparing results for the Athens site, the temperature increase among current and future weather data is underlined. Similarly, an increase is highlighted in the city context concerning the airport. For wind, general urban weather slightly modifies the wind, although, in urban canyons, wind velocities are drastically reduced, cutting down natural ventilation wind-driven potential. Applying the morphed urban conditions to building simulation results, the impact of Urban Heat Island (UHI) and climate changes show a reduction in heating demand and growth in cooling demand. At the same time, the effect is higher in upper building floors where solar heat gains are higher (fewer shades), reducing heating and increasing cooling needs. When urban canyon wind is adopted, the mentioned effect increases in magnitude, showing that without a proper urban morphed file, we risk overestimating heating needs and underestimating cooling ones.

In the last presentation, Giacomo Chiesa (POLITO) discussed the initial results of the PRELUDE climate-resilient task, considering a new approach that couples massive simulations with large climate territorial databases. The scope is to include the climate change phenomenon as a dynamic variable in building energy and IEQ performance evaluations. The latter is essential for correctly evaluating low-energy and bioclimatic technologies whose applicability is firmly climate- and microclimate-dependent. The work included the definition of a new methodology hybridising climate and bioclimatic design, the identification of a specific series of key performance indicators (KPIs), the integration and elaboration of large climate/weather databases into building simulation flows, and the application of massive simulation runs to support territorial and specific site studies on climate change resilience. KPIs refer to climate-based variables, such as virtual building and building simulation. The adopted climate databases are re-analysis hourly defined data from ERA5 (1949-2022) and ERA5-land (1950-2022), and future models from EUROCORDEX (20 couple of global and regional models, four elaborated for the final analyses) with historical data from 1970-2005 and projections RCP2.6, 4.5 and 8.5 (2006-2100). Data are elaborated, and specific EPW is generated with modified versions of the PREDYCE EPW compiler tool (ERA5 for Europe, ERA5-land for a smaller territory and EUROCORDEX for single points). Furthermore, simulations are run to compute the KPIs using a climate PREDYCE version and re-elaborated PREDYCE KPIs to run via CDO and Python. Initial results for single PRELUDE demo sites, mainly for Turin, Ry and Athens, and territorial bioclimatic potential analyses are shown and discussed.

3. Educational projects and exhibition

3.1 Introduction and Organisation

The second educational activity focuses on the proposal and elaboration of didactical projects. The scope is to involve POLITO's university students in developing innovative solutions to focused challenges compatible with the PRELUDE-project-treated topics and objectives. It needs to be mentioned that the approach is didactical, pursuing the possibility of challenging students with innovative issues but focusing on results reaching a TRL (Technical readiness level) among 3 to 5. Involved students are from architecture and telecommunication engineering, covering PRELUDE correlated knowledge backgrounds. The POLITO research team conceived student project topics, objectives, and expected outcomes and proposed them to groups of students (interdisciplinary works) and single ones (thesis works). The main obtained results are summarised homogeneously to prepare a series of posters.

3.2 Overview of the developed student projects and correlation to PRELUDE topics

During the PRELUDE project, 10 student project activities have been carried out, supporting the development of a specifically proposed thesis and interdisciplinary project contents. In particular, among these activities are treated the following primary PRELUDE-correlated topics:

- Design optimisation studies and sensitivity analyses via parametric simulation platforms supporting free-running building and retrofitting – see 3.3.I, 3.3.II, 3.3.IV, 3.3.V;
- Monitoring IoT cloud-accessible system development – see 3.3.VI, 3.3.VIII, (3.3.IX, 3.3.X);
- Actuation and operational building management approaches – see 3.3.X, (3.3.VI, 3.3.VII);
- Occupancy profile developments via data analyses – 3.3.VII;
- Climate change and urban climate data analysis tools, including cloud-accessible weather monitoring system development – see 3.3.III, 3.3.IX, (3.3.II, 3.3.IV).

The projects and their main results have been disseminated to the public via the organisation of one poster exhibition parallel to the PRELUDE 7th consortium meeting and open to the public in the Atrium of the Turin Energy Center building facility – 27th and 28th of June 2023 (7 projects)[4]. Additionally, one final exhibition, including all the PRELUDE educational results (T9.5) coupled with a PRELUDE final educational event (20th November 2024), has been held in the Sala delle Colonne, at Valentino Castle[5], Turin – from 20th to 22nd of November 2024. Students from projects 3.3.VIII and 3.3.IX also discussed their works during the 7th PRELUDE consortium meeting in a devoted T9.5 session and during two meetings organised with the Piedmont Region advisory board member, one of which is open to high-school teachers (28/03/2024 and 18/05/2023).

In both exhibitions, each project is represented by a 70x100 cm poster, including the following sections: title, abstract and keywords, short state-of-the-art and background definition, proposed methodology description, results, and discussion. Each poster is prepared by POLITO on the base of the student post-elaborated materials. Below are the two panels presenting the exhibition group projects' contents and guiding the visitors, while Section 3.3 reports all the educational project posters.

[4] Research into innovative and proactive smart-building solutions continues at the Politecnico | Politecnico di Torino (polito.it)

[5] Valentino Castle – Humanity UNESCO Heritage site

Figure 9 - Introductive poster for the 1st Educational Activity Poster Exhibition (Educational projects) – 27-28 June 2023, Atrium of the EnergyCenter, Via P.Borsellino 38/16, Turin

Figure 10 - Introductive poster for the Educational projects section of the 2nd PRELUDE Educational activity exhibition – 20-22 November 2024, Sala delle Colonne, Valentino Castle, V.le PA Mattioli 39, POLITO, Turin

3.3 Main obtained educational project results

The ten projects are the following:

I. MEng (ICT4SS Master Degree in Telecommunication Eng.) Thesis: "Surrogate Modelling and Optimisation in EnergyPlus Environments for Smart Buildings", P.Carrisi, A.Y. 2021-22;
II. MArch (Architecture for Sustainability) Thesis: "Rhino-Grasshopper EnergyPlus interfaces. Development of a simple input compiler to study technological strategies for low-energy buildings", E.Vignani, A.Y. 2021-22;
III. MEng (ICT4SS Master Degree in Telecommunication Eng.) Thesis: "Collecting and Using Weather Data from OpenSources for climate analysis and building simulations", P.De Santis, A.Y. 2022-23;
IV. MArch (Architecture for Sustainable Design) Thesis: "Scripting Architecture: Orienting Early Design Choices via Optimisation", Z.Zhuo, A.Y. 2023-24;
V. MArch (Architecture for Sustainability) Thesis: "Scenari di retrofit e cost-optimal / Retrofitting scenarios and cost-optimal", D.Mecca Cici, work started A.Y. 2022-23, discussion planned A.Y. 2023-24;
VI. MEng (Telecommunication Eng.) group project: "Smart Building PMV/PPD Monitoring Platform and Visual Interface", A.Avignone, T.Carluccio, A.Y. 2020-21;
VII. MEng (Telecommunication Eng.) group project: "Mobile User-Occupancy App for Building Smart Management", T.Song, D.Wang, Z.Zhao, A.Y. 2021-22;
VIII. MEng (Telecommunication Eng.) group project: "Multi Comfort Citizencience Platform", D.Montrucchio, G.A.Patarino, D.Ruta, A.Y. 2022-23
IX. MEng (Telecommunication Eng.) group project: "Weather sensoring cloud-connected kit", M.Bogoni, A.Corino, L.De Matteis, G.Sarvia, A.Y. 2022-23
X. MEng (Telecommunication Eng.) group project: "FRYZZY – Free-Running and Hybrid Building Comfort Optimisation via Fuzzy Logic Alerting", R.F.Bratu, L.Crocchi, F.Callerio, J.Heru, S.Viccari, A.Y. 2023-24

All projects' posters are reported below, summarising the obtained outcomes by reporting the abstracts, objectives and conclusions in a larger font dimension and adding PRELUDE's connection points.

3.3.I M.Eng thesis: Paolo Carrisi, "Surrogate modelling and Optimisation in EnergryPlus environment for Smart Buildings", A.Y. 2021-22

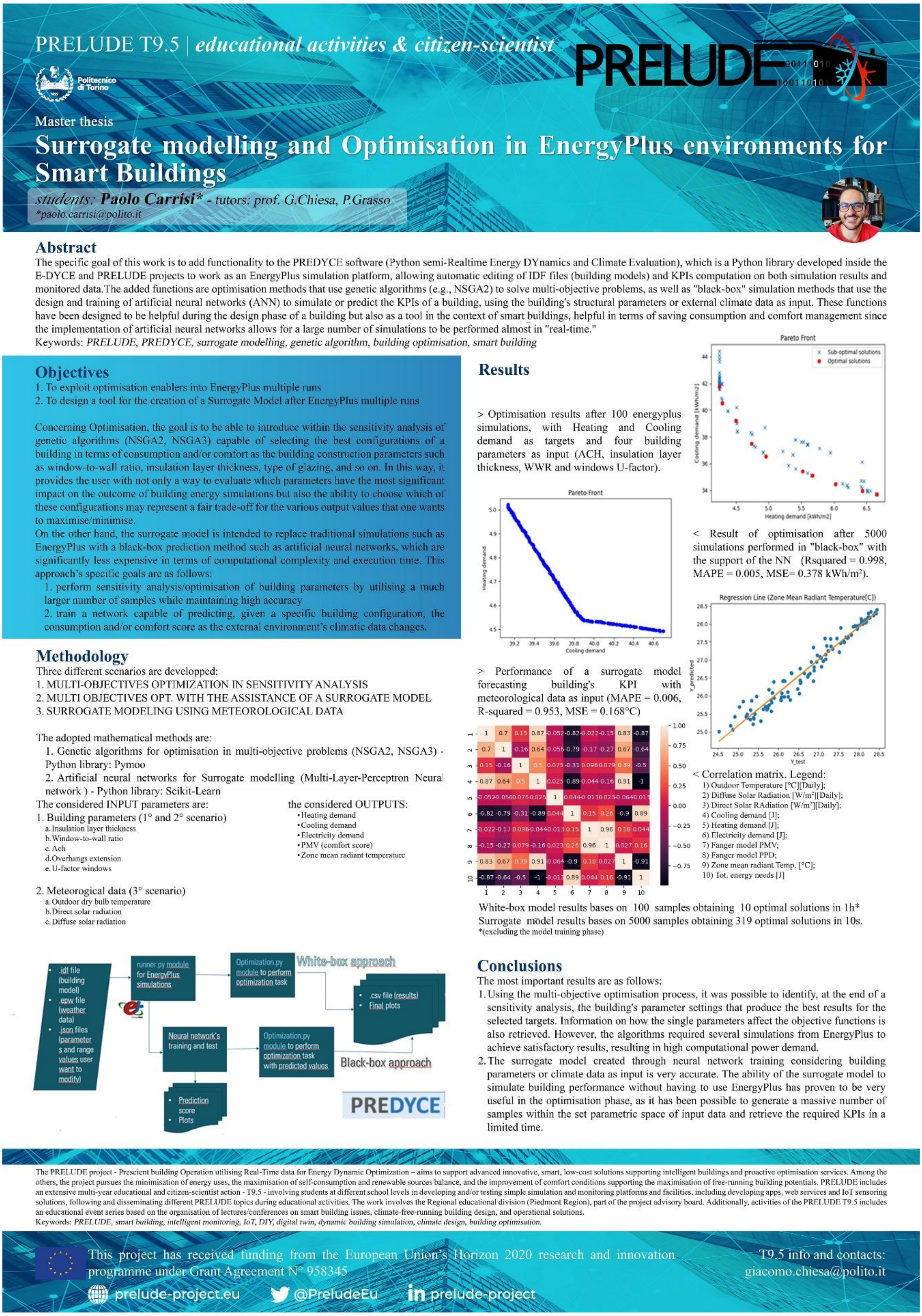


Figure 11 - Poster: Surrogate Modelling and Optimisation in EnergyPlus Environments for Smart Buildings (P.Carrisi)

Abstract:
The specific goal of this work is to add functionality to the PREDYCE software (Python semi-Realtime Energy DYnamics and Climate Evaluation), which is a Python library developed inside the EU H2020 co-funded E-DYCE (GA 893945) and PRELUDE (GA 958345) projects to work as an EnergyPlus simulation platform, allowing automatic editing of IDF files (building models) and KPIs computation on both simulation results and monitored data. The added functions are optimisation methods that use genetic algorithms (e.g. NSGA2) to solve multi-objective problems, as well as "black-box" simulation methods that use the design and training of artificial neural networks (ANN) to simulate or predict the KPIs of a building, using the building's structural parameters or external climate data as input. These functions have been designed to be helpful during the design phase of a building but also as a tool in the context of smart buildings, useful in terms of saving consumption and comfort management since the implementation of artificial neural networks allows for a large number of simulations to be performed almost in "real-time."
Keywords: PRELUDE, PREDYCE, surrogate modelling, genetic algorithm, building optimisation, smart building

Objectives:
The educational project pursues the following two main objectives:
1. To exploit optimisation enablers into EnergyPlus multiple runs;
2. To design a tool for the creation of Surrogate Models after multiple EnergyPlus runs.

Concerning the Optimisation topic, the goal is to introduce within the sensitivity analysis scenario of PREDYCE a series of genetic algorithms (NSGA2, NSGA3) able to select the best configurations of building input parameters, e.g. window-to-wall ratio, insulation layer thickness, type of glazing, and so on, to minimise energy consumption and/or maximise indoor environmental comfort conditions. This potentiality allows the user to evaluate which parameters have the most significant impact on the outcome of building energy simulations and the ability to choose which of these configurations may represent a fair trade-off for the various output values that one wants to maximise/minimise.
On the other hand, the surrogate model is intended to replace traditional white-box simulations, such as EnergyPlus-based ones, with a black-box prediction method, such as artificial neural networks, which are significantly less expensive in terms of computational complexity and execution time. This approach's specific goals are as follows:
1. perform sensitivity analysis/optimisation of building parameters by utilising a much larger number of samples while maintaining high accuracy;
2. train a network capable of predicting, given a specific building configuration, the consumption and/or comfort score as the external environment's climatic data changes.

Conclusions:
The most essential obtained results are reported below:
1. Using the multi-objective optimisation process, it was possible to identify, at the end of a sensitivity analysis, the building's parameter settings that produce the best results for the selected targets. Information on how the single parameters affect the objective functions is also retrieved. However, the algorithms required several simulations from EnergyPlus to achieve satisfactory results, resulting in high computational power demand.
2. The surrogate model created through neural network training considering building parameters or climate data as input is very accurate. The ability of the surrogate model to simulate building performance without having to use EnergyPlus has proven to be very useful in the optimisation phase, as it has been possible to generate a massive number of samples within the set parametric space of input data and retrieve the required KPIs in a limited time.

PRELUDE connection:
This work supports the first use of surrogate models inside the PREDYCE simulation library, suggesting future developments of the tool, potentially substituting white-box real-time modelling with black-box simulation solutions. Additionally, thanks to this work, optimisation genetic algorithms have been added to PREDYCE. Paolo's work continued after the thesis, entering the POLITO PRELUDE team.

3.3.II M.Arch thesis: Eleonora Vignani, "Rhino-Grasshopper EnergyPlus Interfaces – Development of a simple input compiler to study technological strategies for low-energy buildings", A.Y. 2021-22

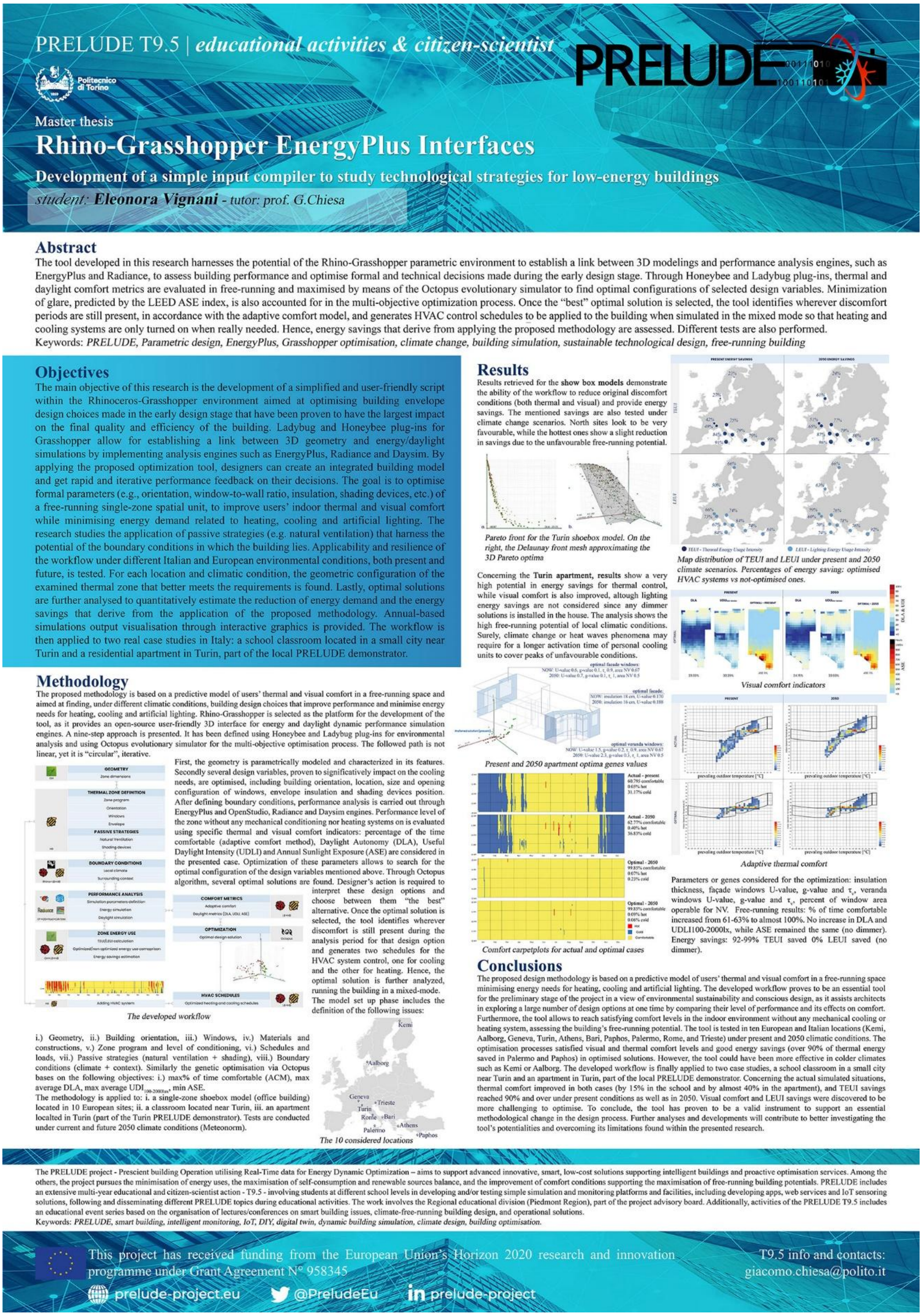


Figure 12 - Poster: Rhino-Grasshopper EnergyPlus Interfaces (E.Vignani)

Abstract:
The tool developed in this research harnesses the potential of the Rhino-Grasshopper parametric environment to establish a link between 3D modelling and performance analysis engines, such as EnergyPlus and Radiance, to assess building performance and optimise formal and technical decisions made during the early design stage. Through Honeybee and Ladybug plug-ins, thermal and daylight comfort metrics are evaluated in free-running and maximised using the Octopus evolutionary simulator to find optimal configurations of selected design variables. Minimisation of glare, predicted by the LEED ASE index, is also accounted for in the multi-objective optimisation process. Once the "best" optimal solution is selected, the tool identifies wherever discomfort periods are still present by the adaptive comfort model and generates HVAC control schedules to be applied to the building when simulated in the mixed mode so that heating and cooling systems are only turned on when needed. Hence, energy savings that derive from applying the proposed methodology are assessed. Different tests are also performed.
Keywords: PRELUDE, Parametric design, EnergyPlus, Grasshopper optimisation, climate change, building simulation, sustainable technological design, free-running building

Objectives (short):
The main objective is the development of a simplified and user-friendly script within the Rhinoceros-Grasshopper environment aimed at optimising building envelope design choices made in the early design stage that have been proven to have the most significant impact on the final quality and efficiency of the building. Ladybug and Honeybee plug-ins for Grasshopper allow for establishing a link between 3D geometry and energy/daylight simulations by implementing analysis engines such as EnergyPlus, Radiance, and Daysim. By applying the proposed optimisation tool, designers can create an integrated building model and get rapid and iterative performance feedback on their decisions. The goal is to optimise formal parameters (e.g., orientation, window-to-wall ratio, insulation, shading devices, etc.) of a free-running single-zone spatial unit to improve users' indoor thermal and visual comfort while minimising energy demand related to heating, cooling and artificial lighting. The research studies the application of passive strategies (e.g. natural ventilation) that harness the potential of the boundary conditions in which the building lies. The tool is tested in ten European and Italian locations (Kemi, Aalborg, Geneva, Turin, Athens, Bari, Paphos, Palermo, Rome, and Trieste) under present and 2050 climatic conditions. The workflow is then applied to two real case studies in Italy: a school classroom in a small city near Turin and a residential apartment in Turin, part of the local PRELUDE demonstrator.

Conclusions (short):
The proposed design methodology is based on a predictive model of users' thermal and visual comfort in a free-running space, minimising energy needs for heating, cooling and artificial lighting. The developed workflow proves to be an essential tool for the preliminary stage of the project, given environmental sustainability and conscious design, as it assists architects in exploring many design options at one time by comparing their level of performance and its effects on comfort. The optimisation processes satisfied visual and thermal comfort levels and good energy savings (over 90% of thermal energy saved in Palermo and Paphos) in optimised solutions. However, the tool could have been more effective in colder climates such as Kemi or Aalborg. The developed workflow is applied to two case studies: a school classroom in a small city near Turin and an apartment in Turin, part of the local PRELUDE demonstrator. Thermal comfort improved in both cases (by 15% in the school and by almost 40% in the apartment), and TEUI savings reached 90% and over under present conditions as well as in 2050. Visual comfort and LEUI savings were discovered to be more challenging to optimise. To conclude, the tool has proven to be a valid instrument to support an essential methodological change in the design process.

PRELUDE connection:
The study investigates using different tools to design free-running optimisations, including building system schedule management. Advanced daylight tools suggest potential future dynamic energy simulation platform development directions.

3.3.III M.Eng thesis: Paolo De Santis, "Collecting and using weather data from open sources for climate analysis and building simulations", A.Y. 2022-23

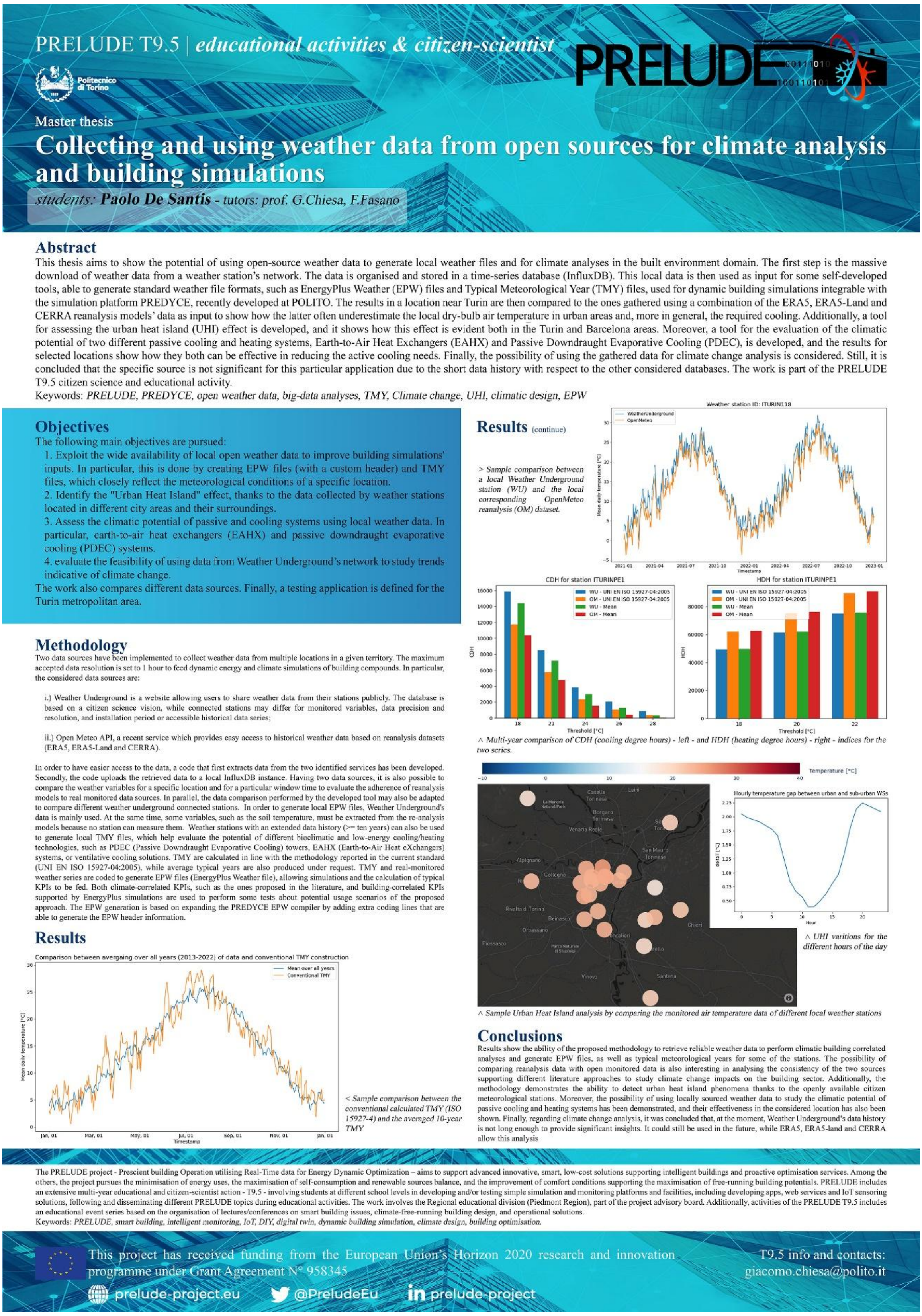


Figure 13 - Poster: Collecting and Using Weather Data from OpenSources for climate analysis and building simulations (P. De Santis) – V.2

Abstract:
This thesis aims to show the potential of using open-source weather data to generate local weather files and for climate analyses in the built environment domain. The first step is the massive download of weather data from a weather station's network. The data is organised and stored in a time-series database (InfluxDB). This local data is then used as input for some self-developed tools, able to generate standard weather file formats, such as EnergyPlus Weather (EPW) files and Typical Meteorological Year (TMY) files, used for dynamic building simulations integrable with the simulation platform PREDYCE, recently developed at POLITO. The results in a location near Turin are then compared to the ones gathered using a combination of the ERA5, ERA5-Land and CERRA reanalysis models' data as input to show how the latter often underestimate the local dry-bulb air temperature in urban areas and, more in general, the required cooling. Additionally, a tool for assessing the urban heat island (UHI) effect is developed, and it shows how this effect is evident both in the Turin and Barcelona areas. Moreover, a tool for the evaluation of the climatic potential of two different passive cooling and heating systems, Earth-to-Air Heat Exchangers (EAHX) and Passive Downdraught Evaporative Cooling (PDEC), is developed, and the results for selected locations show how they both can be effective in reducing the active cooling needs. Finally, the possibility of using the gathered data for climate change analysis is considered. Still, it is concluded that the specific source is not significant for this particular application due to the short data history with respect to the other considered databases. The work is part of the PRELUDE T9.5 citizen science and educational activity.
Keywords: PRELUDE, PREDYCE, open weather data, big-data analyses, TMY, Climate change, UHI, climatic design, EPW

Objectives:
The following main objectives are pursued: i.) Exploit the wide availability of local open weather data to improve building simulations' inputs. In particular, this is done by creating EPW files (with a custom header) and TMY files, which closely reflect the meteorological conditions of a specific location; ii.) Identify the "Urban Heat Island" effect, thanks to the data collected by weather stations located in different city areas and their surroundings; iii.) Assess the climatic potential of passive and cooling systems using local weather data. In particular, earth-to-air heat exchangers (EAHX) and passive downdraught evaporative cooling (PDEC) systems; and iv.) evaluate the feasibility of using data from Weather Underground's network to study trends indicative of climate change.
The work also compares different data sources. Finally, a testing application is defined for the Turin metropolitan area.

Conclusions:
Results show the ability of the proposed methodology to retrieve reliable weather data to perform climatic building correlated analyses and generate EPW files, as well as typical meteorological years for some of the stations. The possibility of comparing reanalysis data with open monitored data is also interesting in analysing the consistency of the two sources supporting different literature approaches to study climate change impacts on the building sector. Additionally, the methodology demonstrates the ability to detect urban heat island phenomena thanks to the openly available citizen meteorological stations. Moreover, the possibility of using locally sourced weather data to study the climatic potential of passive cooling and heating systems has been demonstrated, and their effectiveness in the considered location has also been shown. Finally, regarding climate change analysis, it was concluded that, at the moment, Weather Underground's data history is not long enough to provide significant insights. It could still be used in the future, while ERA5, ERA5-land and CERRA allow this analysis.

PRELUDE connection:
This work is correlated to the PRELUDE climate resilience works of T8.5, anticipating some actions on the PREDYCE EPW compiler, integrating TMY generation and EPW headers. Additionally, it investigated the potential for future expansions, integrating existing data sources in urban climate analyses via a big-data approach, both considering future expansions and applications of PREDYCE or other actions.

3.3.IV M.Arch thesis: Ziyan Zhuo, "Scripting Architecture: Orienting Early Design Choices via Optimisation", A.Y. 2023-24

Figure 14 - Poster: Scripting Architecture (Z.Zhuo)

Abstract:
This work, part of the PRELUDE T9.5 educational project activity, explores how parametric design, simulation, and optimisation methodologies intertwine, showcasing their effectiveness in architectural early design across various climatic contexts. Firstly, a way to design an imagined box office with parametric skill is defined. Secondly, we evaluated the latter from 3 perspectives: economic assessment, energy needs intensity and comfort performances. Thirdly, a genetic algorithm is scripted and applied to get multi-variable optimised results and allow experiment repetitions under different climate conditions. Lastly, we collect the results and visualise and analyse them.
Keywords: Multiple-objectives Optimisation, Building energy simulation, Genetic algorithm, PRELUDE

Objectives:
Three categories of target variables are defined to analyse and optimise architecture design correlated performances. These categories are i. comfort, ii. EUI (Energy Use Intensity), and iii. cost. Correlated performances coordinate with sustainability goals in the built environment to support early-design choice optimisation by parametrically acting on shapes and technological design configurations. Performances are expected to be measured in a simulated environment. To face this goal, genetic algorithms are applied to find the optimal configuration, maximising the building performance in each target category and the most balanced configuration. The work aims at testing and adopting an automatic genetic algorithm workflow that repeatedly tries several combinations of defined design parameters, i.e. insulation thickness, glazing type, louvres count, Window-to-Wall Ratio (WWR), and delta control temperature of ventilative cooling. A sample showbox office unit is designed in the Rhinoceros®-Grasshopper® environment to test the workflow in several climatic conditions, identifying optimal local design conditions.

Conclusions:
This work entered into design optimisation solutions, suggesting an early-design approach including dynamic energy and visual comfort simulations and adopting energy needs, comfort issues and cost aspects as target variables. The approach can be correlated to some PREDYCE functionalities, suggesting alternative development directions.

PRELUDE connection:
This thesis work investigates the parametric optimisation of design choices, aligning with the PREDYCE sensitivity analysis scenario. The work is here based on existing Grasshopper-Rhinoceros plug-ins, suggesting that dynamic simulation tools like the one co-developed in PRELUDE can be improved by developing interfaces for existing coding CAD environments. Additionally, this educational experience touches the climate change resilience domain, aligning also with this PRELUDE topic.

3.3.V M.Arch thesis: Davide Mecca Cici, "Scenari di retrofit e cost-optimal / Retrofitting scenarios and cost-optimal", started A.Y. 2022-23, discussion planned A.Y. 2023-24

PRELUDE T9.5 | *educational activities & citizen-scientist*

Politecnico di Torino

Master Thesis 2022-24

Retrofitting scenarios and cost-optimal

student: ***Davide Mecca Cici***
tutors: prof. G.Chiesa, prof. E.Fregonara
F.Fasano and P.Grasso are thankfully acknowledged

Abstract
The project aims to develop a transdisciplinary workflow to improve the use of the PREDYCE dynamic energy simulation platform to perform retrofitting and cost-optimal analyses, including new cost-correlated functions and defining a post-production pipeline. The proposed method will identify the most suitable retrofitting solutions for different climates, supporting energy and cost-optimal scenarios considering massive retrofit options. Based on the development of extra PREDYCE cost functionalities and a post-simulation approach, the defined workflow is tested on existing building models, including the Italian PRELUDE demo building. Additionally, two different meteorological year EPWs are assumed to consider climate change aspects, considering historical Typical Meteorological Years and data monitoring in recent years (2022) from cloud-connected weather station facilities. The workflow supplies feedback to end-users considering energy and comfort aspects together with economic data. Results show a high interest in the proposed approach, which is demonstrated to be suitable for supporting designers in early design choices.
Keywords: *PRELUDE, Retrofitting, cost-optimal, sensitivity analyses, building simulation, technological design, PREDYCE*

Objectives
This project will demonstrate that the existing PREDYCE dynamic simulation platform can be adapted to investigate optimal energy retrofit solutions from a technical and economic perspective. This work, developed together with the POLITO research team, aims to define a preliminary workflow allowing the use of advanced analysis to support designers, from early design stages, in the identification of the most appropriate retrofitting package, including passive solutions, according to the climate zone and typical user profiles, including cost analyses. The main objectives can be summarised as follows:

1. Define a workflow to use the PREDYCE platform to identify retrofitting optimal solutions, including energy and technological choices and cost-optimal values;
2. Support the beta-integration in PREDYCE of a cost database, based on the local, regional price catalogue, correlating IDF modification actions, e.g. "add wall insulation";
3. Test the workflow on calibrated building models assumed from ongoing projects, including the Turin PRELUDE demo case.

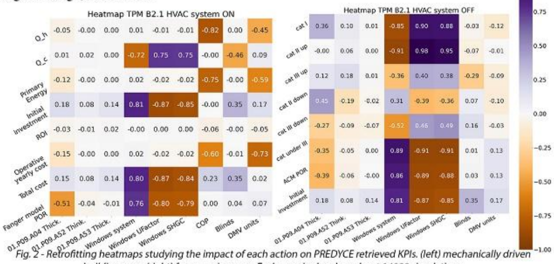
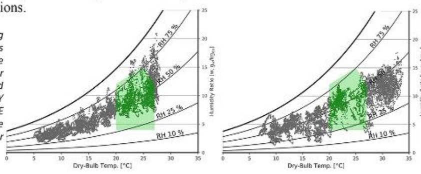


Fig. 2 - Retrofitting heatmaps studying the impact of each action on PREDYCE retrieved KPIs. (left) mechanically driven building case, (right) free-running case. Each map is absed on about 14000 simulations.

Methodology
The developed workflow is structured in two phases: i. the PREDYCE dynamic energy simulation platform run, inputting the proposed retrofitting packages into the chosen building model(s); ii. the data elaboration of the retrieved calculated KPIs, including manual elaborations via a spreadsheet defining the overall cost of each simulated package. Firstly, relevant retrofitting interventions are identified considering each IDF model's specific climate and building characteristics, e.g., adding external insulation, replacing windows, adding shading, increasing system efficiencies, or installing mechanical ventilation units (CMV). Different options, e.g. insulation thickness, are defined for each intervention. The work is based on PREDYCE, which is parametrically editing the various solutions on a building IDF model to analyse a pool of thousands of simulations. Several retrofitting actions are combined to generate the different user-defined intervention packages and obtain correlated building energy needs. The same building model is also simulated in free-running conditions, deactivating the systems to evaluate Adaptive thermal Comfort conditions (ACM). Concerning the weather files, a Turin Typical Meteorological Year (TMY) was generated from Meteonorm. At the same time, an Actual Meteorological Year (AMY) was defined from measured weather data (2022-23) – see Fig.1. The simulation workflow uses an additional functionality that can combine IDF modification with correlated initial investment costs. Costs are correlated to each action and intensity (e.g., thickness), considering the Piedmont Regional cost database and company quotes. Via PREDYCE, the following KPIs are provided: Energy signature, initial scenario costs, system energy needs, Fanger comfort conditions with the system active, and the adaptive comfort model distribution for free-running simulations.

Fig. 1 - Indoor free-running simulated temperatures considering a sample retrofitting solution for (left) the Turin TMY and (right) the measured AMY (2022-23 POLITO-PRELUDE weather station). Note the increase in summer temperatures.



Secondly, the workflow post-elaborates the massive data provided by the tool to identify the optimal economic and energy solutions. This step focuses on the economic evaluation of the mechanical system scenarios. The user (designer), starting from the extrapolated outputs, will derive the annual energy demand based on the efficiency of the systems (final energy) to calculate, via the developed spreadsheet, the operative yearly costs based on the energy unitary costs per vector (e.g. electricity, natural gas) published by the energy national agency ARERA. As a final step, a simplified discounted cash-flow analysis is carried out, considering 20 years of operation, through which the overall cost is calculated and cost-optimal retrofitting solutions are identified using the European Standard EN 15459:2007 methodology and according to the designer's interpretation.

Results
The PREDYCE platform provided about 14,000 simulations for each reference building and scenario of use retrieving massive KPI databases. Results are obtained via the research unit server facility, including a synthetic multi-simulation CSV file and graphical KPI results for each simulation. To elaborate on these data, a PREDYCE post-elaboration Python code compares KPIs with correlated input variations using heatmaps to quantify the magnitude of actions' impacts –see Fig. 2.

The energy demand during the winter period is the most influential component for the given climates, both economically and in primary energy. Therefore, adding envelope thermal insulation remains the solution with the highest impact on energy efficiency. Nevertheless, the cooling demand triples when the recent AMY scenario is assumed (compared to TMY), increasing the effect of cooling-correlated actions (shading and ventilative cooling). The economic analysis confirmed that the main cost-optimal packages are adding thermal insulation and replacing the lighting system with effective LED solutions. Still, it has also revealed how other energy-effective actions, such as installing DMV systems and window replacement, drastically increase the total cost of the retrofit intervention, negatively counterbalancing the positive effect on energy needs

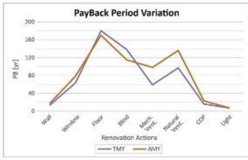


Fig. 3 - PayBack times of different renovation actions.

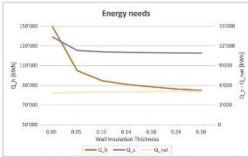


Fig. 4 - Variations in energy needs for different wall insulation thicknesses.

Conclusions
The PREDYCE tool enabled massive simulations of retrofit packages, analysing final energy needs and retrofitting initial investment costs, further elaborated to include operational costs. Resuming the specific outcomes, thermal insulation of the external envelope and heat recovery are demonstrated, as expected, to be crucial for the analysed climate. Nevertheless, recent years showed a significant increase in air conditioning demand, underlining the growing importance of low-energy cooling solutions. The parallel economic analysis provided a comprehensive view of the practical impact of each retrofitting package on the building's performance, identifying a proper balance between energy and monetary savings. Cost-optimal solutions can differ from energy-optimal ones because, for example, the high installation and operating costs of mechanical systems increase the positive impact of passive solutions. In conclusion, the work demonstrated the considerable advantage of using such a versatile and semi-automated simulation platform to obtain detailed calculations. A significant limitation is the high requirements in terms of computational efforts requiring a severe facility, although optimisation algorithms and/or surrogate modelling may strongly reduce this issue.

The PRELUDE project - Prescient building Operation utilising Real-Time data for Energy Dynamic Optimization – aims to support advanced innovative, smart, low-cost solutions supporting intelligent buildings and proactive optimisation services. Among the others, the project pursues the minimisation of energy uses, the maximisation of self-consumption and renewable sources balance, and the improvement of comfort conditions supporting the maximisation of free-running building potentials. PRELUDE includes an extensive multi-year educational and citizen-scientist action - T9.5 - involving students at different school levels in developing and/or testing simple simulation and monitoring platforms and facilities, including developing apps, web services and IoT sensoring solutions, following and disseminating different PRELUDE topics during educational activities. The work involves the Regional educational division (Piedmont Region), part of the project advisory board. Additionally, activities of the PRELUDE T9.5 includes an educational event series based on the organisation of lectures/conferences on smart building issues, climate-free-running building design, and operational solutions.
Keywords: *PRELUDE, smart building, intelligent monitoring, IoT, DIY, digital twin, dynamic building simulation, climate design, building optimisation.*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement N° 958345

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Figure 15 - Poster: Retrofitting scenarios and cost-optimal (D.Mecca Cici)

Abstract:
The project aims to develop a transdisciplinary workflow to improve the use of the PREDYCE dynamic energy simulation platform to perform retrofitting and cost-optimal analyses, including new cost-correlated functions and defining a post-production pipeline. The proposed method will identify the most suitable retrofitting solutions for different climates, supporting energy and cost-optimal scenarios considering massive retrofit options. Based on the development of extra PREDYCE cost functionalities and a post-simulation approach, the defined workflow is tested on existing building models, including the Italian PRELUDE demo building. Additionally, two different meteorological year EPWs are assumed to consider climate change aspects, considering historical Typical Meteorological Years and data monitoring in recent years (2022) from cloud-connected weather station facilities. The workflow supplies feedback to end-users considering energy and comfort aspects together with economic data. Results show a high interest in the proposed approach, which is demonstrated to be suitable for supporting designers in early design choices.
Keywords: PRELUDE, Retrofitting, cost-optimal, sensitivity analyses, building simulation, technological design, PREDYCE

Objectives:
This project will demonstrate that the existing PREDYCE dynamic simulation platform can be adapted to investigate optimal energy retrofit solutions from a technical and economic perspective. This work, developed together with the POLITO research team, aims to define a preliminary workflow allowing the use of advanced analysis to support designers, from early design stages, in the identification of the most appropriate retrofitting package, including passive solutions, according to the climate zone and typical user profiles, including cost analyses. The main objectives can be summarised as follows: i.) Define a workflow to use the PREDYCE platform to identify retrofitting optimal solutions, including energy and technological choices and cost-optimal values; ii.) Support the beta-integration in PREDYCE of a cost database, based on the local, regional price catalogue, correlating IDF modification actions, e.g. "add wall insulation"; and iii.) Test the workflow on calibrated building models assumed from ongoing projects, including the Turin PRELUDE demo case.

Conclusions:
The PREDYCE tool enabled massive simulations of retrofit packages, analysing final energy needs and retrofitting initial investment costs, further elaborated to include operational costs. Resuming the specific outcomes, thermal insulation of the external envelope and heat recovery are demonstrated, as expected, to be crucial for the analysed climate. Nevertheless, recent years showed a significant increase in air conditioning demand, underlining the growing importance of low-energy cooling solutions. The parallel economic analysis provided a comprehensive view of the practical impact of each retrofitting package on the building's performance, identifying a proper balance between energy and monetary savings. Cost-optimal solutions can differ from energy-optimal ones because, for example, mechanical systems' high installation and operating costs increase the positive impact of passive solutions. In conclusion, the work demonstrated the considerable advantage of using such a versatile and semi-automated simulation platform to obtain detailed calculations. A significant limitation is the high requirements in terms of computational efforts requiring a severe facility, although optimisation algorithms and/or surrogate modelling may strongly reduce this issue.

PRELUDE connection:
This work is strongly supported by the research unit that prepared the massive simulation runs and integrated the new database in a transdisciplinary vision. The activity is a beta test analysing the possibility of adding cost-optimal functions inside the PREDYCE simulation library correlated with the sensitivity scenario of use. Results focused on integrating some possible initial costs, although operative ones are post-elaborate in Excel.

3.3.VI Eng.group project: Andrea Avignone, Tommaso Carluccio, "Smart Building PMV/PPD Monitoring Platform and Visual Interface", A.Y. 2020-21

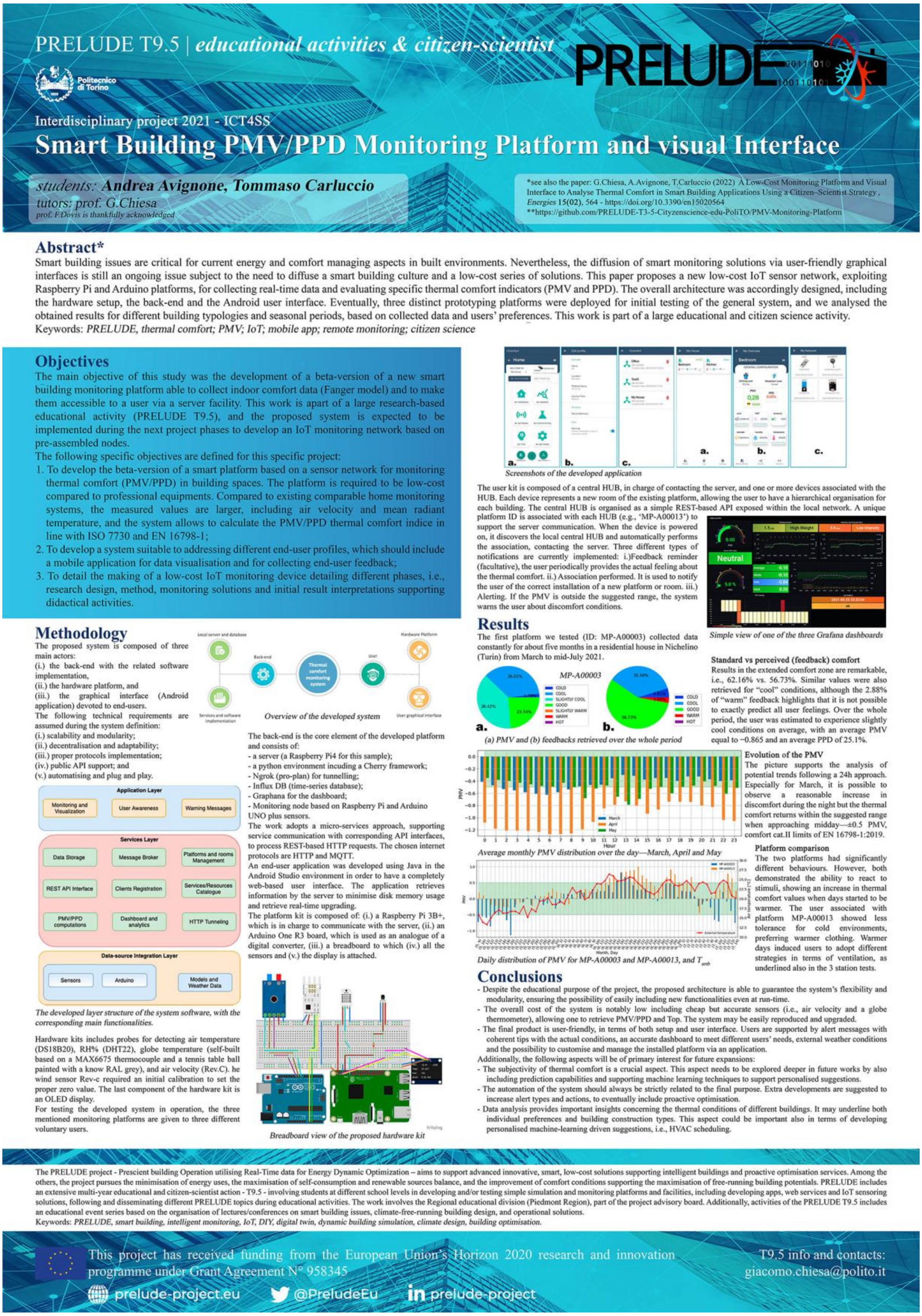

Figure 16 - Poster: Smart Building PMV/PPD Monitoring Platform and Visual Interface (A.Avignone, T.Carluccio)

Abstract:
Smart building issues are critical for current energy and comfort managing aspects in built environments. Nevertheless, the diffusion of smart monitoring solutions via user-friendly graphical interfaces is still an ongoing issue subject to the need to diffuse a smart building culture and a low-cost series of solutions. This paper proposes a new low-cost IoT sensor network, exploiting Raspberry Pi and Arduino platforms for collecting real-time data and evaluating specific thermal comfort indicators (PMV and PPD). The overall architecture was accordingly designed, including the hardware setup, the back end and the Android user interface. Three distinct prototyping platforms were deployed for initial testing of the general system, and the obtained results were analysed for different building typologies and seasonal periods.

Keywords: PRELUDE, thermal comfort; PMV; IoT; mobile app; remote monitoring; citizen science

Objectives:
This study's main objective was to develop a beta version of a new smart building monitoring platform that can collect indoor comfort data (Fanger model) and make them accessible to a user via a server facility. This work is part of an extensive research-based educational activity (PRELUDE T9.5), and the proposed system is expected to be implemented during the subsequent project phases to develop an IoT monitoring network based on pre-assembled nodes. The following specific objectives are defined in this particular project: i.) To develop the beta-version of a smart platform based on a sensor network for monitoring thermal comfort (PMV/PPD) in building spaces. The platform is required to be low-cost compared to professional equipment. Compared to existing comparable home monitoring systems, the measured values are more significant, including air velocity and mean radiant temperature, and the system allows the calculation of the PMV/PPD thermal comfort indices in line with ISO 7730 and EN 16798-1; ii.) To develop a system suitable for addressing different end-user profiles, including a mobile application for data visualisation and collecting end-user feedback; and iii.) To detail the making of a low-cost IoT monitoring device detailing different phases, i.e., research design, method, monitoring solutions and initial result interpretations supporting didactical activities.

Conclusions:
The proposed architecture can guarantee the system's flexibility and modularity, ensuring the possibility of easily including new functionalities even at run-time. The overall cost of the system is notably low, including cheap but accurate sensors (i.e., air velocity and a globe thermometer) that allow one to retrieve PMV/PPD and Top. The system may be easily reproduced and upgraded. The final product is user-friendly in terms of both setup and user interface. Users are supported by alert messages with coherent tips about the actual conditions, an accurate dashboard to meet different users' needs, external weather conditions, and the possibility to customise and manage the installed platform via an application. The following aspects will be of primary interest for future expansions: i.) the subjectivity of thermal comfort is a crucial aspect. This aspect needs to be explored deeper in future works by also including prediction capabilities and machine learning techniques to support personalised suggestions; ii.) the automation of the system should always be strictly related to the final purpose; iii.) data analysis provides important insights concerning the thermal conditions of different buildings. It may underline both individual preferences and building construction types. This aspect could also be important in terms of developing personalised machine-learning-driven suggestions, i.e., HVAC scheduling.

PRELUDE connection:
The work correlates with the citizen science IEQ and IAQ monitoring actions of T9.5 and the PRELUDE interest in building monitoring and end-user informing via GUIs.

A post-elaboration of the obtained results was also published in a journal paper: G.Chiesa, A.Avignone, T.Carluccio (2022) A Low-Cost Monitoring Platform and Visual Interface to Analyse Thermal Comfort in

Smart Building Applications Using a Citizen-Scientist Strategy, *Energies* **15**(2): 564, https://doi.org/10.3390/en15020564

3.3.VII Eng.group project: Song Tailai, Wang Di, Zhao Zhiqiang, "Mobile User-Occupancy App for Building Smart Management", A.Y. 2021-22

Figure 17 - Poster: Mobile User-Occupancy App for Building Smart Management (T.Song, D.Wang, Z.Zhao)

Abstract:
In order to reduce energy consumption, the optimised management of intelligent buildings based on personalised occupant profiles is essential. In this project, we have developed a mobile application to detect the user's presence and generate the user occupancy profile accordingly to feed the intelligent building management. Furthermore, our system allows visualisation and simulation through a graphical user interface (GUI). Finally, to identify the performance of our system and verify the impact of occupancy, we derive and compare four experimental results using a simple cube-like building as a case study.
Keywords: PRELUDE, occupancy detection, building scheduling, building optimisation, smart building, mobile app

Objectives:
Building occupancy considerably impacts simulation results, although quickly adapting user profiles to specific end-user behaviours is still an open issue. This work investigates the possibility of efficiently extracting user profiles via mobile apps and automatically feeding a simulation pipeline. The proposed approach can be adopted for short-term investigations, supporting model calibration periods, or long-term analyses, defining typical adapted behaviours helping the optimisation of intelligent control solutions. The main objectives pursued in this paper are:

- to develop an Android mobile application able to detect people's presence in target buildings and collect data based on different detecting methodologies;
- to develop a tool that can elaborate personalised actual presence conditions and aggregate occupants' information into building occupancy profiles;
- to develop a device/interface able to transform occupancy profiles into simulation-ready inputs to feed an existing building energy dynamic simulation tool – i.e. EnergyPlus – to adapt standard conditions to adapted ones in simulations, nearing the model to actual conditions. The data may also be potentially sent to intelligent building management systems.

Conclusions:
The proposed approach includes a mobile app with three occupancy detection methodologies and a GUI allowing elaborated scheduling profiles to support building energy simulations and, eventually, BMS functionalities. The performed tests show how all three detection approaches can help properly detect user presence, even if automatic ones ensure better long-term applicability, avoiding continuous user activations. Nevertheless, additional efforts are needed to guarantee the backend functionalities in the long run to prevent tool blocks. Results show how customised profiles may enormously differ from standard ones, allowing for better detect user presence and consequently improving user comfort optimisation and building energy need identifications. Further studies are suggested.

PRELUDE connection:
Customised occupancy profiling is a PRELUDE-correlated topic, considering works in WP3 and the technologies supported by other partners (e.g., FB). This educational project acts as an early test activity looking at extracting customised occupancy profiles from different measurement solutions based on the development of a mobile app. Profiles are furthermore generated and elaborated to extract statistically aggregated weekly schedules. In order to correlate this action to the PRELUDE building simulation flow, an EnergyPlus simplified interface was produced (PREDYCE compatible) to compare the effect of the use of real, aggregated, and standard (i.e. EN 16798-1) schedules on building KPIs, supporting future potential expansions to high real-time alignments of digital twin models. The results are interesting, and we expect to expand this research point.

3.3.VIII Eng.group project: Davide Montrucchio, Giuseppe Antonio Patarino, Dario Ruta, “Multi Comfort Citizencience Platform”, A.Y. 2022-23

Figure 18 - Poster: Multi Comfort Citizenscience Platform (D.Montruccio, G.A.Patarino, D.Ruta)

Abstract:
This project proposal is part of PRELUDE T9.5 citizen science and education activities. This project aims to develop communication and cloud storage solutions for multi-comfort IoT sensor kits distributed in several Piedmont buildings. Kits will measure different comfort variables in confined spaces (thermal comfort for mechanical and free-running buildings, including IAQ, visual comfort, and/or acoustic comfort). Kits are expected to be based on Arduino and use local Wi-Fi for data transmission. The platform is developed based on the concept that nodes may be independent (single node + Wi-Fi communication) and able to share data through the service created using data format and protocols already well-known. The solution involves a server facility that collects and manages data from nodes, stores it in a database, and displays it through a web application. A microservices architecture was developed to make the platform more flexible and adaptable to fit the subsequent phases of the PRELUDE project.
Keywords: PRELUDE, smart building, IoT monitoring, multi-comfort, microservices architecture

Objectives:
The overall architecture must be able to manage and distinguish data from different electronic kits, ensuring the attributes of availability, scalability, fault tolerance and disruption to achieve a resilient microservices platform capable of handling large amounts of data and issue management, alerting and monitoring. The proposed electronic kit aims to be an effective and low-cost solution capable of interfacing with the platform and sending messages via Wi-Fi containing the different measurements taken in the place of installation. As an added value of the platform, the cloud must be transparent to the chosen hardware, thus ensuring complete customisation for future developments with custom kits and sensors other than those selected.

Results and Conclusions:
Concerning results, the correctness of the measurements sampled from the kit was tested by comparing them to professional sensors. The validity of the messages sent by the Arduino board was verified using MQTT via Wi-Fi in a local test environment. Once the local board test succeeded, the cloud software was tested by presenting missing or wrong data as input to study its behaviour and verify its fault-tolerant properties. In conclusion, the platform can run even if there are maintenance services, so it matches the microservices requirement for the project. The platform is even responsible for writing data in the database, the layer through which the GUI retrieves data. The dashboard is resilient and can effectively manage logins and information retrieval to collect and display raw and processed data from each kit.
In conclusion, the platform has proven to be solid and capable of handling even large workloads correctly. The possibility of the final user being able to add kits and have a single access point for monitoring the collected data makes the software scalable and highly customisable. The main problems encountered were choosing the MQTT server and the non-solid internet connection. For future uses, it is recommended that the electronic kit be created with higher quality sensors and more reliable microcontrollers with higher enhanced hardware performance in order to reduce the difference between the measurements taken in the field and bring them closer to those captured by professional sensors.

PRELUDE connection:
Real-time building performance measurements and restitution to end-users of data via GUIs are part of the PRELUDE main activities. This educational project aims to face this topic with a parallel exercise, developing a low-cost multi-comfort IoT measuring kit connected with a web interface to show building KPIs aligned with the PRELUDE comfort ones (see, for example, the PREDYCE KPI list). Selected KPIs cover the thermal (Fanger and adaptive thermal comfort models), visual, acoustic and air quality comfort domains.

3.3.IX Eng.group project: Matteo Bogoni, Andrea Corino, Luca De Matteis, Giacomo Sarvia, "Weather sensoring cloud-connected kit", A.Y. 2022-23

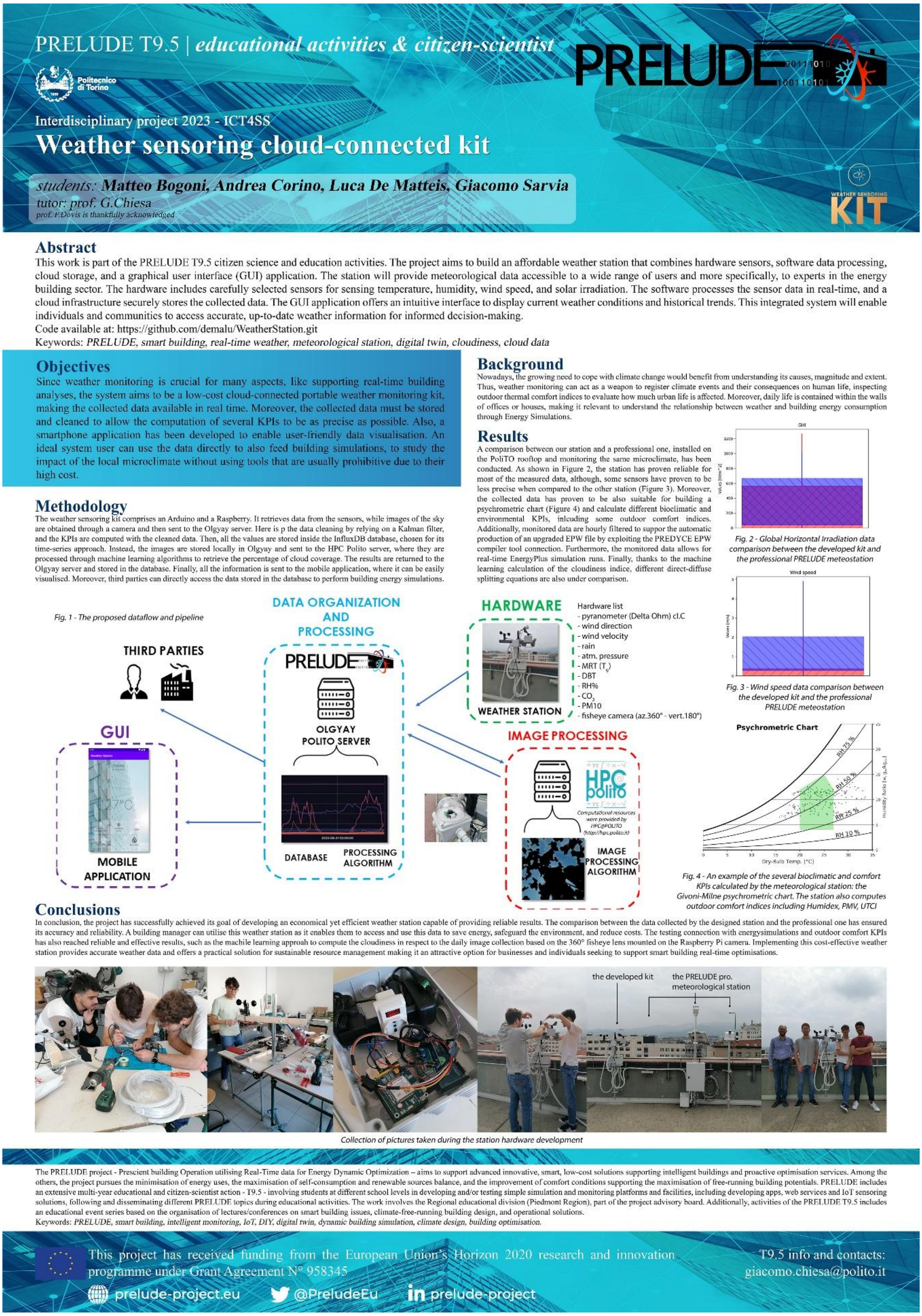

Figure 19 - Poster: Weather Sensoring Cloud-Connected Kit (M.Bogoni, A.Corino, L.De Matteis, G.Sarvia)

Abstract:
This work is part of the PRELUDE T9.5 citizen science and education activities. The project aims to build an affordable weather station that combines hardware sensors, software data processing, cloud storage, and a graphical user interface (GUI) application. The station will provide meteorological data accessible to a wide range of users and, more specifically, to experts in the energy building sector. The hardware includes carefully selected sensors for sensing temperature, humidity, wind speed, and solar irradiation. The software processes the sensor data in real-time, and a cloud infrastructure securely stores the collected data. The GUI application offers an intuitive interface to display current weather conditions and historical trends. This integrated system will enable individuals and communities to access accurate, up-to-date weather information for informed decision-making.
Keywords: PRELUDE, smart building, real-time weather, meteorological station, digital twin, cloudiness, cloud data

Objectives:
Since weather monitoring is crucial for many aspects, like supporting real-time building analyses, the system aims to be a low-cost cloud-connected portable weather monitoring kit, making the collected data available in real time. Moreover, the collected data must be stored and cleaned to allow the computation of several KPIs to be as precise as possible. Also, a smartphone application has been developed to enable user-friendly data visualisation. An ideal system user can use the data directly to feed building simulations and study the impact of the local microclimate without using tools that are usually prohibitive due to their high cost.

Conclusions:
In conclusion, the project has successfully achieved its goal of developing an economical yet efficient weather station capable of providing reliable results. The comparison between the data collected by the designed station and the professional one has ensured its accuracy and reliability. A building manager can utilise this weather station as it enables them to access and use this data to save energy, safeguard the environment, and reduce costs. The testing connection with energy simulations and outdoor comfort KPIs has also reached reliable and effective results, such as the machine learning approach to compute the cloudiness with respect to the daily image collection based on the 360° fisheye lens mounted on the Raspberry Pi camera. Implementing this cost-effective weather station provides accurate weather data. It offers a practical solution for sustainable resource management, making it an attractive option for businesses and individuals seeking to support smart building and real-time optimisations.

PRELUDE connection:
Using real-time weather data to feed building digital twin models and to inform/suggest user/BMS control actions is part of the PRELUDE activities – see for example the 24h forecasting scenario of the PREDYCE platform. The need for near-weather station data is essential to guarantee the correct implementation of control operational logic and to manage building simulations using current weather and site-correlated typical conditions by elaborating long series of measured data. Developing low-cost solutions with high-reliability sensors is also significant, as current solutions are expensive or lack specific sensors to feed all the required variables to feed a building's dynamic simulation.

3.3.X Eng.group project: Roberto F. Bratu, Lorenzo Brocchi, Fabio Callerio, Jia Heru, Stefano Viccari, "FRYZZY – Free-Running and Hybrid Building Comfort Optimisation via Fuzzy Logic Alerting", A.Y. 2023-24

PRELUDE T9.5 | *educational activities & citizen-scientist*

Politecnico di Torino

Interdisciplinary project 2023-24 - ICT4SS

FRYZZY Free-Running and hYbrid building comfort optimisation via fuZZY logic alerting

students: **Roberto F. Bratu, Lorenzo Brocchi, Fabio Callerio, Jia Heru, Stefano Viccari**
tutors: prof. G.Chiesa
prof. F.Dovis is thankfully acknowledged

Abstract

A fuzzy logic alerting system is developed to recommend optimal management decisions based on indoor and outdoor environmental circumstances. This system's essential features include lighting, shading, cooling, heating, IAQ, humidification and ventilation. The system produces recommendations that can be implemented manually or automatically through environmental data analysis. In parallel, a simulation environment is also developed to test the methodology. To enable mechanical actuation, the system can communicate with a Building Management System (BMS) in a virtual setting. This method harmonises energy efficiency and occupant comfort, offering a smart solution for contemporary smart buildings. By allowing users to make well-informed decisions, the fuzzy logic-based recommendations improve the overall efficacy and flexibility of building control, enhanced concerning other types of logic, like Boolean or threshold ones.

Objectives

The project aims to develop and test an ad-hoc ICT environment that can monitor the environment via real-time data sensors, e.g. measuring temperature, relative humidity (RH) and CO_2 concentration of different rooms. The system also needs to retrieve the perceived feeling in each room with a sliding bar from the user, which contributes to setting a proper user-centric solution by shifting state variables. Finally, the FRYZZY solution must suggest actuation actions to optimise multi-comfort performances coupled with indoor and outdoor conditions. The system needs to be scalable and allow interoperability while being technology-neutral. The selection of the best configuration needs to be performed using a fuzzy logic control approach that can manage multi-variable optimisation without requiring high computational power. Hence, the three main objectives are: i. develop a user-suggestion system using fuzzy logic to optimise building multi-comfort; ii. create a simple, user-friendly graphical interface for bi-directional user communication; iii. maximise comfort conditions and reduce energy needs in testing environments.

Methodology

The project pipeline is based on the following steps: i. set a monitoring solution to retrieve real-time indoor and outdoor environmental conditions, ii. define a cloud-based platform able to store, filter, and elaborate on the measured data to calculate relevant multi-comfort KPIs for summer and winter, iii. analyse the data via a fuzzy logic controller (fuzzification, membership functions, defuzzification of results), retrieving alerting and actuation suggestions, iv. communicate outcomes to end-users (or to automatic actuators via BMS) via GUI to support actuation.

Measured input data are analysed by developing a "Fuzzy logic" control unit to select proper actuation actions considering the different variables. The fuzzy logic control will be based on a "main unit" (Raspberry-driven) that is interoperable with a GUI furnished by a "control app". The project gives users suggestions to guide their energy-saving behaviour and better understand their comfort state. An alerting system will be implemented via a Telegram bot to present real-time alerts and advice to support self-actuation actions. All the solutions are hence tested by adopting a double approach: i.) a Long-term simulation, comparing the Fuzzy logic performances with the ones of two other control logics (a simple Boolean logic and a refined threshold logic); and ii. an actual demo flat where physical sensors are cloud-connected and the Fuzzy logic is used to support user suggestions for a few days.

Fig. 1 - The proposed methodology

The first test integrates an EnergyPlus building model into OpenHAB-supporting Energym facilities. The approach allows Openhab to simulate a BMS facility by combining a series of artificial sensors and actuators in each EnergyPlus simulation step, expanding the EMS possibilities by externalising the control logic in the artificial BMS platform for each simulation step. The simulated outputs of the previous step (or the measured data in the actual test) are retrieved by MQTT binding deploying the actuation phase. Finally, they are published through the MQTT broker to feed the following simulation phase inputs (or to support control alerting in the actual test). Both virtual simulated and real sensors (here based on Netatmo weather sensors and expansion sets) are passed to the OpenHAB platform, which is also connected to the Telegram bot for user alerting. The HABapp allows the creation of a a fully functional system, collecting inputs from OpenHAB, passing them to the fuzzy logic code, and sending back outputs to be published by OpenHab using the MQTT protocol. A Raspberry is used as a server to manage the activities for the actual test. Data are managed via InfluxDB, and Graphana is used for visualisation. Hence, the Flutter application is used to support user-friendly GUIs.

Fig. 2 - External interface and connections

Results

Concerning the EnergyPlus virtual BMS environment, a sample model of one of the Turin PRELUDE demo flats is used but simulated under a hotter climate (Larnaca). Actuators are managed outside the EnergyPlus simulation engine connecting BCVTB (Building Controls Virtual Test Bed), to run the Fuzzy control algorithm and passing EMS the results to the IDF actuators. Connections demonstrated to be very effective. Results showed that the Fuzzy is able, concerning a Binary actuation, to minimise failure in adaptive thermal comfort conditions from 51% (binary) to 1.6% (Fuzzy) in January and from 41.3% to 0% in July. Considering mechanically driven conditions, energy needs are reduced in starting and ending seasonal months, while in January and July, needs look to be slightly higher than in the Binary case, suggesting extra analyses better integrate thermal mass activation.

Fig. 3 - Sample Membership functions, (a) input user feeling on current indoor temperature, (b) output heating set point, (c) output humidification setpoint, (d) input CO_2, (e) output window opening percentage

The actual demo test is conducted in Rivalta (TO) in a residential house, supporting the test of the Telegram bot and the self-actuation methodology. The data flow and the GUI were demonstrated to be very effective, while by following the suggestion provided by the Telegram Bot, higher temperature peaks were rapidly decreased and managed. Hence, we can state that our logic offers an adaptive and correct response to the change in environmental parameters.

Fig. 4 - (left) Telegram bot suggestions (temperature peak, 12-13:00), (right) GUI rooms and sensors sample view

Fig. 5 - Indoor and outdoor temperature profiles during a fuzzy logic testing day. Note the ability of FRYZZY to support self-actuations to maintain stable temperature conditions

Finally, a survey was conducted with several people to discuss user GUI usability. Usability is high, and all the people are generally satisfied and will be happy to suggest the product to others. User-friendliness is rated around 4/5, with minimal scores at 3.

Conclusions

The initial tests proved the advantages of the FRYZZY proposed solution, compared with existing control logic, which can be run on a simple BMS facility. The proposed fuzzy-based control combines the hardware simplicity of a simple Boolean (on/off) control system and the improved forecasting control of the fuzzy logic theory. Moreover, the long-term simulation test shows that the employed solution can reduce underheating and overheating. Consequently, a reduction in operational costs and energy waste can be observed. Noteworthy, the installation step requires few simple passages and a limited cost; the user interface Mobile App, interoperable with the alerting system, provides an intuitive and practical tool to communicate with the underlying management system directly. Also, the short-term test in a real environment confirmed the friendliness of the approach and the ability to support end-users in optimising their environmental performances by exploiting the real-time free-running potential of their house by maximising multi-comfort KPIs via the same approach.

The PRELUDE project - Prescient building Operation utilising Real-Time data for Energy Dynamic Optimization – aims to support advanced innovative, smart, low-cost solutions supporting intelligent buildings and proactive optimisation services. Among the others, the project pursues the minimisation of energy uses, the maximisation of self-consumption and renewable sources balance, and the improvement of comfort conditions supporting the maximisation of free-running building potentials. PRELUDE includes an extensive multi-year educational and citizen-scientist action - T9.5 - involving students at different school levels in developing and/or testing simple simulation and monitoring platforms and facilities, including developing apps, web services and IoT sensoring solutions, following and disseminating different PRELUDE topics during educational activities. The work involves the Regional educational division (Piedmont Region), part of the project advisory board. Additionally, activities of the PRELUDE T9.5 includes an educational event series based on the organisation of lectures/conferences on smart building issues, climate-free-running building design, and operational solutions.
Keywords: *PRELUDE, smart building, intelligent monitoring, IoT, DIY, digital twin, dynamic building simulation, climate design, building optimisation.*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement N° 958345

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Figure 20 - Poster: FRYZZY – Free-Running and Hybrid Building Comfort Optimisation (R.F.Bratu, L.Crocchi, F.Callerio, J.Heru, S.Viccari)

Abstract:
A fuzzy logic alerting system is developed to recommend optimal management decisions based on indoor and outdoor environmental circumstances. This system's essential features include lighting, shading, cooling, heating, IAQ, humidification and ventilation. The system produces recommendations that can be implemented manually or automatically through environmental data analysis. In parallel, a simulation environment is also developed to test the methodology. The system can communicate with a Building Management System (BMS) in a virtual setting to enable mechanical actuation. This method harmonises energy efficiency and occupant comfort, offering a smart solution for contemporary smart buildings. By allowing users to make well-informed decisions, the fuzzy logic-based recommendations improve the overall efficacy and flexibility of building control, enhanced concerning other types of logic, like Boolean or threshold ones.

Keywords: PRELUDE, ICT, IoT, SmartHome, Fuzzy Logic Control (FLC), Home Automation, Openhab, RaspberryPi, Mobile App, Building Energy optimisation

Objectives:
The project aims to develop and test an ad-hoc ICT environment that can monitor the environment via real-time data sensors, e.g. measuring temperature, relative humidity (RH) and CO2 concentration of different rooms. The system also needs to retrieve the perceived feeling in each room with a sliding bar from the user, which contributes to setting a proper user-centric solution by shifting state variables. Finally, the FRYZZY solution must suggest actuation actions to optimise multi-comfort performances coupled with indoor and outdoor conditions. The system needs to be scalable and allow interoperability while being technology-neutral. The selection of the best configuration needs to be performed using a fuzzy logic control approach that can manage multi-variable optimisation without requiring high computational power. Hence, the three main objectives are: i. develop a user-suggestion system using fuzzy logic to optimise building multi-comfort; ii. create a simple, user-friendly graphical interface for bi-directional user communication; iii. maximise comfort conditions and reduce energy needs in testing environments.

Conclusions:
The initial tests proved the advantages of the FRYZZY proposed solution, compared with existing control logic, which can be run on a simple BMS facility. The proposed fuzzy-based control combines the hardware simplicity of a simple Boolean (on/off) control system and the improved forecasting control of the fuzzy logic theory. Moreover, the long-term simulation test shows that the employed solution can reduce underheating and overheating. Consequently, a reduction in operational costs and energy waste can be observed. Noteworthy, the installation step requires few simple passages and a limited cost; the user interface Mobile App, interoperable with the alerting system, provides an intuitive and practical tool to communicate with the underlying management system directly. Also, the short-term test in a real environment confirmed the friendliness of the approach and the ability to support end-users in optimising their environmental performances by exploiting the real-time free-running potential of their house by maximising multi-comfort KPIs via the same approach.

PRELUDE connection:
This educational project strongly correlates with the PRELUDE control logic technological development. This activity opens a different point of view on the currently developed logic, supporting and testing an alternative vision to thresholds or advanced ML techniques, able to correlate decisions with a fast and low-computational vision based on fuzzy logic methods. Furthermore, the project adopts, on the one hand, dynamic energy simulation to test BMS conditions and, on the other hand, an actual demo building with sensors, which correlates to the professional tests developed in the PRELUDE project. Results also suggest that future PREDYCE developments may integrate alternative platforms to use the EnergyPlus simulation as a set of sensors and actuators, detaching the decisional logic from the simulation flow.

4. Citizen-science action

4.1 Introduction and Objectives

In addition to the educational event series and the educational projects, the activities of T9.5 included a significant citizen science aiming at involving students of middle and high schools and their teachers in studying and improving the Indoor Environmental Quality (IEQ) with particular regard to the Indoor Air Quality (IAQ) of selected school environments, i.e. classrooms and laboratories. The citizen science has disseminated PRELUDE and smart building correlated topics to a large audience, thanks to installing sensor networks, activating LED alerting for CO_2 thresholds, and focused lectures/discussions with students or teachers to support the self-actuation exercise.
More focused actions have been defined for middle schools, such as directly giving lectures to students. In contrast, in high schools, with the exclusion of one case, the communication level stays at the teaching level, involving school professors in activating their students when the IAQ level overpasses the given threshold, suggesting starting space ventilation. The activities have been strongly supported by the PRELUDE advisory board member Giovanni Borgarello, Piedmont Region, allowing the dissemination of the activity among many schools and involving six of them directly in the citizen science action.

Here below is described the developed methodology considering on the one side (4.2) the monitoring infrastructure and pre-defined KPIs to be elaborated and, on the other side (4.3), the citizen science pipeline for user engagement. Finally, the main obtained results (4.4) are underlined shortly.

4.2 Citizen science methodology (data acquisition and elaboration)

The citizen science action aims at supporting the dissemination of smart building culture and attention to IEA and IAQ topics in participant users and the extended communities of people reached during dissemination actions. For this reason, citizen science actions are based on the use of measurement solutions that can monitor typical building variables to detect indoor air and environmental quality and retrieve potentially typical key performance indicators aligned with the PRELUDE project ones. A series of monitoring systems have hence been acquired and installed in the participating schools, reproducing real solutions in line with the ones adopted during the project. At first, there was the idea of adopting a series of IoT do-it-yourself solutions developed by specific participating high school students based on the models designed and tested during the PRELUDE Educational projects. Although this relay approach is exciting, it couldn't be applied in practice, as these types of solutions are based on prototypes without administrative documentation or certificates. In order to cover all needed requirements and to ensure an approach acceptable to all schools, the installed sensors have been selected among commercial solutions. Sensors are described in the following sub-sections, while the expected data elaborations are mentioned afterwards.

4.2.I Monitoring solutions

Monitoring systems need to be easily installed, considering a flexible network configuration that allows the addition and the reduction in the number of sensors in each building to follow citizen science requirements and to support a fast installation process. Sensors are required to measure IEQ, especially IAQ Key Performance Indicators (KPIs), which help user engagement when a specific threshold is overpassed. To identify the proper monitoring solution, the following requirements have been defined:

- Being a commercial solution allowing for proper documentation and certificates;
- Allowing to have on CO_2 sensors (as a minimum) a lighting alerting solution to inform when ventilation is required*;
- Allowing data storage and cloud access;
- Allowing to manage alerting threshold in remote to reduce the number of physical interventions;

- Based on batteries, to reduce electricity plug requests to the minimum, e.g. one point per school supporting cloud connection (plugs are not available in most classrooms, complex to be managed, requiring technical interventions and additional costs);
- Allowing to measure minimal IEQ and IAQ variables, including CO_2 concentration, air temperature and relative humidity, and potential additional variables, e.g. TVOC, Particulate matter, thermal transmission…;
- Being able to work, minimising data losses, also if the internet connection or the energy plug (e.g. gateways) envisage interruptions, requiring local data storage;
- If possible, have an autonomous internet connection, reducing dependencies on local Wi-Fi networks;
- If possible, being correlated to the other PRELUDE monitoring systems, aligning data management and elaboration with one of the actual project demos, coupling potential costs for accessing the cloud platform, etc.

*Discussing with teachers and the advisory board member during preliminary meetings, it was determined that the teaching staff does not require sound alerts. Moreover, teachers were worried that sound alerting would interrupt the didactical activities, reducing the students' concentration. Finally, the list of sensors with an embedded sound alerting system is limited, and the use of apps or web interfaces is incompatible with the policies on using mobiles during lectures.

Table 1 - Short description of the relevant sensor types

		
New CO_2 probe. It measures i. ambient temperature, ii. relative humidity, iii. CO_2 concentration, and iv. pressure Note: it has an LED alert based on cloud-defined threshold(s)	CO_2 probe. It measures i. ambient temperature, ii. relative humidity, and iii. CO_2 concentration. Note: it has an LED alert based on cloud-defined threshold(s) Note: some of them are already available, thanks to a former E-DYCE EU co-founded H2020 project (GA 893945)	TVOC probe. It measures i. ambient temperature, ii. relative humidity, and iii. TVOC
		
PM10-PM2.5 probe. It measures i. ambient temperature, ii. CO_2 concentration, iii. PM10, and iv. PM2.5	U-value kit. The kit allows the measurement of thermal transmission through an opaque wall, detecting the wall U-value.	Sample SIM gateway for cloud transmission and connection

Note: this sensor has a high battery consumption		

Considering these requirements, the Capetti Winecap system was selected, which is in line with the measuring solutions adopted in some of the Italian PRELUDE demos. In each school, they have been installed a SIM gateway and a series of probes able to cover at a minimum 3 classrooms or other didactical spaces with sensors including LED alerting. Additional sensors (e.g. TVOC, particulate matter) were defined with each school aligning with specific activities and local interests. Table 1 briefly describes the different types of installed sensors.

4.2.II KPIs and Expected Elaborations

Sensors are used to detect indoor environmental variables related to IAQs. In particular, the users will be activated based on IAQ levels, assuming CO_2 as the reference gas – e.g. [1–4], requiring lighting alerting when certain thresholds are overpassed. In addition, air temperature and relative humidity are also detected for potentially covering a large IEQ spectrum of KPI, which is also correlated to thermal comfort conditions. In specific cases, e.g. chemistry labs in a high school or sample classrooms in middle ones, TVOC probes are included to potentially underline the difference among the use of CO_2 or other pollutant sensors, showing the differences in graphical restitutions. Furthermore, 7 PM10-PM2.5 sensors have also been installed, focusing on indoor and outdoor conditions to detect potential peaks. Adopting multi-IAQ variables allows us to check several indices in school environments, considering the large number of variables suggested in these cases – see, for example, the Italian DPCM 26 July 2022 [5]. However, CO_2 has been chosen as the tracking IAQ gas to support citizen science alerting.

Focusing on CO_2, the measured values are analysed, adopting the French [6] and Swiss [7] ICONE methodology. This method was introduced in [8] and classifies CO_2 ppm levels in different air confinement domains, assigning them a simple number and a colour and aligning specific counteractions. The domains assured for this citizen science are six, elaborating on the mentioned sources: i. <450ppm (aligned with outdoor conditions), ii. 450<ppm≤1000 (very good – ventilation may be excessive if naturally performed in winter), iii. 1000<ppm≤1700 (good/acceptable), iv. 1700<ppm≤2000 (slightly bad, action needed), v. 2000<ppm≤3500 (bad condition, urgent action), and vi. >3500ppm (very bad condition). These domains are used for data post-elaboration, while the student self-actuation action is based on LED activation using a single threshold value. Additionally, a specific study is also elaborated to verify the ability of the users to follow the LED suggestions by subdividing the occupied hours above and below the primary adopted threshold (1700 ppm) and comparing this performance before and after the LED activation.

In addition, also, CO_2 concentration carpet plots are elaborated. During specific restitution communications, the latter has also been used to communicate with students about their IAQ levels in their classes. Similarly, TVOC and PM10-PM2.5 results are also reported in carpet plots.

Considering thermal comfort, temperature distribution during the occupancy is elaborated. Additionally, are also elaborated, in some specific cases, adaptive thermal comfort plots (summer) – see EN 16798-1 and [9,10] – assuming that the mean radiant temperature is mainly aligned with the measured air temperature [11]. Sample KPI restitutions are given in Figure 21.

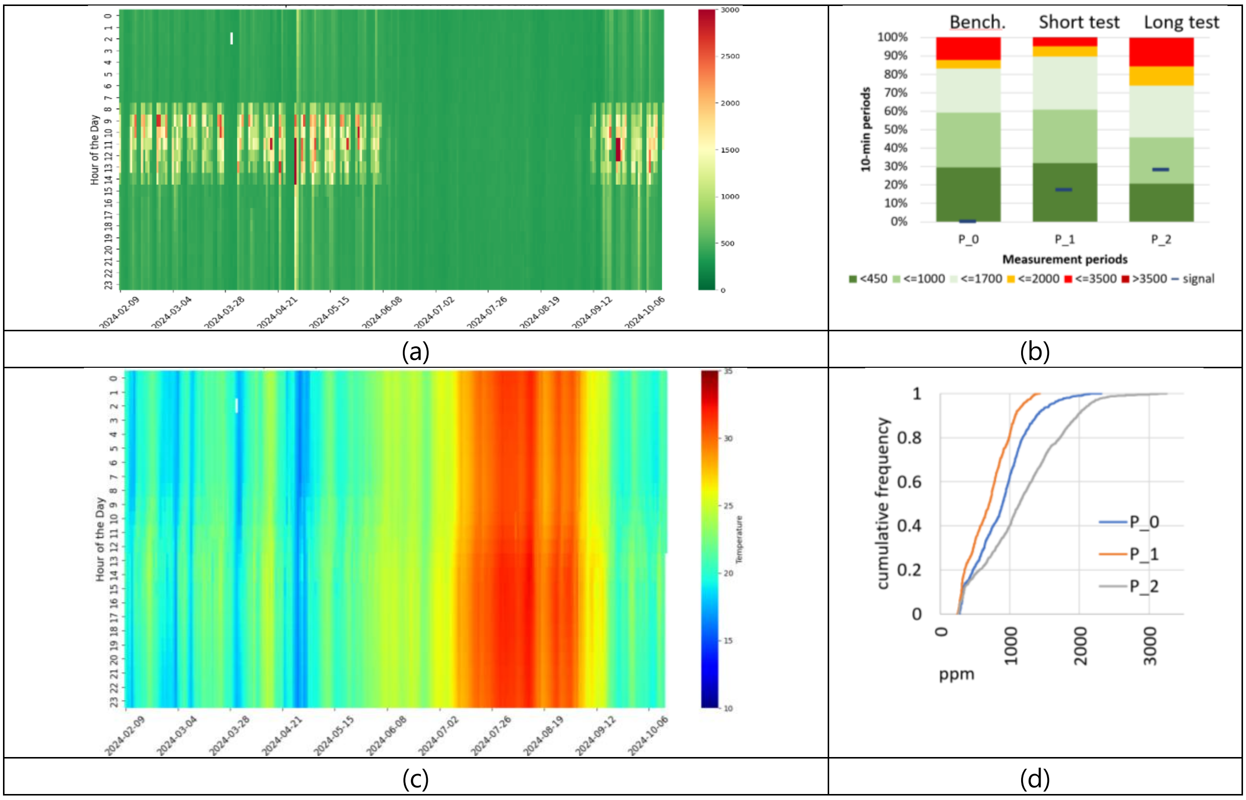


Figure 21 - Sample KPI restitutions: (a) CO_2 carpet plot distribution – av. hourly, (b) CO_2 data distribution (10' intervals), (c) temperature carpet plot, (d) CO_2 cumulative distribution

4.3 Citizen science methodology (user engagement)

4.3.I Citizen-science pipeline

A methodological citizen-science pipeline is defined by identifying five operative steps. In step 1, sensors are installed in the selected rooms, including a discussion with representative teachers. Secondly, in step 2a, sensors are left monitoring the actual conditions without any alerting activations to define a benchmark. Retrieved 2-3 weeks of data, step 2b, a lecture is given to involved students (middle schools) discussing building IEQ and IAQ topics, the PRELUDE project, and the citizen science action; a survey on smart building topics is also distributed. During this moment, LED alerting is started, defining the set thresholds with students. The lecture in Step 2b can be substituted (high schools) with specific communication with the teaching staff. The following step, 3 (3-8 weeks), is the self-actuation period during which students will look at sensors to activate manual window operation when the IAQ overpasses the threshold of acceptability. After 3-4 weeks, a slight reset of the thresholds may be defined together with teachers, especially in one of the schools where personalised ambitious thresholds were defined during the first year of activity (e.g. around 1000ppm), requiring too many actions. In step 4, data are partially elaborated to communicate to teachers the advancement of the action, and optional restitution is given to the involved classes. Finally, in step 5 (optional), the activity will continue maintaining the sensor system active for more extended periods (end of the school year), allowing for verification of the long-term impact of self-actuation actions. Hence, the retrieved data were elaborated to analyse the effect of the citizen science action.

Nevertheless, step 0 is needed before starting the pipeline, including a detailed discussion with the involved school representatives and an inspection allowing the definition of sensor localisations.

4.3.II The involved schools

Six schools have participated in the project, answering the open call shared by the Piedmont Educational Division via the Eco-active school group. Among them, three are high schools ("Scuola secondaria di secondo grado", in Italy) and three middle schools ("Scuola secondaria di primo grado", in Italy). Considering the high schools: one of them is a technical industrial high school involving students from the Telecommunication, Informatic, Electronic, Energy and Chemical educational domains, one is a Classic, Scientific and Linguistic Liceo, involving mainly scientific profile classes, and one is a Scientific, Scientific with Applied Sciences, Cambridge, Mathematic, Digital Liceo and a Technical Economic school, where primarily involved students come from the Scientific with Applied Sciences educational domain. Middle schools do not have a specialisation domain in Italy, presenting a traditional domain and an extended domain with some extra hours (mainly Italian and Maths) not affecting on specialisations – a music address exist, but is not here represented –, while contact teachers are from the technological, mathematics, and science teaching domains.

Additionally, three are positioned outside Turin, while the other three are in the Turin extended city area. In addition, two of the high schools and one of the middle schools also adopted the measured data in their activities, allowing to include, in parallel to the base citizen-science action, the development of local projects, asking the students to participate in data analysis. Two of these schools were former EU H2020 E-DYCE project (GA 893945) demonstrative buildings, allowing us to take advantage of previous POLITO monitoring systems. However, maintenance, sensor integration and substitution, and re-organisation actions have been performed for the PRELUDE activities. At the same time, new sensors were required for the other schools.

The schools are:

- IC "Luserna S. Giovanni" (Middle school), Luserna S.Giovanni, Italy [3 classes 2023-24, 3 thematic classes 2024-25];
- IC "Foscolo" (Middle school), Turin, Italy [5 classes 2024-25 (4 classes mute sensoring in 2023-24)]
- IC "Gianni Rodari" (Middle school), Torre Pellice, Italy – note: former demo B2.1 of the E-DYCE EU H2020 co-funded project [9 classes 2023-24, 2 new classes +6 classes (continuation) 2024-25]
- ITIS Pininfarina (High School), Moncalieri (Turin extended city area), Italy [6 laboratories with multi-sensors, 1 classroom 2024-25]
- Liceo Valdese (High School), Torre Pellice, Italy – note: former demo B2.2 of the E-DYCE EU H2020 co-funded project [8 thematic classes and 1 office both 2023-24 and 2024-25]
- IIS Ettore Majorana (High School), Turin, Italy [4 thematic classes 2024-25]

A total of 42 classes/rooms[6] have participated in citizen science, directly reaching about 250 students in 2023-24 and 420 students in 2024-25, plus a total of 22 professors, 10 of whom actively contribute to the local organisation. An additional 750 students, at the minimum, have used the rooms (classes and laboratories) with sensors installed[7] participating in the activities thanks to teachers' support. Since the activity has also been disseminated inside each school, the action has indirectly reached more than 2000 people.

[6] Bi-annual participation of the same class is not counted. Differently, the passage (between school years 2023-24 and 2024-25) from one class per room to thematic room is counted as a class addition, such as the involvement of a different student class (e.g. a new first year class).

[7] For laboratories it has been considered average class dimension for two turns, even if the room is used by a larger number of classes/turns.

4.3.III Step 1: sensor installation

POLITO has installed sensors in all schools. In order to reduce potential damages, sensors have been positioned in several cases at about 2 m from the ground instead of the suggested 1.5 m height. Nevertheless, they guarantee a sufficient distance from room ceilings. Additionally, they are placed on the wall opposite the window side, or laterally in limited cases, to avoid direct exposure to the direct solar radiation. The following pictures – Figure 22 – show sample installed sensors.

Figure 22 - Sample installation pictures from different schools

In particular, the following sensors have been positioned – note that the order of schools is not following the following one (Table 2):

Table 2 - List of the adopted sensors

School[8]	Gateways	CO_2 sensors	TVOC sensors	PM10-2.5 sensors	Others
P01	2	9	4	3	Heat meters
P02	1	8			Heat meter
P03	1	3	1	2	
P04	1	8	1	2	

[8] Schools' identifier is not following the previous order

P05	1	4			
P06	1	9	4		
TOT:	7	41	10	7	U-value sensor[9]

It can be noted that in one school, the building's technical characteristics made signal transmission between probes and the gateway very complicated, requiring the installation of routers (signal repeaters) and the refinement of the sensor network over time to avoid black zones. For example, Figure 23 shows one of the sensor configurations (the grid can vary over time when the system is self-optimised).

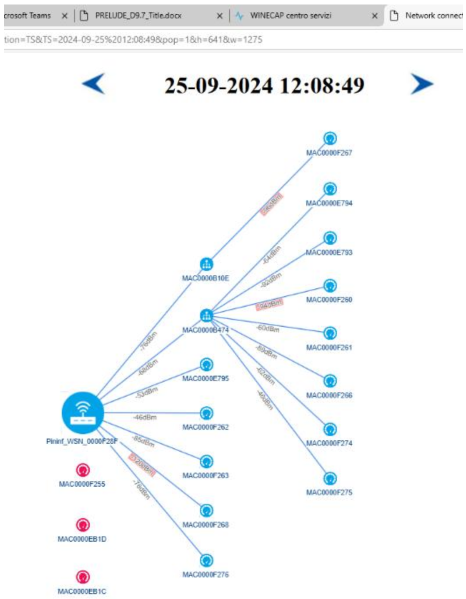


Figure 23 - Sample sensor grid self-configuration in one of the schools with a poor signal

4.3.IV Step 2: introductory lecture

An introductory lecture has been prepared for the involved Middle Schools and further customised for the different schools to align with specific local requirements. The lecture was performed in all middle schools and a scientific high school, excluding the other two high schools, which directly participated in the self-actuation exercise for a total of 26 frontal didactical hours, reaching 33 classes. The lecture's main treated topics are:

- Climate changes and energy efficiency (reminder/introduction) – e.g. the ecological footprint, some contents from T8.5;
- Building Sector and intelligent buildings – e.g. buildings are responsible for 40% of total primary energy, GHG emissions, energy labels & EPC, energy meters;
- SURVEY on intelligent buildings and IEQ-IAQ;
- PRELUDE project objectives;
- PRELUDE educational activities (including the citizen science);
- Comfort in buildings, Indoor Environmental Quality and Indoor Air Quality – e.g. comfort domains, IAQ and IAQ-thermal comfort correlations, comfort classification and monitoring;
- The citizen science action on IAQ – e.g. reading monitoring data, how data can be used to feed actuators;

[9] Installed using an additional gateway to provide data to high-school and university students for didactical purposes.

- The citizen science self-actuation activity, e.g., what to do, the flux control diagram, defines the limit threshold together.

Below are some sample slides extracted from the developed base lecture to give examples of contents – see Figure 24. Slide contents are partially adapted for each lecture to focus on the specific school context and report to students their proper condition. The texts are in Italian, the language used in the involved schools.

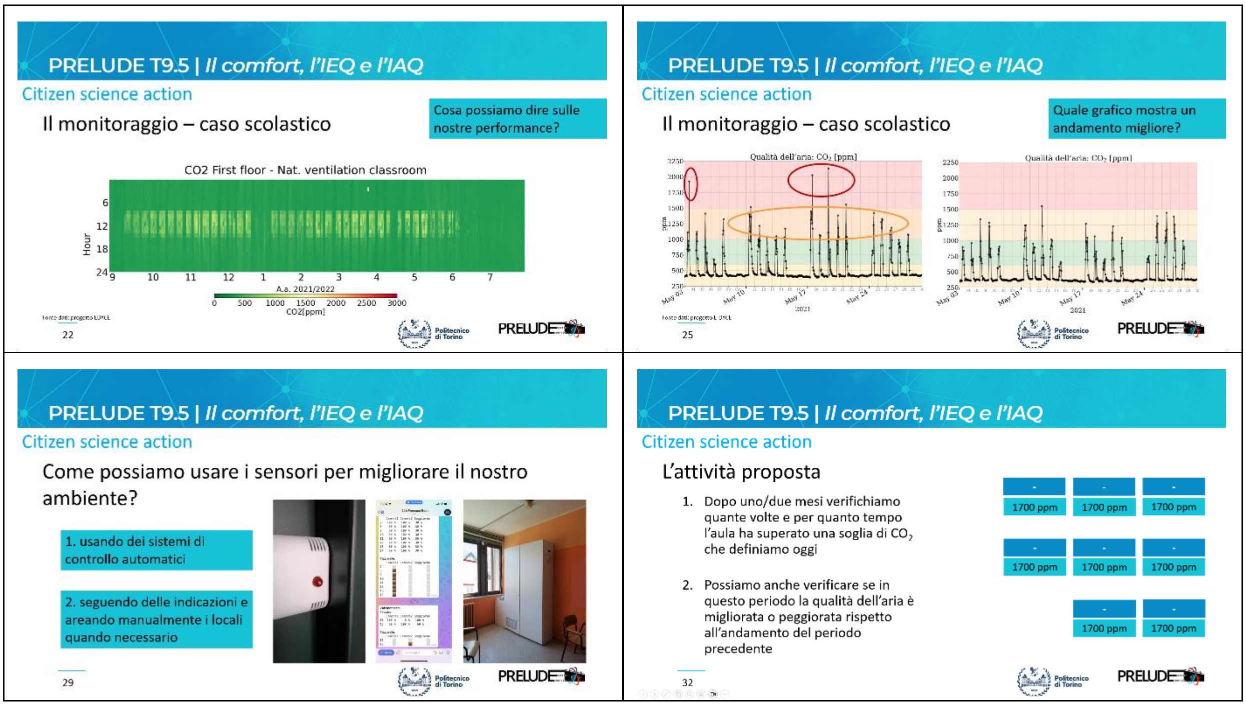


Figure 24 - Sample slides extracted from the base reference lecture (original Italian text)

During the lecture, a survey was conducted via an anonymous questionnaire focused on intelligent buildings, indoor environmental quality, and smart monitoring conceptions. The questionnaire, named "PRELUDE CitizenScience on IEQ-IAQ", is composed of 11 questions that are reported (translated from Italian for this report) here below, including the available potential answers (A):

1. *Do you know the meaning of the expression "intelligent building"? (If the answer is no, this is not a problem! We will explain to you what it is)* – A: Y/N
2. *Have you ever studied or lived in an intelligent building?* – A: Y/N
3. *Have you ever seen an intelligent building?* – A: Y/N
4. *If you answered Yes to questions 2 and/or 3, which type of intelligent building do you refer to?* – A: School/House/other: ....
5. *How important do you think it is to visualise the status of your building at any moment?* – A: From 1 (nothing)-to-6 (totally)
6. *How much would you like to have the possibility to apply smart solutions and monitoring technologies in the buildings you are using?* – A: From 1 (nothing)-to-6 (totally)
7. *Which aspects are more essential to be visualised and monitored? (multiple selections are possible, e.g. 2 points)* – A: Energy-consumptions (electricity, natural gas, ...)/temperature/humidity/indoor air quality (IAQ)/ lighting (illuminance)/other: ....
8. *Have you ever heard about thermal comfort*? – A: Y/N – *If yes where?* – A: School/House/media (information channels)/others: ....
9. *Have you ever heard about indoor air quality*? – A: Y/N – *If yes where?* – A: School/House/media (information channels)/others: ....
10. *Are you happy about the indoor air quality of your class (window opening)?* – A: From 1 (nothing)-to-6 (totally)
11. *How important is managing the window openings on the base of the real-time monitored indoor air quality level?* – A: From 1 (nothing)-to-6 (totally)

The results of the survey are reported in the following Section 4.5.

In high schools, students are informed by their teachers about the experiment and will follow the citizen-science self-actuation exercise as the middle school ones.

4.3.V Step 3: citizen-science user self-actuation exercise

In all involved schools, CO_2-installed sensors host a luminous blinking alerting LED – the other sensors do not have an alerting system, supporting mainly post-analysis elaborations – allowing them to be remotely controlled by setting specific activation thresholds. When the CO2 concentration overpasses the given threshold, the light alerts occupants that the IAQ level is not optimal, suggesting that they manually self-actuate windows or ventilation systems to exchange the indoor foul air. The self-actuation action – in Italian schools, mechanical ventilation systems have rarely been present, requiring natural ventilation manual activations, for example [12] – can be described with the following logical scheme (Figure 25).

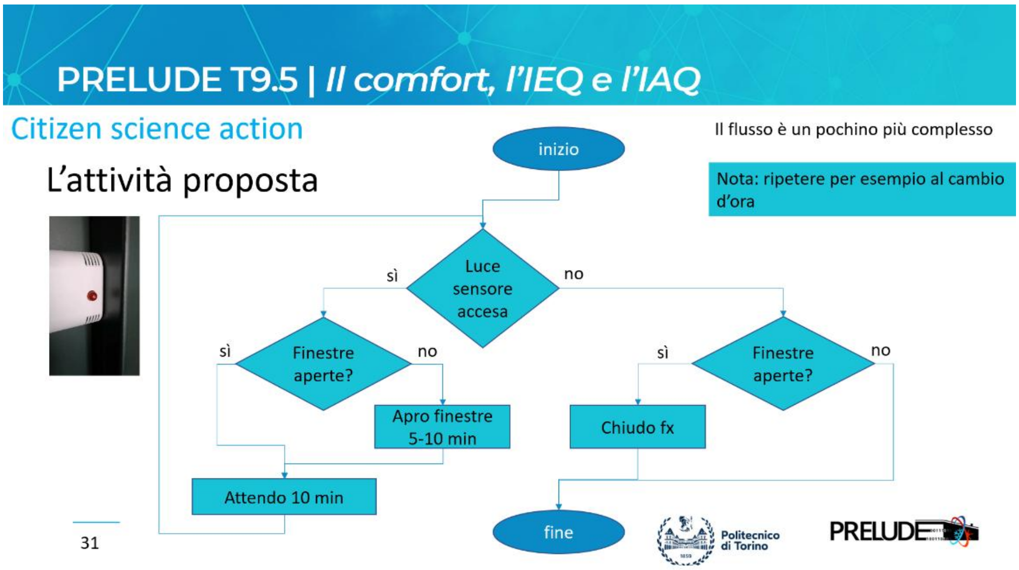


Figure 25 - The proposed flowchart describing the self-actuation procedure (original Italian text)

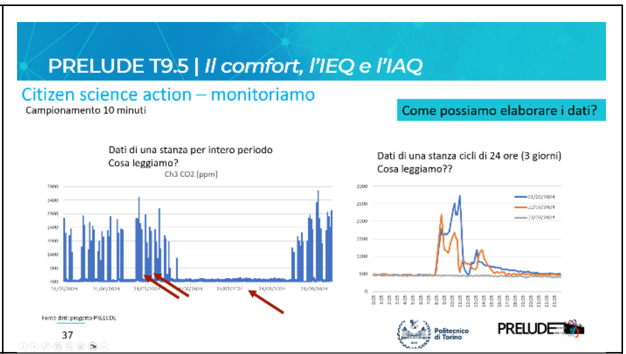
As a reference, the base chosen led activation threshold is 1700 ppm, aligning with the French ICONE method for school buildings, detecting the index of confinement [6]. This approach has also been adopted in Swiss buildings – see SIA 180 [7]. ICONE allows the classification of indoor CO_2 concentrations in levels, starting from outdoor nearer values to hazardous concentrations, assuming 800ppm for sufficient air renovation and 1500ppm for fast action requirements. This aligns with the Swiss dimension, allowing for a 1000-2000ppm range for action activation, e.g., assuming 1700ppm as a potential threshold.

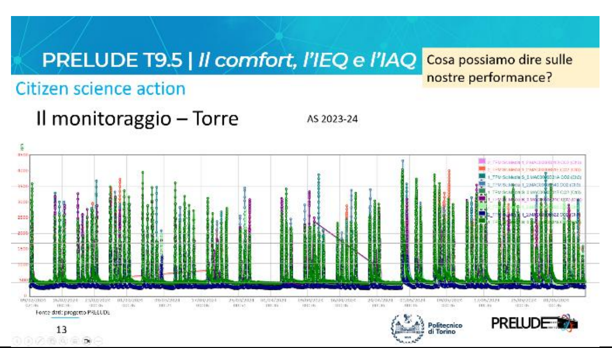
Nevertheless, to increase the participation level of students and to avoid excessive lighting activation with the consequent risk of annoying and causing education activity interruptions, the set thresholds are discussed with middle school students to define more rigid thresholds like in a contest among classes and/or with the teaching staff to balance potential issues. In high schools, the reference threshold is instead directly communicated and selected.

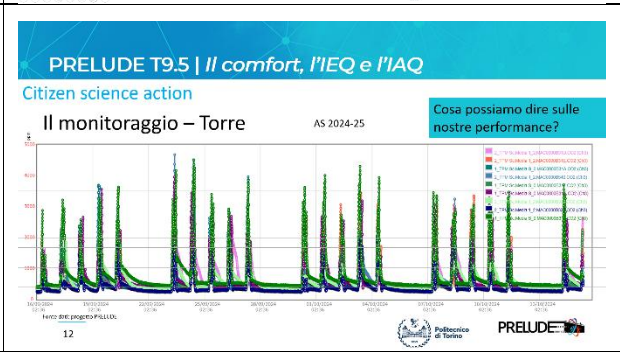
4.3.VI Step 4: restitution of results

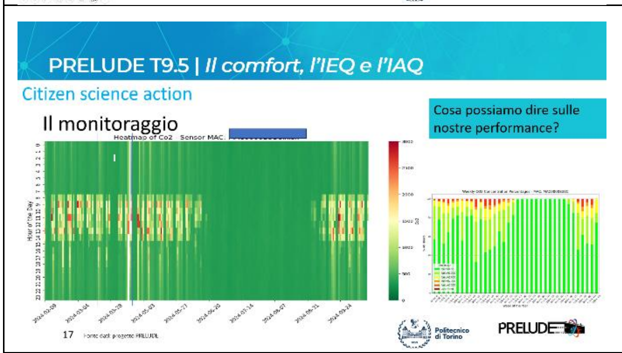
Results have been communicated to participating middle schools and students via a devoted second lecturing moment or sharing a presentation file with relevant teachers to be disseminated to students. Regarding Liceo Valdese, restitutions are given to selected students who follow the scientific high-school course profile. Nevertheless, in all cases, all students using the monitored rooms were directly engaged with their teachers in the self-actuation activity.

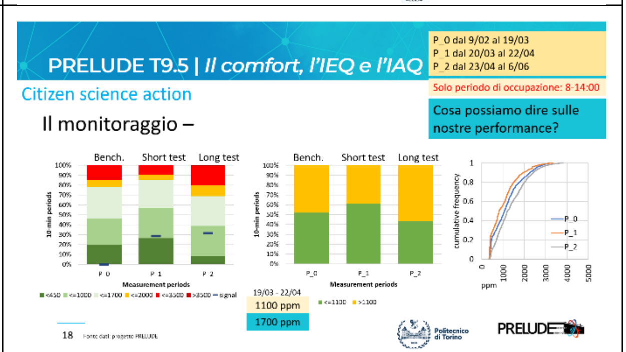
Here below are reported some sample slides used during one of the restitution lectures (texts are in the original Italian language):

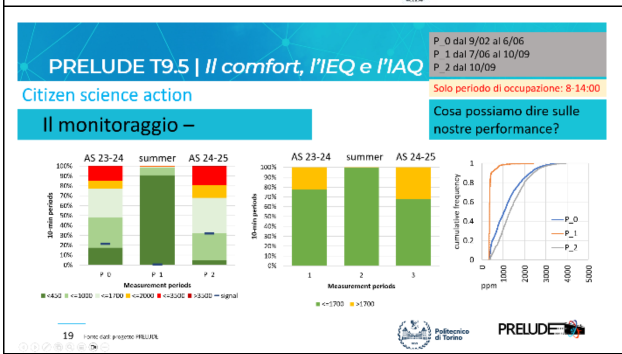


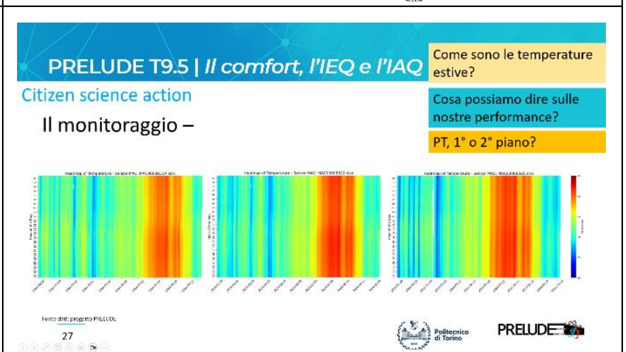












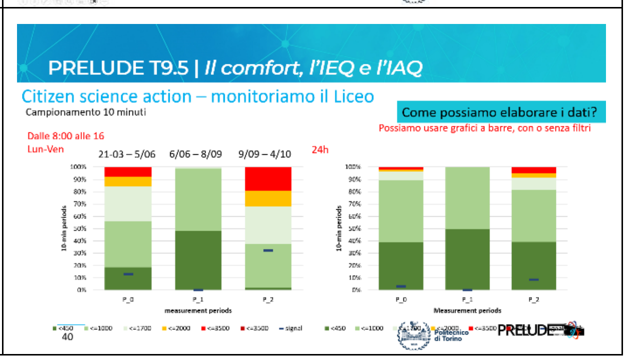


Figure 26 - Sample slides extracted from result-based lectures aiming at discussing outcomes and student engagement levels (original Italian text)

Participating students and teachers communicate a great interest in the activity and the topics being discussed. Additionally, the continuous self-actuation action results demonstrate a general improvement in the IAQ conditions.

Numerical results are reported in the following Section 4.4.

4.3.VII Step 5: (optional) Continuous monitoring action

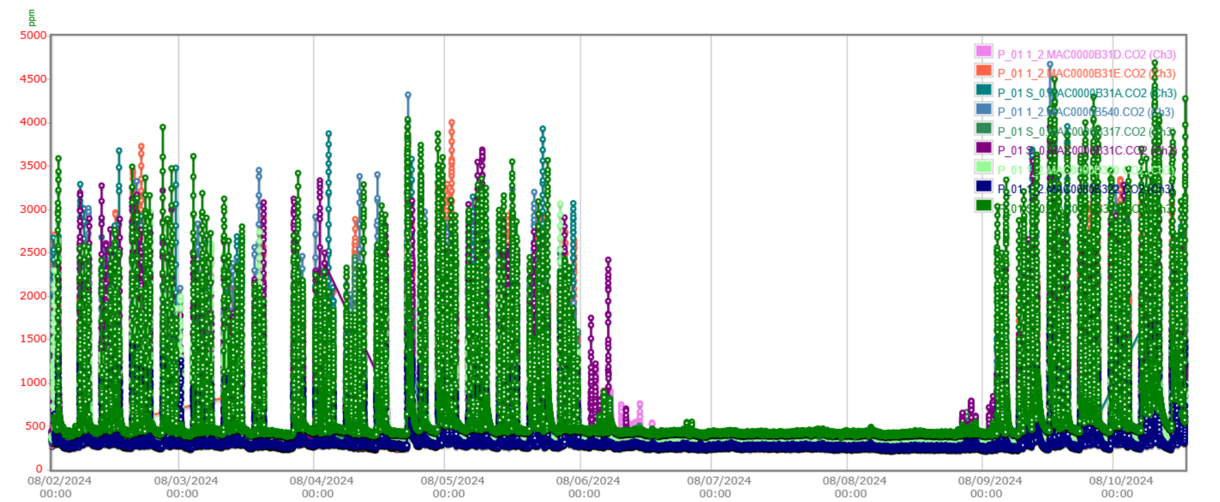
This methodological step refers to the possibility given to the participating schools in extending the monitoring and the citizen-science activities for a longer period, e.g. the whole school year. In particular, in the school year 2023-24, three schools with sensors installed extended the activities for the entire didactical period, requiring participation in the action also in the following year (2024-25). Furthermore, all six schools are now defined to continue the activities until the end of the current school year. This underlines the high interest of all schools in citizen science and the possibility of supporting self-actuation actions to improve the IAQ of the used spaces.

4.4 Main obtained results (data analysis)

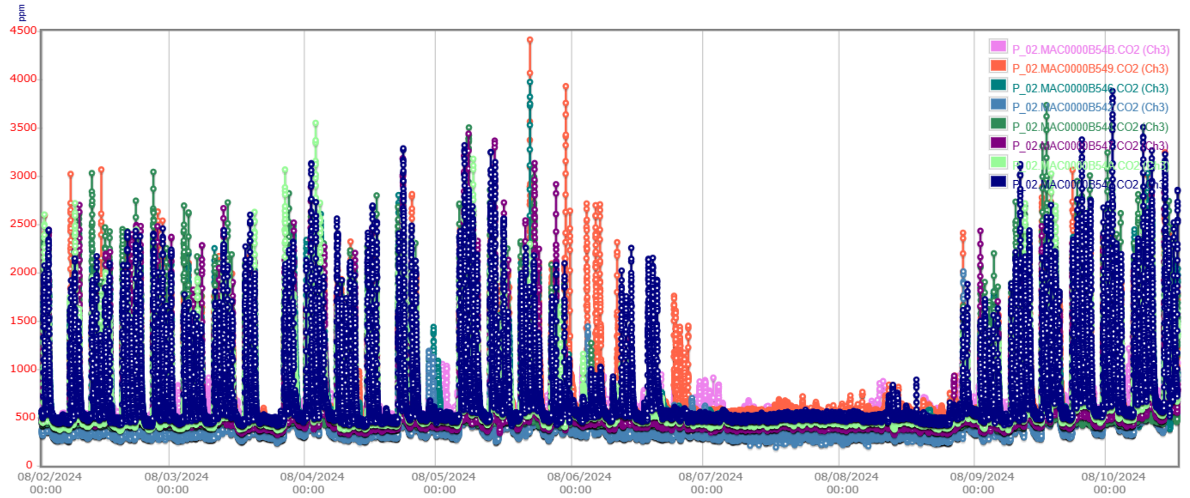
The collected data are elaborated to discuss the main results of the citizen science action. In particular, the IAQ concentration levels are studied to verify the impact of the self-actuation activity. Selected results are retrieved using the MAC of each sensor to avoid the identification of the specific room.

CO_2 concentrations (IAQ)

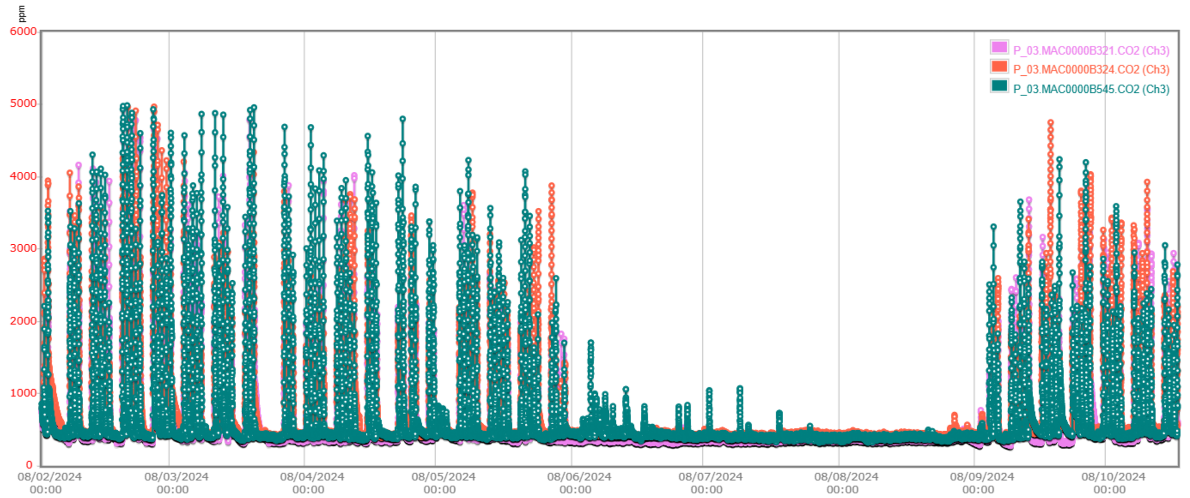
A first analysis was conducted by simply representing the measured CO_2 concentrations on a linear chart via the Capetti Winecap system. Sample results are shown below with some comments – see Figure 27.



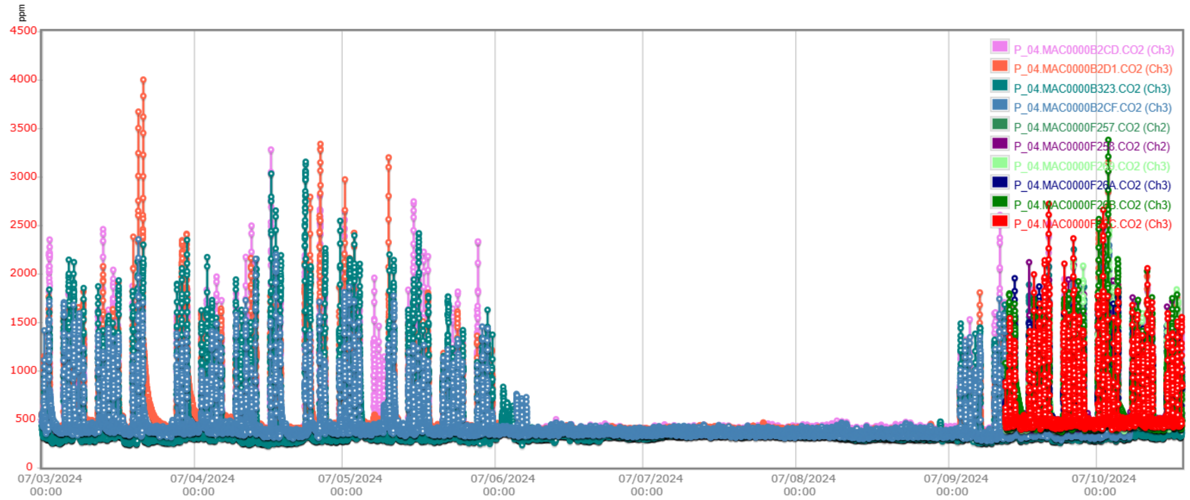
P_01 – data from the School Year (S.Y.) 2023-24 (from 8/02/2024) and 2024-25 (till 24/10/2024). The school's general trend shows that in several hours, different rooms overpass 2000 ppm of CO_2 concentration, with some peaks between 3500-4000 ppm in the first year and above 4500 ppm in the current one. This suggests that improving the IAQ level is needed. After the LED activation (19-20/04/2024), an improvement is visible for most sensors (at least during the first weeks). Looking at the new school year, the starting condition is worse, while a slight improvement is visible for some classes after the latest series of lectures (17/10/2024).



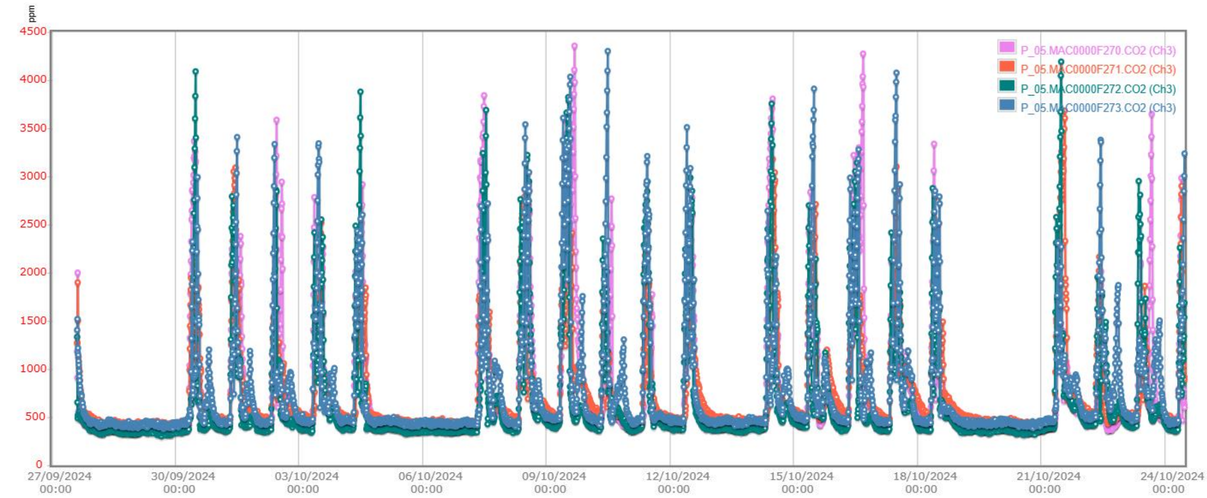
P_02 – data from the School Year (S.Y.) 2023-24 (from 8/02/2024) and 2024-25 (till 24/10/2024). Data show a general trend in the first year, with most hours below 2000 ppm and some peaks in the 2500-3000 ppm range. Near the end of the year, higher values are reached in limited days, suggesting unique occupancy profiles. During the current S.Y., higher values are detected, requiring greater attention to the LED alerts.



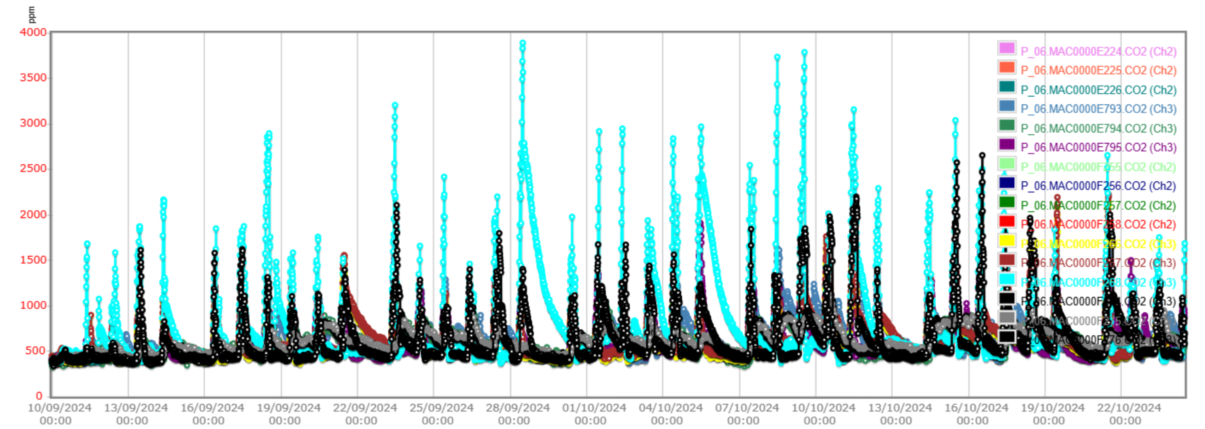
P_03 – data from the School Year (S.Y.) 2023-24 (from 8/02/2024) and 2024-25 (till 24/10/2024). During the first S.Y., very high CO2 concentrations were detected with an improvement after the LEDs' activation (24/04/2024), underling how the activity has the ability to improve the IAQ levels (in this school, windows have been retrofitted with highly performing solutions that also have a very low infiltration rate). In the current year, the conditions have improved, and concentrations are reduced after the new series of lectures (18/10 and 6/11).



P_04 – data from the School Year (S.Y.) 2023-24 (from 7/03/2024) and 2024-25 (till 24/10/2024). In this building, the CO2 concentration is very good, showing a general trend below 2000ppm with most time below 1700ppm. In the first S.Y., only a few peaks overpass 3000 ppm. In the current year, the positive trend is maintained, and some improvements are visible after the activation of LED alerts (11/10/2024).



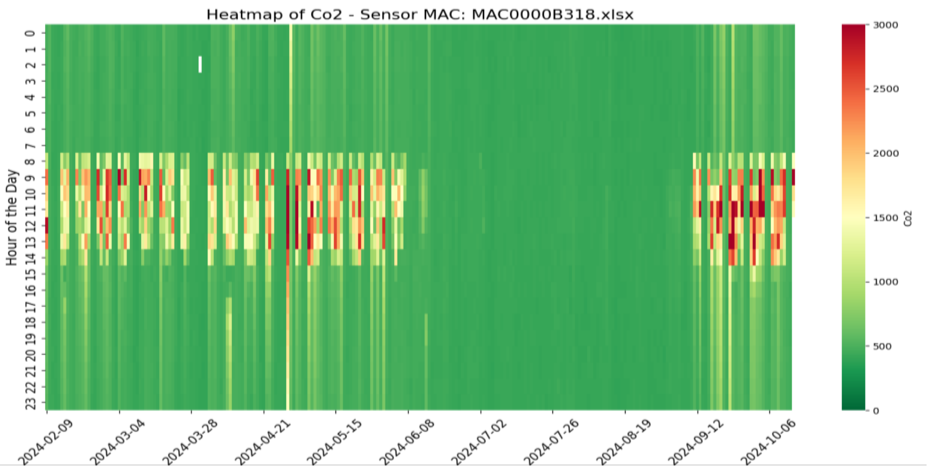
P_05 – data from the School Year (S.Y.) 2024-25 (from 27/09 till 24/10/2024). Classrooms show a general trend of high concentrations during the morning occupation hours, with daily peaks above 3500 ppm. After activating the LEDs (13/10/2024), a slight improvement is underlined.



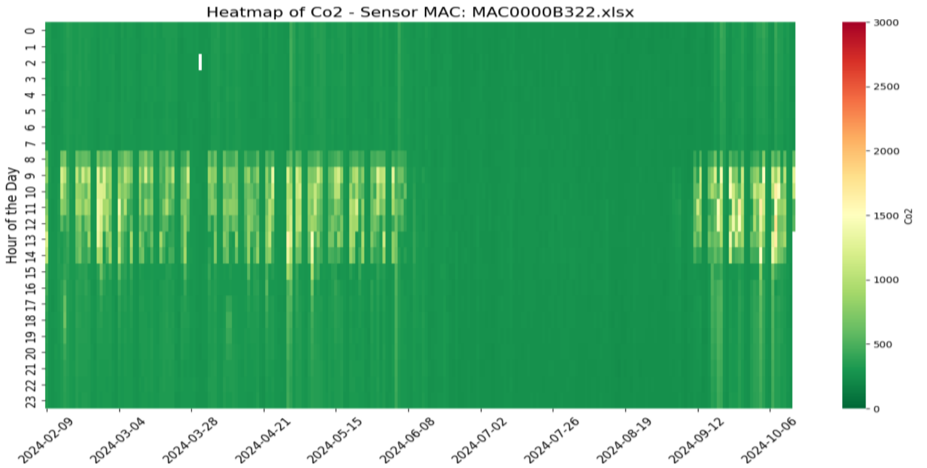
P_06 – data from the School Year (S.Y.) 2024-25 (from 10/09 till 24/10/2024). The school spaces are generally well managed regarding air confinement levels (mainly below 1500 ppm), except for a sensor positioned in a crowded classroom. The activation of the LEDs arrived on 11/10/2024, and a reduction in CO2 concentrations is visible after this date.

Figure 27 - Measured CO_2 concentrations in all schools - simple initial restitutions

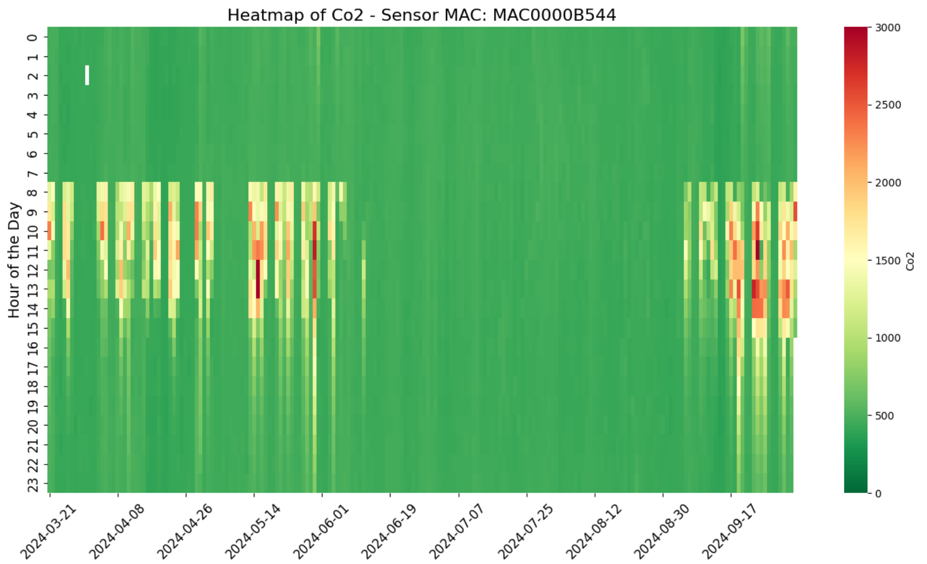
Secondly, data are elaborated to produce via Python coding more readable restitution based on carpet plots representing the CO_2 hourly concentrations [ppm]. In this case, it is possible to see that schools may have a general variation in the local behaviours being the latter also correlated with inputs that are not computed in the citizen science, such as the school envelope technical characteristics (e.g. infiltration rates), the occupancy density, or the natural ventilation capacity (e.g. cross or single side ventilation; wind exposure etc.). In addition, three classrooms in one of the schools have a mechanical ventilation system (detached mechanical ventilation – see [12]) supporting an additional ventilation flow. Nevertheless, in all the other spaces, natural ventilation is the sole airflow source with the exclusion of the infiltration rates. The following figures – see Figure 28 – show representative results of different representative cases.



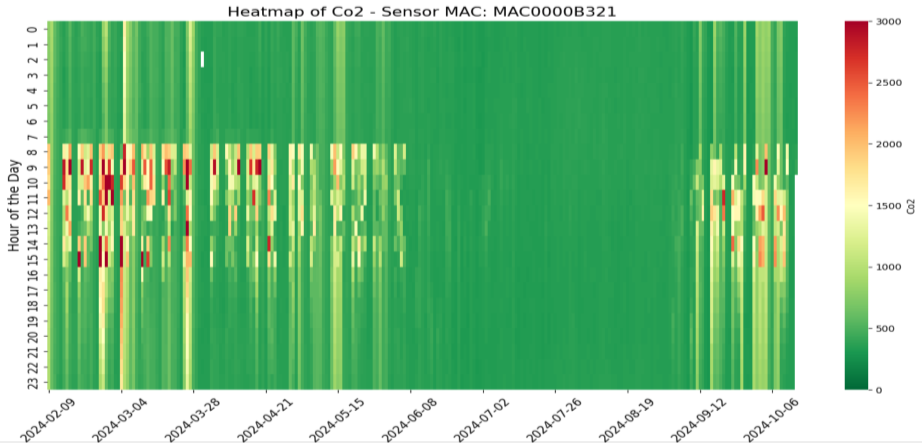
P_01 Sample carpet plot showing a classroom's CO_2 hourly concentration [ppm] (LED is activated on 19/03/2024 – see the improvements after this date, till about the end of April)



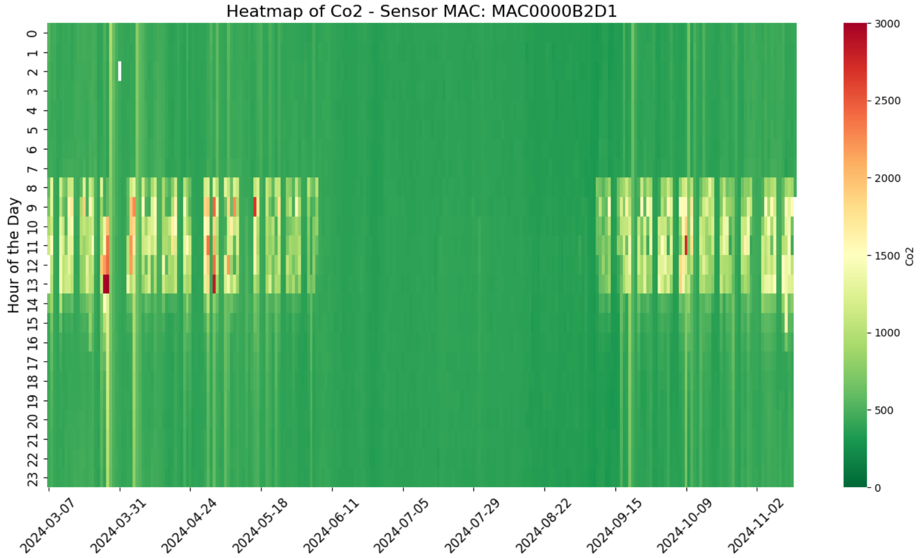
P_01 Sample carpet plot showing a classroom's CO_2 hourly concentration [ppm] with a mechanical ventilation system (DMV) (LED activation arrived on 19/03/2024) – DMV maintain CO2 levels below 1000ppm almost all the time (around 85%), suggesting potential overventilation



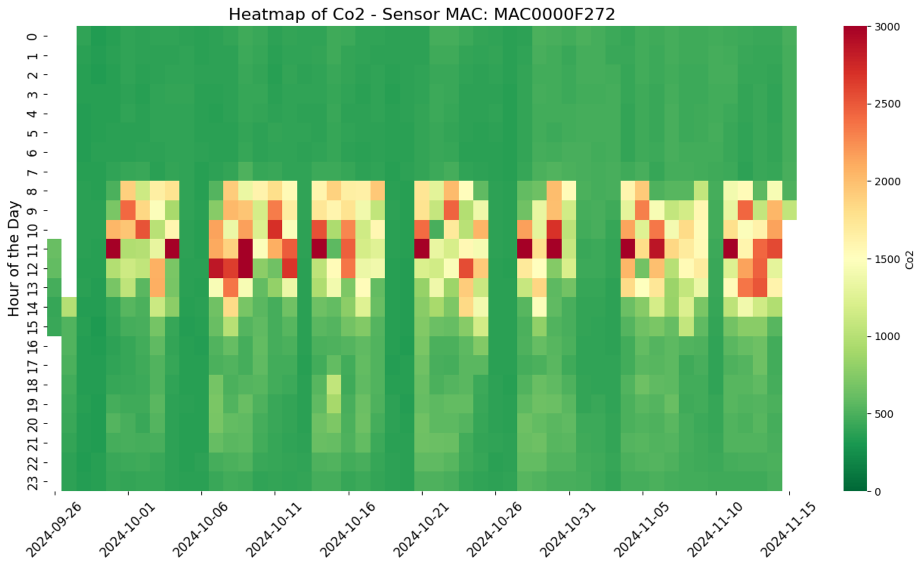
P_02 Sample carpet plot showing a classroom's CO_2 hourly concentration [ppm]



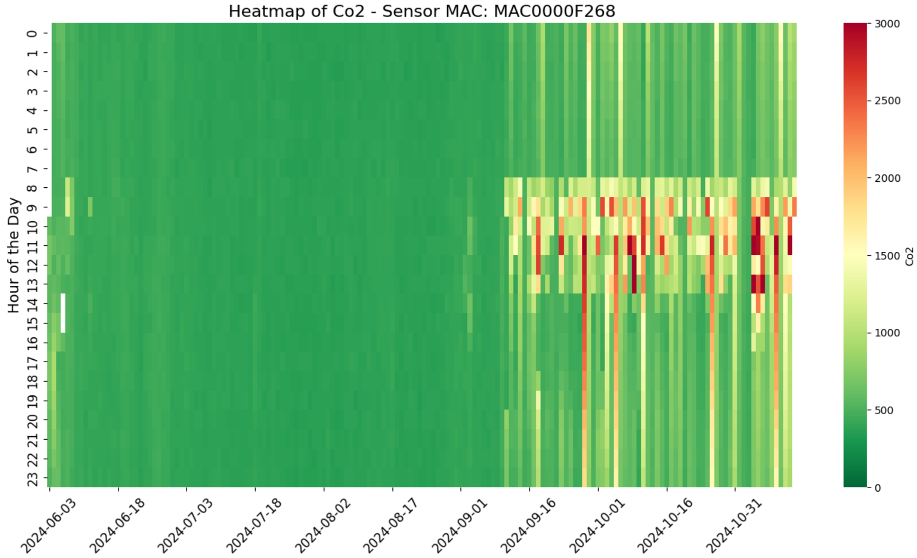
P_03 Sample carpet plot showing a classroom's CO_2 hourly concentration [ppm] (LED is activated on 23/04/2024, followed by a visible improvement in IAQ levels)



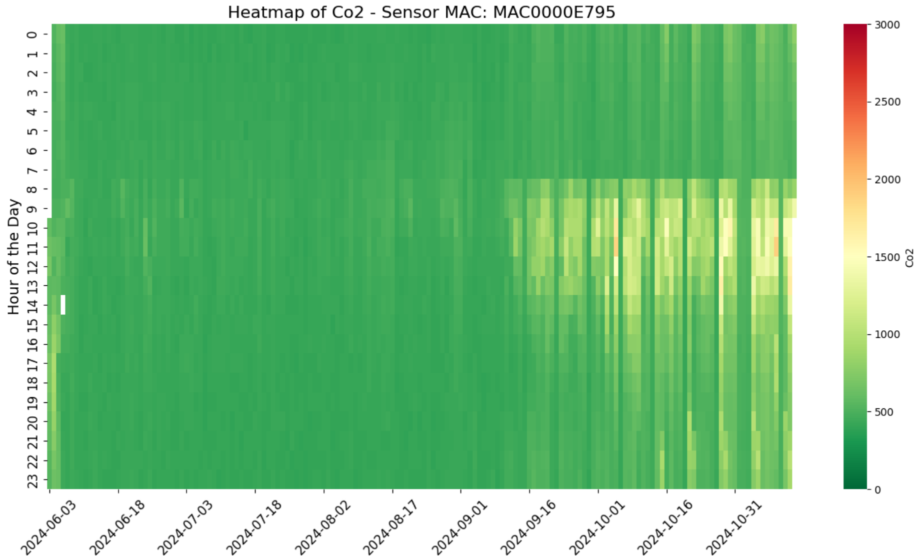
P_04 Sample carpet plot showing a classroom's CO_2 hourly concentration [ppm] (LED was activated on 11/10/2024, showing a following improvement in IAQ, although the original levels were already excellent)



P_05 Sample carpet plot showing a classroom's CO_2 hourly concentration [ppm] (LED starts to blink on 12/10, although information is given to teachers on 25/10/2024 – minor improvements are visible, even considering the activation of the heating system on 15/10)



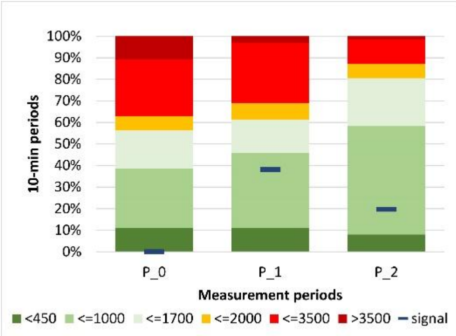
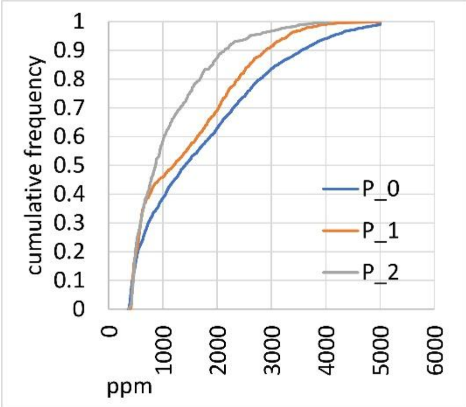
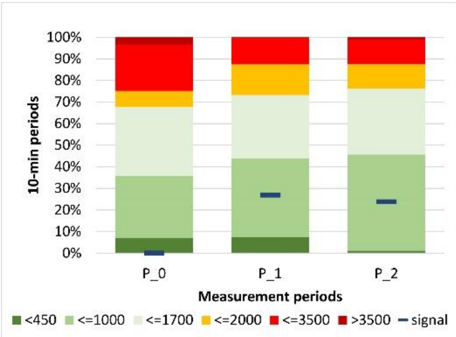
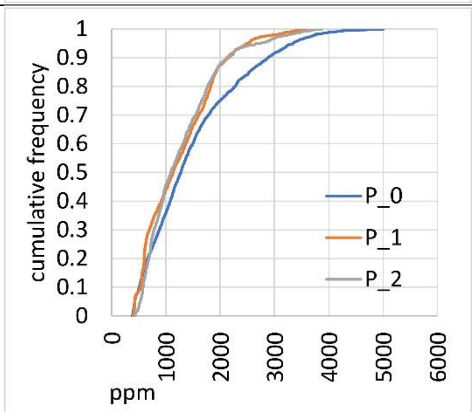
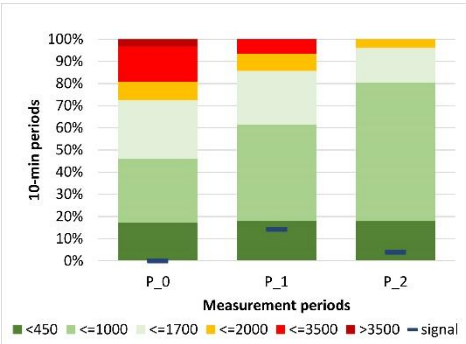
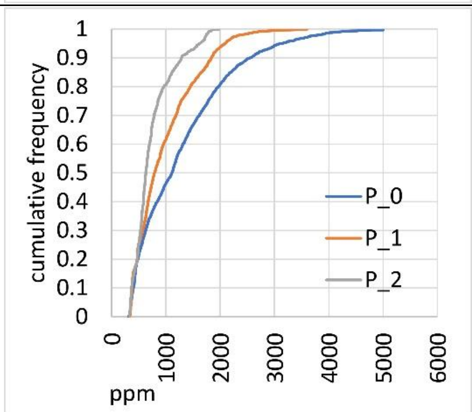
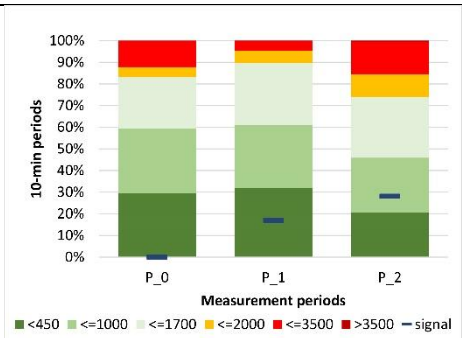
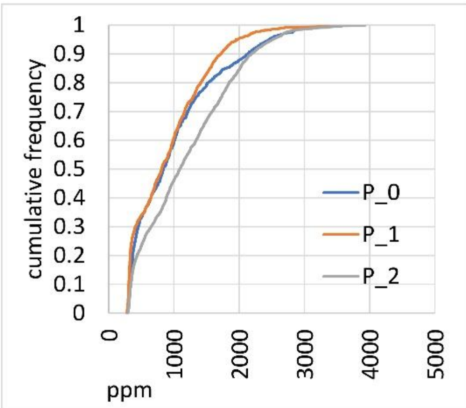
P_06 Sample carpet plot showing a classroom's CO_2 hourly concentration [ppm] (LED was activated on 11/10/2024 without lecturing)

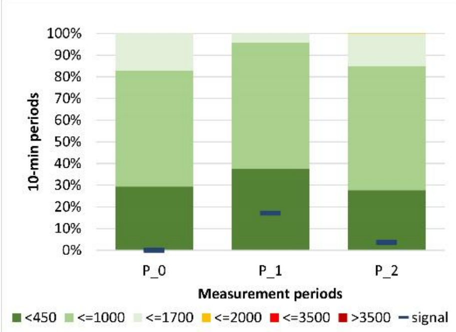
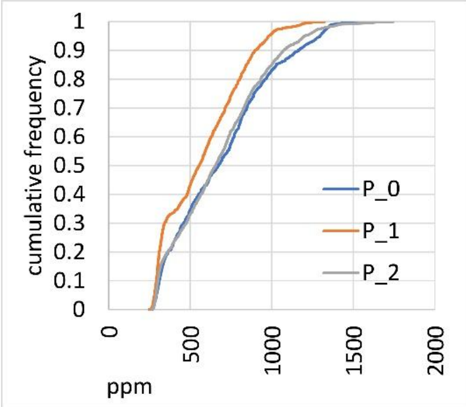
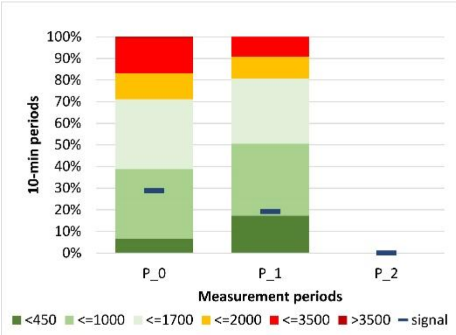
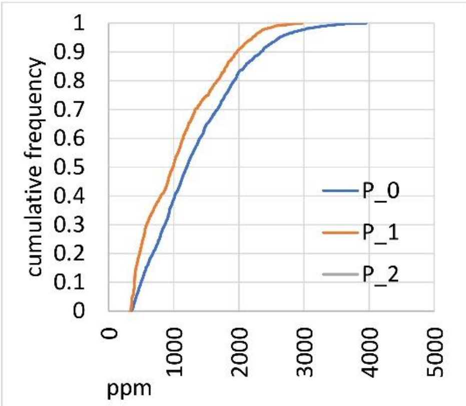
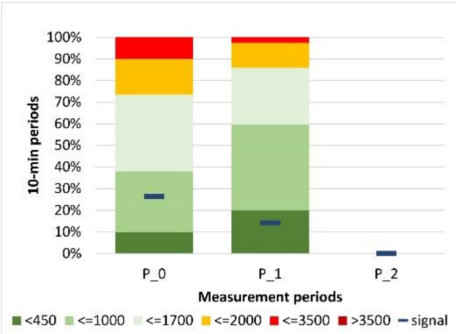
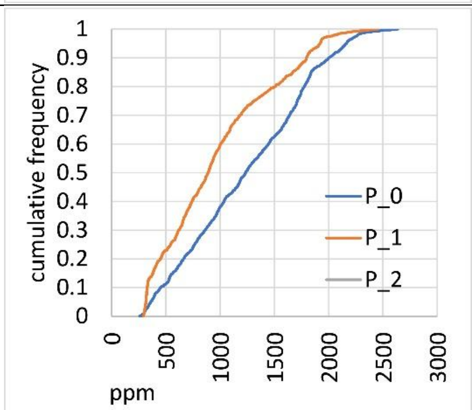
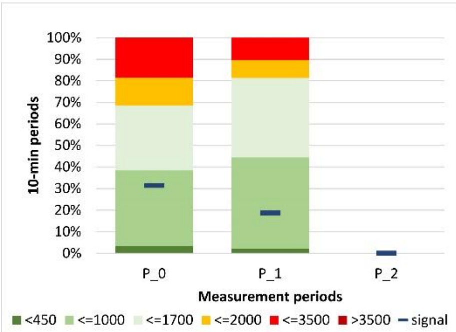
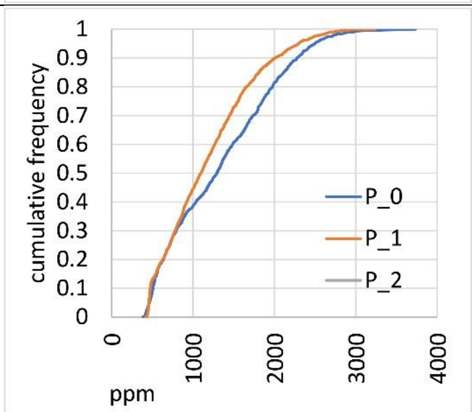


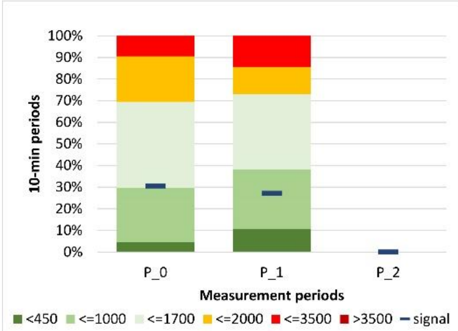
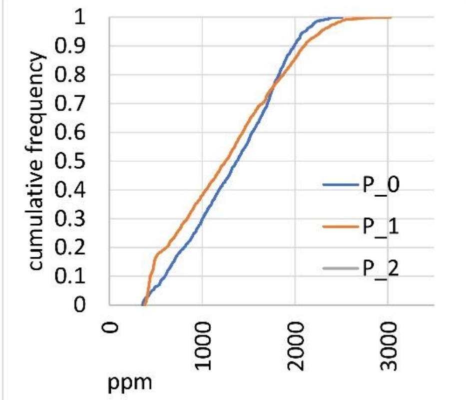
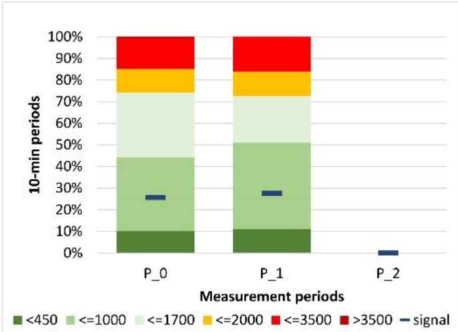
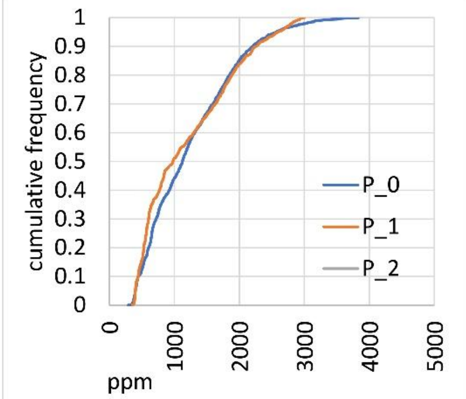
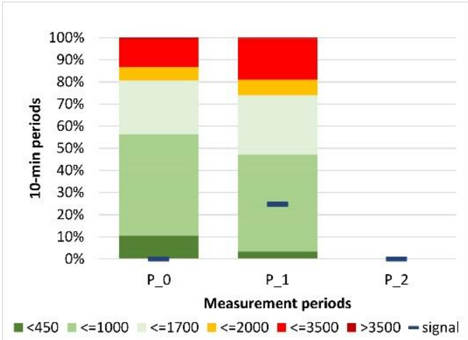
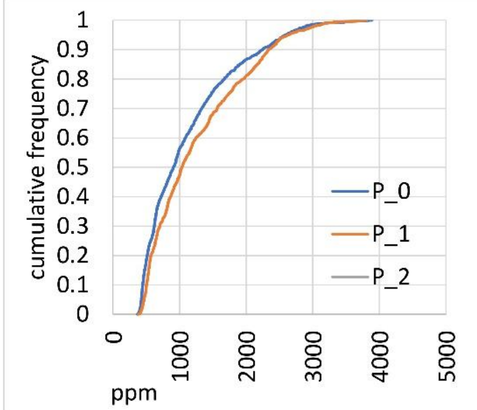
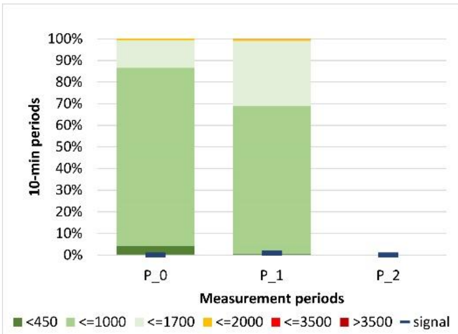
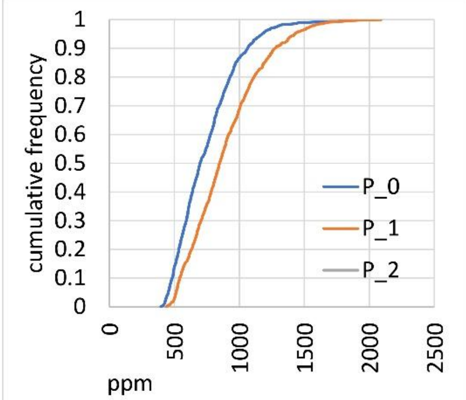
P_06 Sample carpet plot showing a laboratory CO_2 hourly concentration [ppm] (LED was activated on 11/10/2024)

Figure 28 - Sample carpet plots showing CO2 hourly concentration [ppm]

In addition, the distribution of the CO_2-measured data points is analysed in different periods of aggregation in order to verify the impact of citizen science with respect to benchmark periods, i.e. before the activation of the lighting alerting system. Analyses have been refined to focus on the occupancy periods, avoiding the weekends (when the CO_2 concentrations are always very good) and the unoccupied periods (nights and early mornings) during the weekdays. Short special holidays are not filtered. This analysis compares the distribution of time-series measured data (10-min intervals) inside the assumed ICONE thresholds to verify the amount of exposure time to given CO_2 concentrations. In addition, the amount of time of sensor LED activations is also reported on the same graphs (this value is taken by the sensors and not re-calculated). Finally, the cumulative frequency distributions are also reported for each period to allow the reader to analyse the number of periods in personalised threshold values. In three schools, results are given for the first (School Year 2023-24) and second years (S.Y. 2024-25) of citizen science, while for the other three, the results of the current school year are given. Results are shown in Figure 29 for 16 representative selected classes, covering each school (schools are in disorder).

Sensor | S.Y.	Timestep distribution of CO_2	Frequency distribution
B545 | 2023-24	 *High improvements, growing over time*	
B324 | 2023-24	 *Evident improvements maintained over time*	
B321 | 2023-24	 *Huge improvements*	
B31A | 2023-24	 *During the first month after the LED activation, CO2 concentrations considerably improved. Nevertheless, after this previous period, the attention decreased, and self-actuation suggestions were less followed*	

B322 | 2023-24	 *Case with mechanical ventilation. During the first month after the LED activation, the IAQ grew, although in the last period, the quality slightly decreased again*	
S.Y. 2024-25		
B31C | 2024-25	 *IAQ levels improve*	
B31D | 2024-25	 *Improvements are very evident*	
B544 | 2024-25	 *IAQ levels increase, and the red class hours are halved*	

B546 | 2024-25	 *No. Periods above 1700 slightly decrease, but % in the red class increases*	
B321 | 2024-25	 *Improvements mainly in the <=1000ppm class*	
F268 | 2024-25	 *There is a slight decrease in IAQ levels (Class without direct communication with students)*	
E795 | 2024-25	 *Laboratory – IAQ is maintained even when heating is activated*	

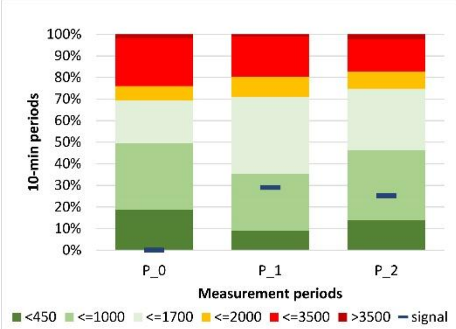
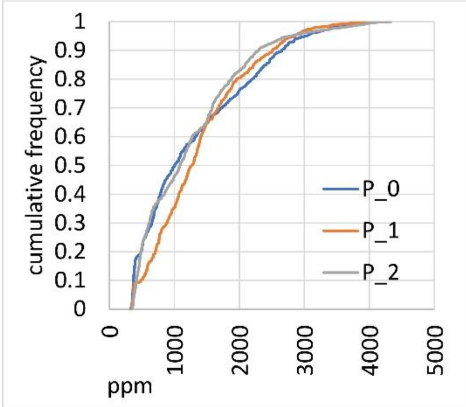
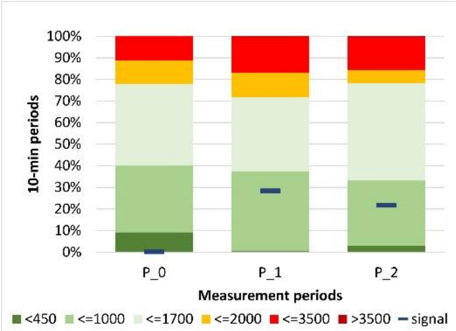
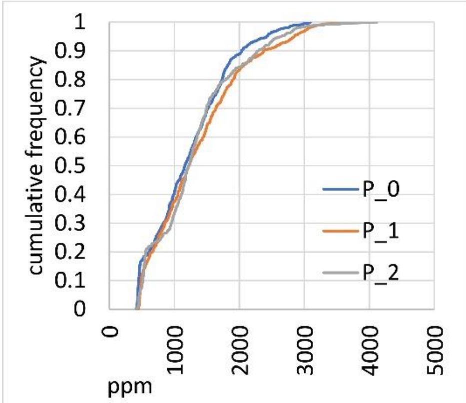
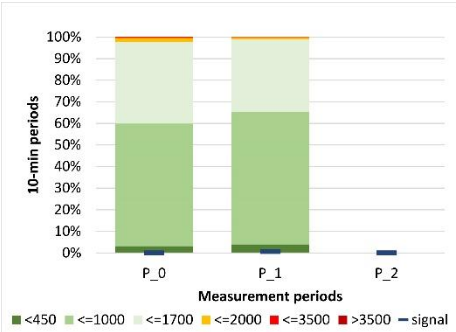
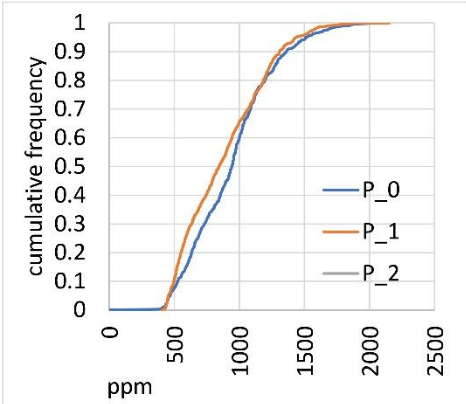
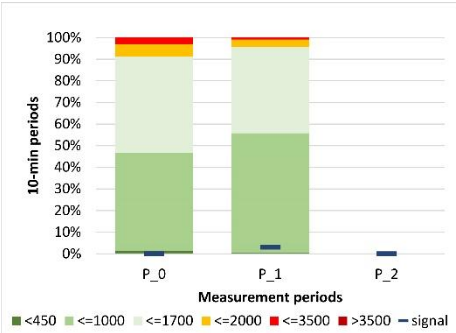
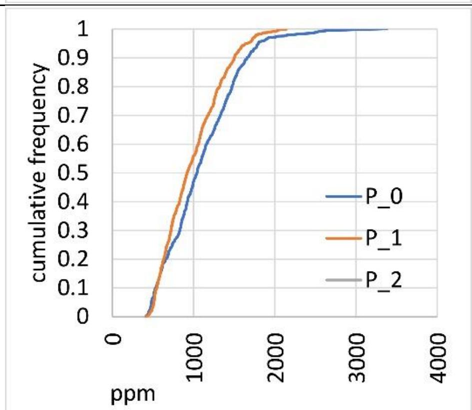
F272 | 2024-25	 *There is a slight increase in IAQ (when activated, second bar, and after alerting the teachers, last bar)*	
F271 | 2024-25	 *There is a slight increase in IAQ only after teaching alerting (last bar)*	
F269 | 2024-25	 *Slight increase. Excellent starting IAQ conditions*	
F26B | 2024-25	 *Slight increase. Excellent starting IAQ conditions*	

Figure 29 - Selected room results of CO_2 concentrations before (first bar, benchmark) and after sensor activations (second bar). Some cases have a third bar for checking long-term attention to alerts (2023-24)

Finally, all results obtained from the CO2 concentration classification during the occupation periods for all 36 measured rooms[10] are considered to study the **impact of the self-actuation citizen science action** on the IAQ by comparing post-LED activation with benchmark conditions. Figure 29 above underlined how citizen science might impact IAQ levels only when LED suggestions are followed thanks to students' and teachers' interests. It can be seen how, after a direct lecture/presentation of the initiative to students, the IAQ grew, while the continuity of the attention was very high in some cases and decreased in other schools. Furthermore, in those schools where lectures were not given, LED alerts were generally less followed, underlining the importance of maintaining high attention and participation levels to support the citizen science effectiveness. As highlighted in the conclusions, one of the outcomes is the suggestion to include, in the future, additional user-engagement solutions, e.g. room monitors and GUIs, sound alerts, and gamification actions to maintain a high engagement over time.

Focusing on the aggregated results from all the rooms in the S.Y. 2023-24, the IAQ grew in 55% of cases thanks to LED activations. However, if the school where lectures are not given is excluded, the IAQ levels rose in 75% of classes. IAQ levels are analysed here, considering occupied time spams (10-minute intervals) and fixing CO2 concentrations below 1700 ppm as a comfort threshold. This outcome correlates the efficiency in self-actuation to the level of direct communication with occupants. Looking at the current S.Y. 2024-25, an increase in the CO_2 periods below 1700 ppm during occupation arrived in 64% of the 36 measured rooms. Nevertheless, excluding the two schools where lectures to students are not given, this percentage passes to 76%! This confirms the previous result: LED activations are effective if students are directly involved in communication activities and informed about the importance of comfort monitoring. In particular, in the four schools where lectures are given to students, the IAQ improved respectively by 78%, 75%, 67%, and 80% of classrooms. On the contrary, where communications are not given directly to students, an improvement in the benchmark CO_2 levels is underlined in 75% and 14% of the classes, while in the others, the IAQ decreases due to the start of the winter season. In these last two cases, it is possible to underline how the first school, which shows positive results, is a case in which teachers are very responsive to IAQ, being that building measured during the COVID pandemic period for air quality, adopting a series of sensors with sound alerts (those sensors are now no more used). A general outcome is the ability of the simple small LED activation signals to improve the IAQ in most cases, suggesting that self-actuation via alerts is a positive approach to controlling air quality in schools. Nevertheless, to increase the impact of this action and reduce the need to support direct communications, it can be possible to suggest for future applications the use of different alerting typologies, e.g. sound alarms and/or large lighting solutions, e.g. using lamps similar to the ones adopted for fire alarms.

Air temperature

Air temperatures are also measured and are used for a preliminary check on the thermal comfort behaviours. Considering the educational purpose of the study, carpet plots were elaborated, allowing for discussion of the temperature differences measured among the different building constructive typologies of the involved schools, i.e. the summer free-running and un-occupied behaviours of a recent building (built around the '70s) and a historic building (built during the XIX century). Additionally, measurements also allow to discuss the thermal stratification of temperatures among the different school floors. Sample results are shown in the following Figure 30, Figure 31, and Figure 32.

[10] Two laboratories have two sensors being significantly extended in plan dimensions, while 3 classes also have double sensors, i.e. the total sensor number is 41, while are here analysed the results for the 36 spaces to avoid double counting for the same room.

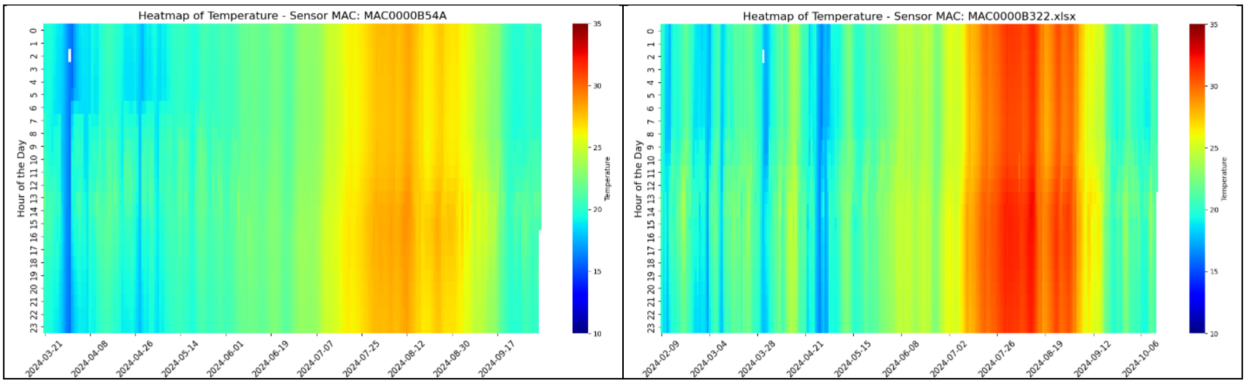


Figure 30 - Temperature carpet plots in rooms positioned on the left in a building of the '70s (6 cm of insulation. medium weight walls) and on the right in a building of the XIX century (no insulation, high thermal mass). The differences in summer temperature behaviours allow to discuss the impact of thermal masses.

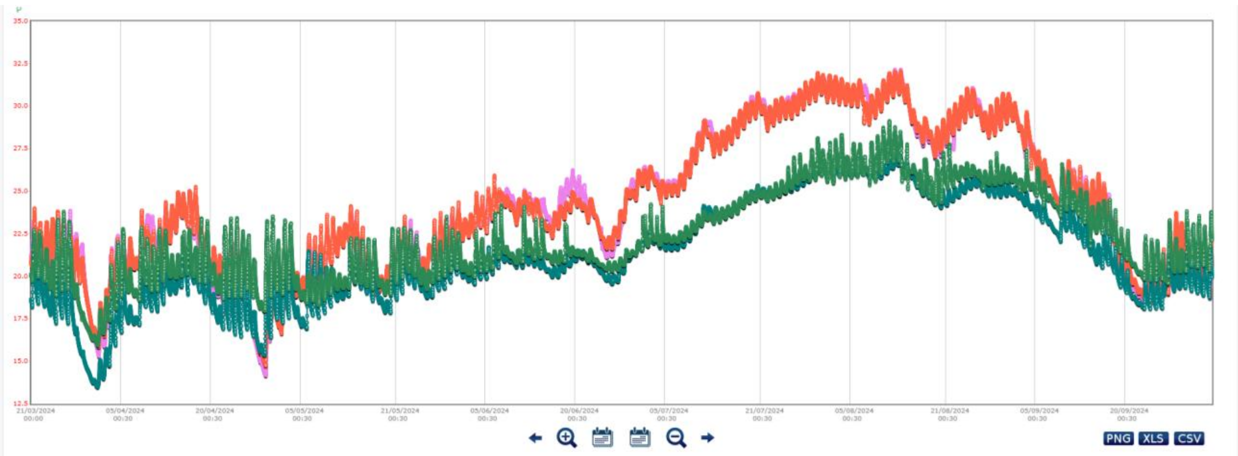


Figure 31 - Representation of the same behaviours using a line chart to increase the readability of the phenomenon. Orange and pink lines represent sensors positioned in a '70s building block, while lines green and blue-green are of an XIX-century building. Continuous differences higher than 5-6°C can be underlined for a long summer period.

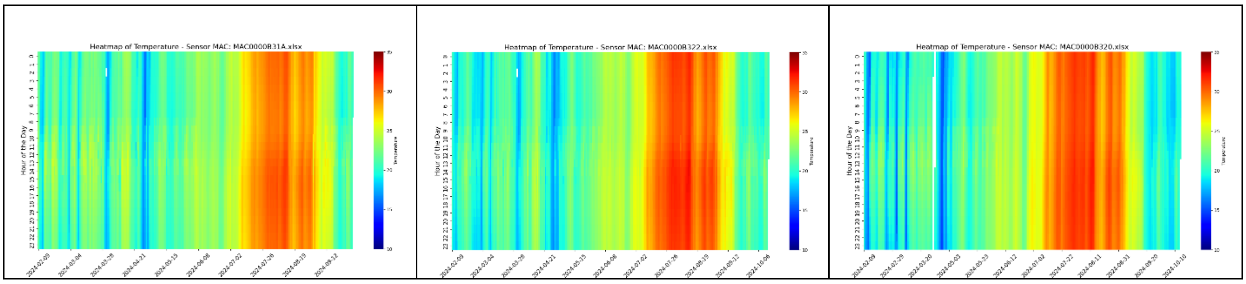
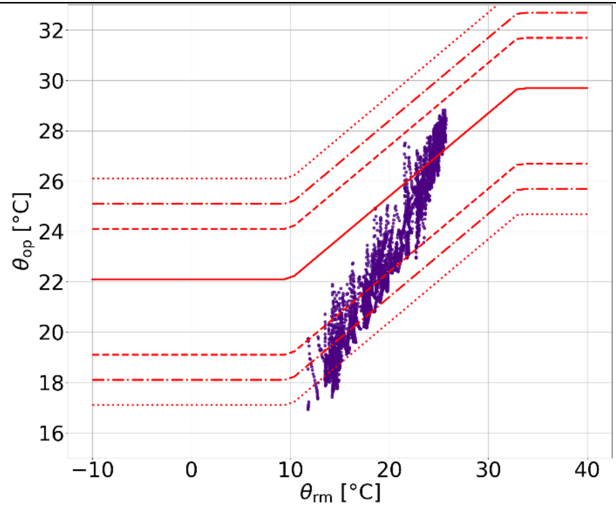


Figure 32 - Temperature carpet plots showing the differences among different floors (sensors are positioned respectively on a ground floor, first, and second-floor room). This analysis helps students discuss the thermal gradient concept, solar access, and obstacle-brought shadings.

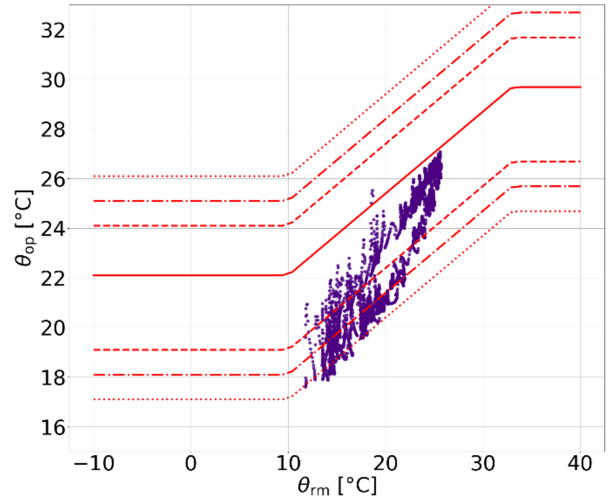
Thermal comfort – ACM for free-running periods

For ten sensors by five buildings, the data measured during the 2024 neutral and summer seasons (01/05/2024 – 30/09/2024) are elaborated via PREDYCE to produce the EN 16798-1 correlated adaptive thermal comfort charts. External temperatures are retrieved by locally installed meteorological stations, including the PRELUDE Turin demo one. Figure 33 compares the results of the five schools with summer 2024 temperature-monitored data. Also in this case, it is possible to underline the effect of different technical characteristics of the envelope being the high mass uninsulated building of case (a) characterised by low summer temperatures due to the high inertia, while cases (b, c, d) have sensibly higher temperatures.

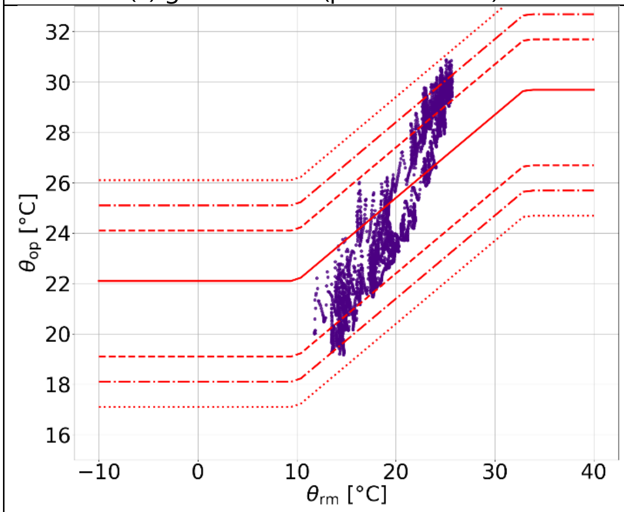
Case (b) has a cavity wall with a 6-cm insulation layer and two bricks, slightly better than the others, double windows, and all classrooms are south-facing. Finally, case (e) has reduced solar gains due to the recent retrofitted windows and different exposures not directly facing south.



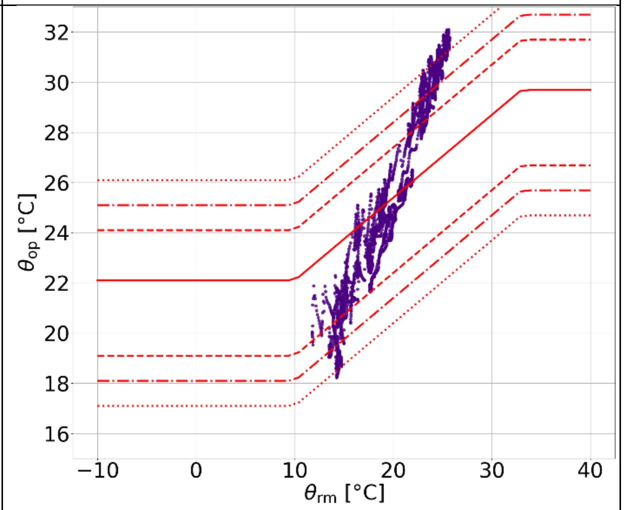
(a) ground floor (piedmont site)



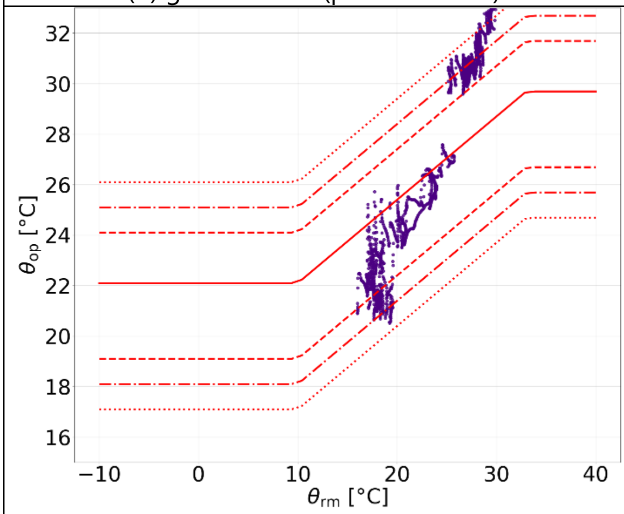
(a) first floor (piedmont site)



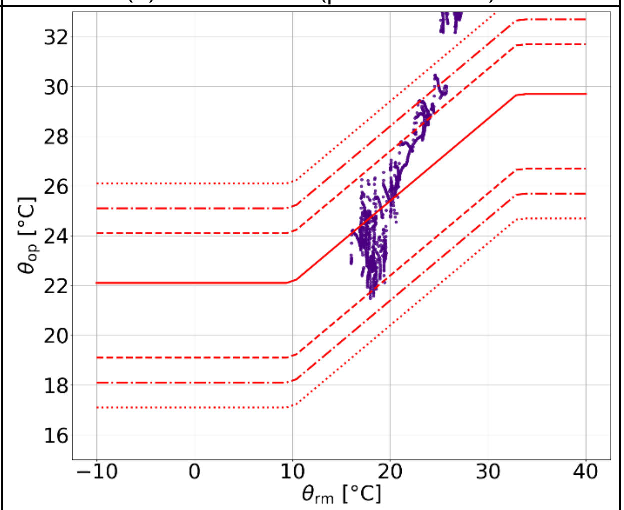
(b) ground floor (piedmont site)



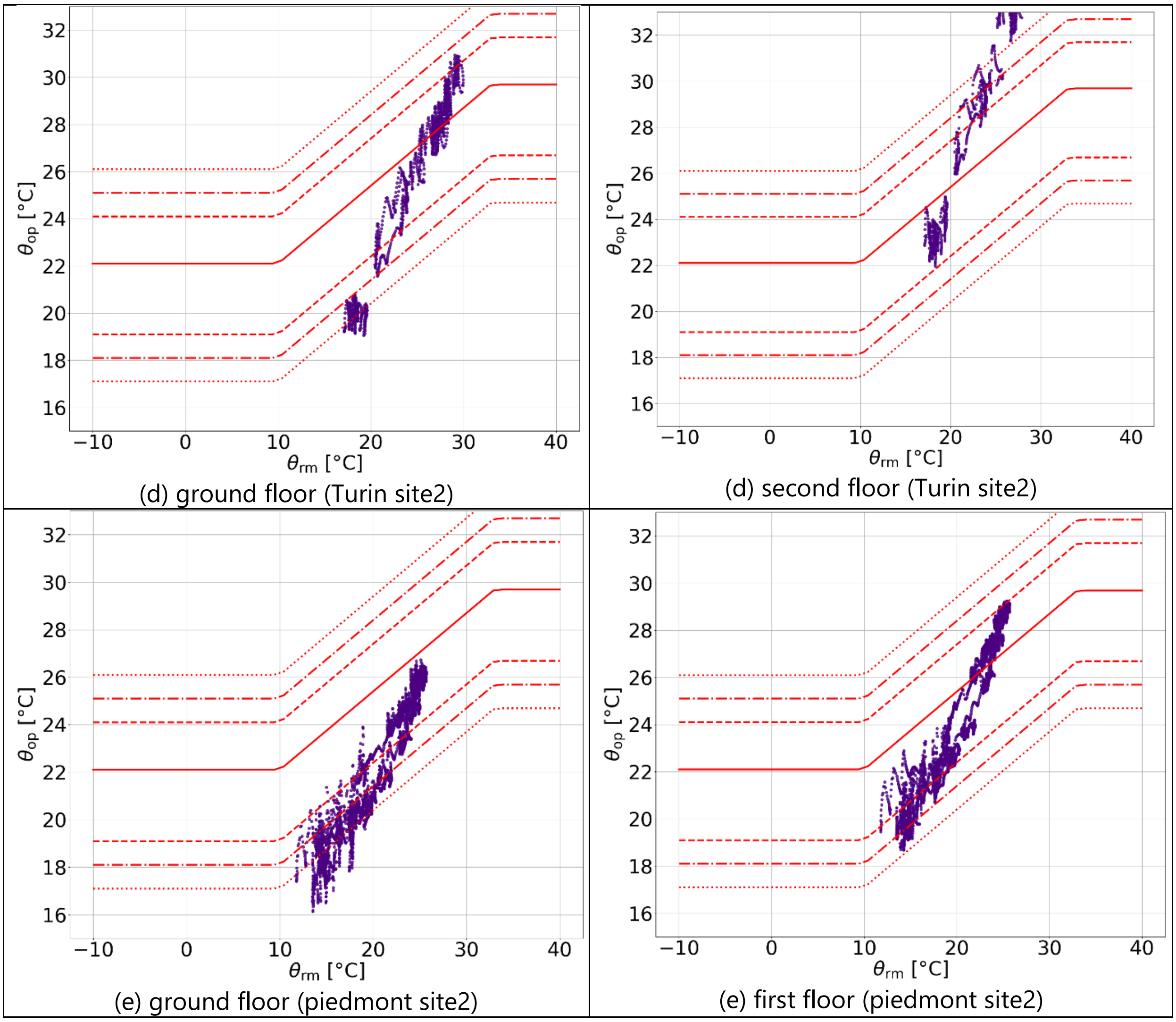
(b) second floor (piedmont site)



(c) central floor (Turin site)



(c) last floor (Turin site)



(d) ground floor (Turin site2) | (d) second floor (Turin site2)

(e) ground floor (piedmont site2) | (e) first floor (piedmont site2)

Figure 33 - Adaptive thermal comfort charts of a selected sensor for each of the five schools monitored during the 2024 neutral season and summer 2024 (from 1st May to 30th September). (a) XIX century building, (b) '70s building, (c) '50s building, (d) second half of the XX century building, and (e) partially retrofitted building. Running mean temperatures are based on local weather stations.

IAQ additional parameters

Additional IAQ types of sensors have also been installed in some rooms in order to discuss different IAQ parameters, i.e. TVOC, PM10 and PM2.5 sensors. These sensors are installed in the school year 2024-25 and results are reported via carpet plots and line charts.

Regarding the **TVOC**, the following graphs – see Figure 34 – show the measured data by the ten sensors considering the current school year. On the left are reported the TVOC, while on the right are the CO_2 levels in the same room. Data underlines that TVOC is not aligned with CO_2 concentrations; the latter is based on occupants, and the previous correlates with multiple other sources. It can be noted that major TVOC peaks arrive after the classroom occupation time, potentially correlated to room washing products. Furthermore, the figures underline that the TVOC are higher in laboratory rooms than in classrooms, as expected – compare, for example, (a, b) with (e, f). Comparing graph (a) and graphs (b & c), it is possible to see that cases (b & c), i.e. a classroom with a mechanical ventilation system, are interested in higher values than the ones of the case (a) that refers to a room with only natural ventilation set in the same building. Nevertheless, peaks arrive mainly after the student occupation times, suggesting space-washing correlations.

<table>
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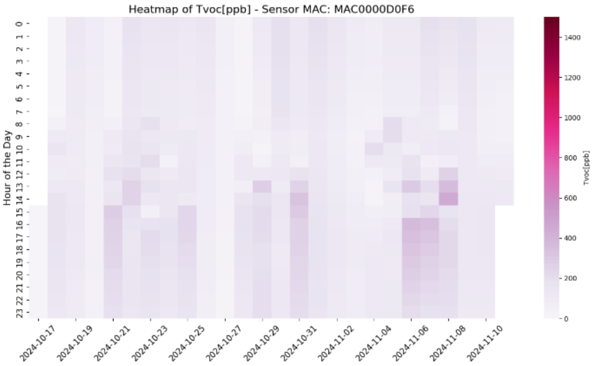
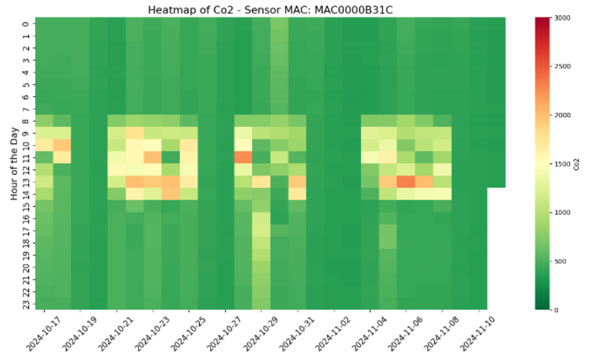
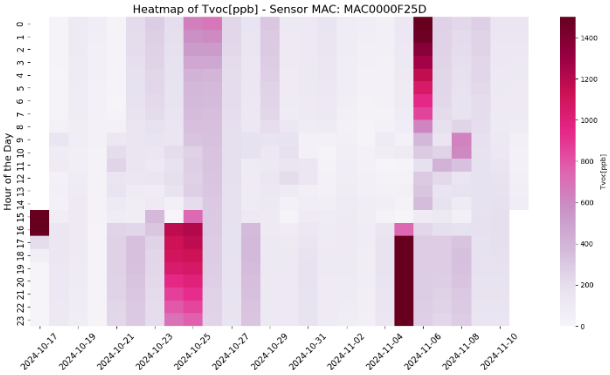
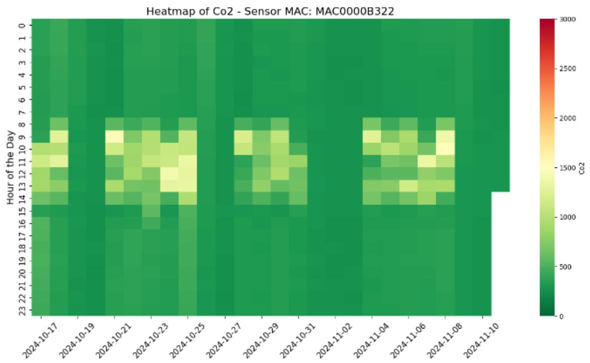
<tr><td>

(a) Classroom</td><td>
</td></tr>
<tr><td>

(b) Classroom with mechanical ventilation (ref.a)</td><td>
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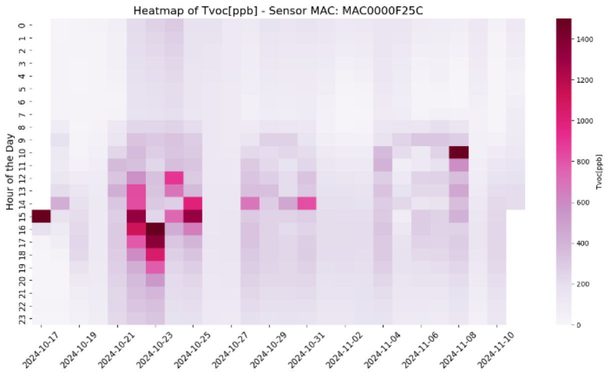
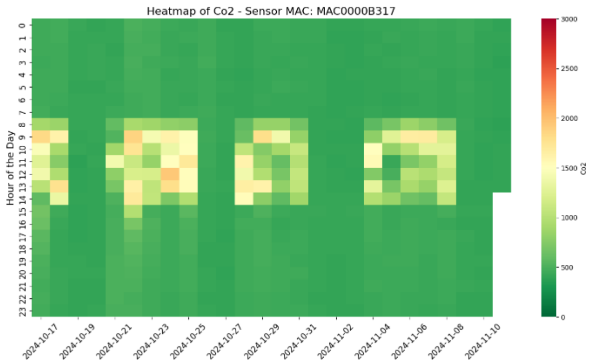
<tr><td>

(c) Classroom with mechanical ventilation (ref.a)</td><td>
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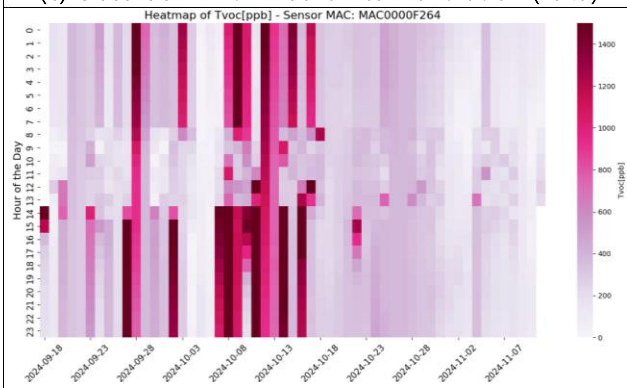
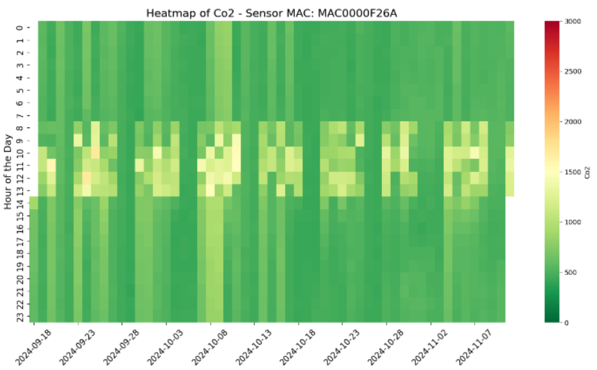
<tr><td>

(d) Classroom</td><td>
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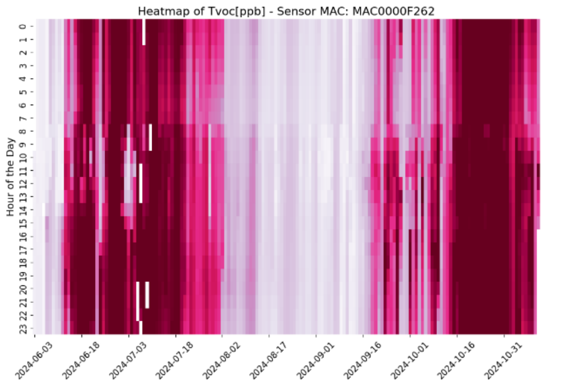
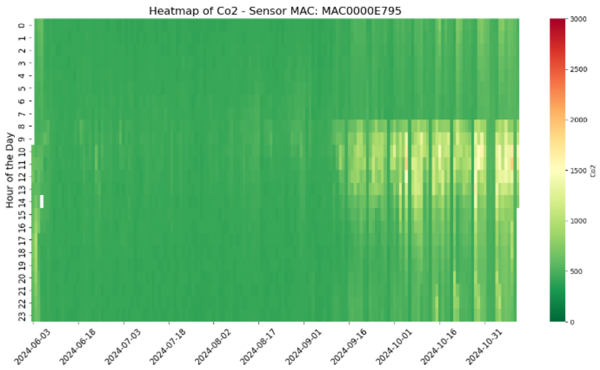
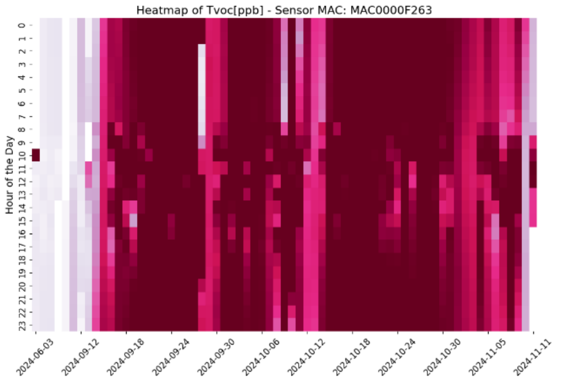
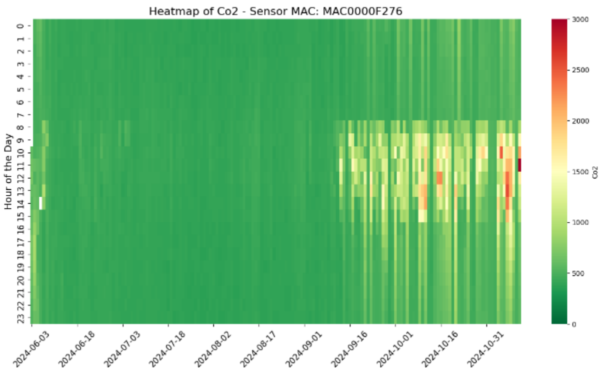


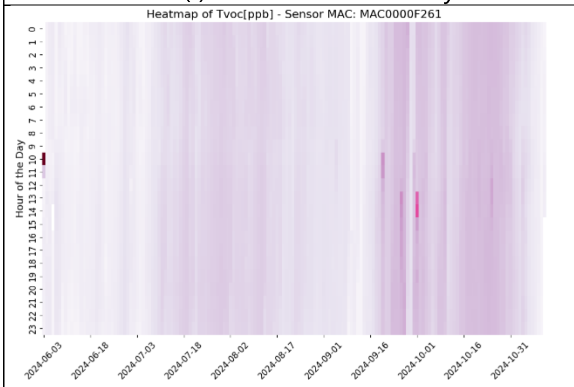


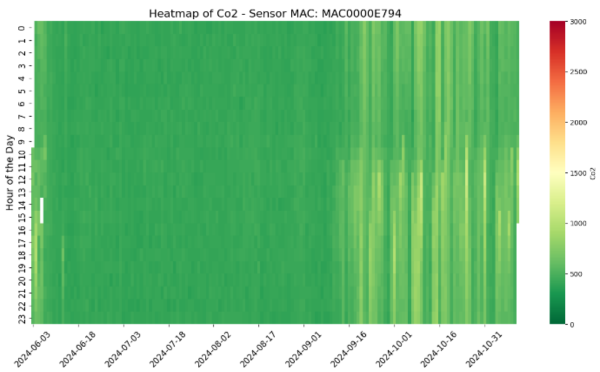
(e) Chemical Laboratory



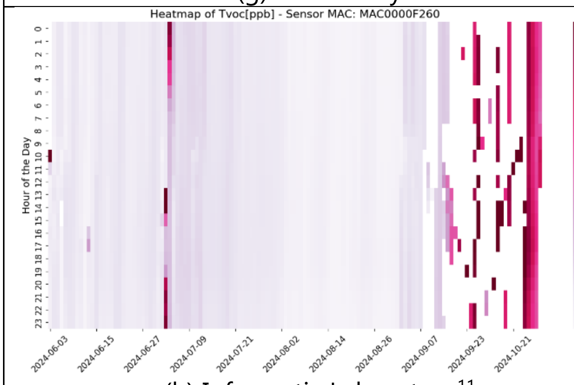


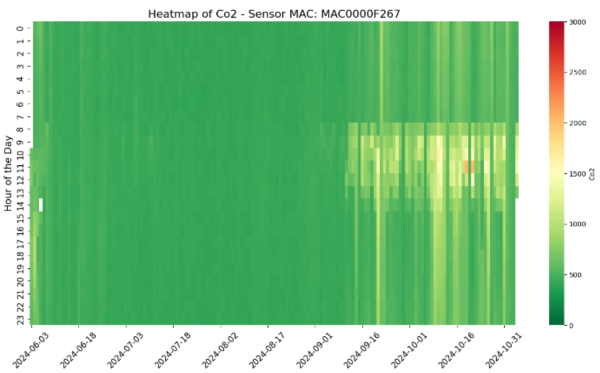
(f) Chemical Laboratory





(g) Laboratory





(h) Informatic Laboratory[11]

[11] Lacks of data are due to local discontinuity in the connection of the specific sensor with the gateway due to the high signal shading effect of the specific building construction elements.

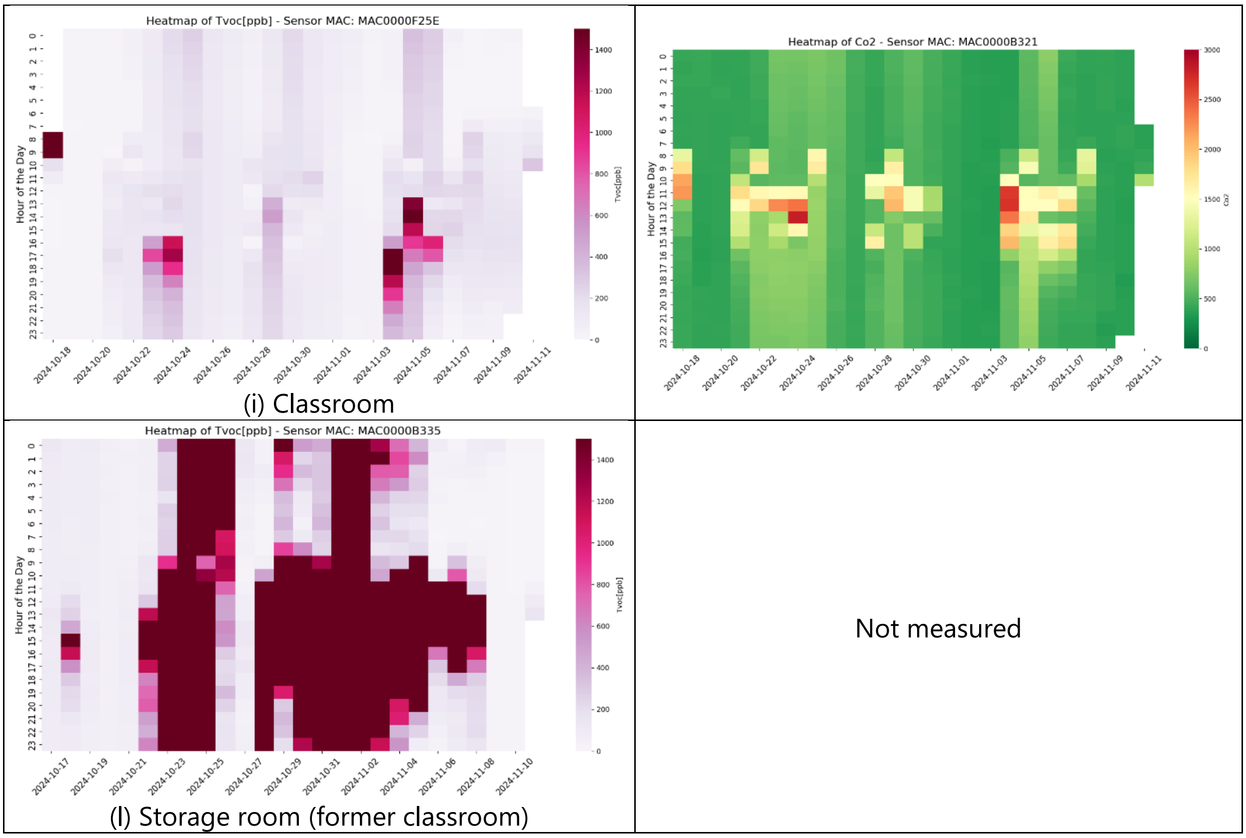


Figure 34 - TVOC carpet plots compared to CO_2 concentrations in the same series of rooms.

In addition, Figure 35 compares CO_2 and TVOC levels in four sample rooms, showing the differences among these two types of sensors. It is interesting to see and discuss with students that several sources, including washing products, may release TVOC and include an extensive set of pollutants that can be differently measured by sensors with difficulties defining proper thresholds. In these samples, it is possible to see the TVOC increases during washing time, i.e. see cases (a) and (b), with different dilution times according to potential variations in air exchanges. Furthermore, special laboratory activities may generate a different trend, i.e. case (c), while the presence of a detached mechanical ventilation unit also affects TVOC trends, i.e. case (d).

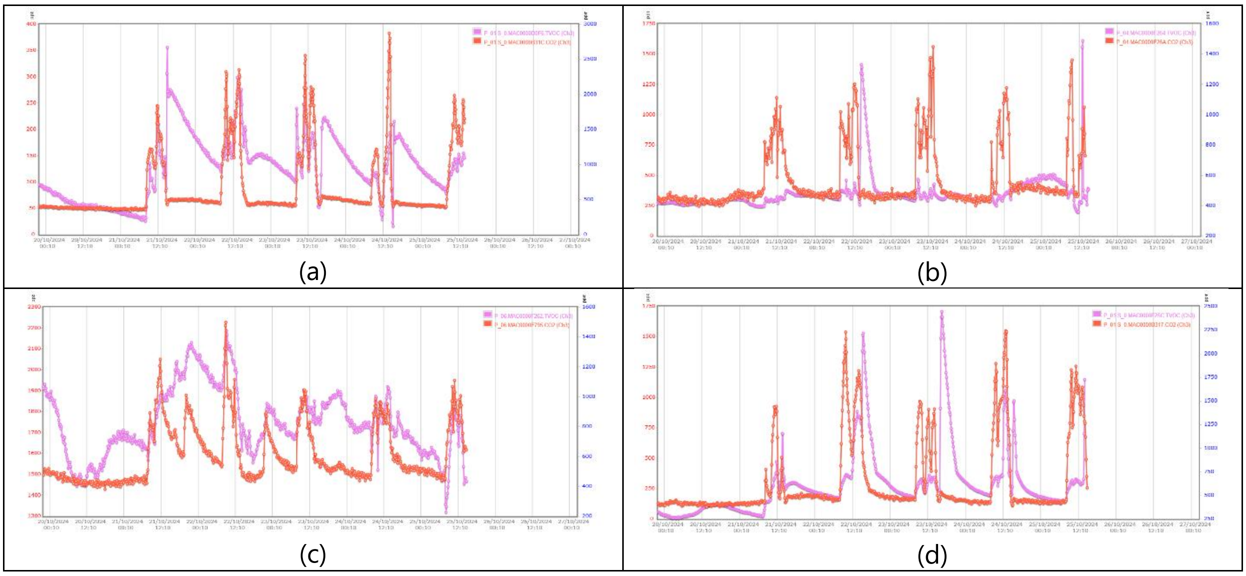
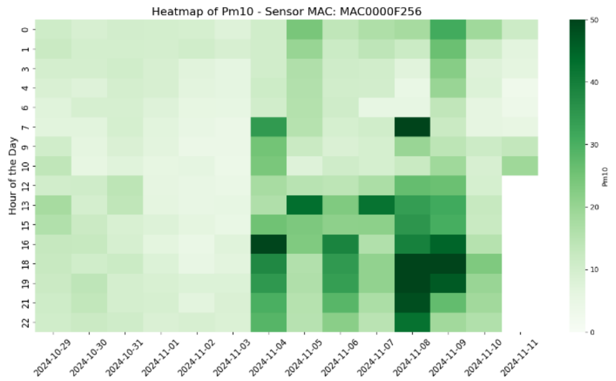
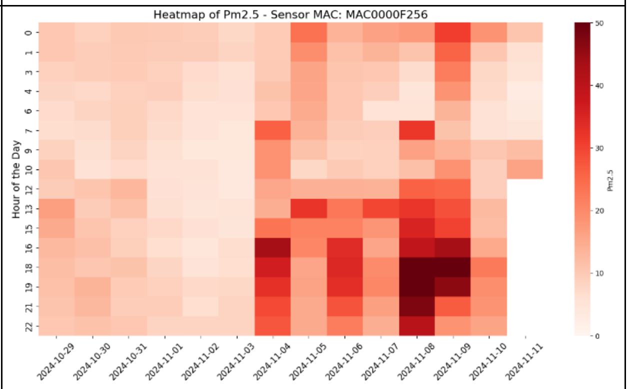
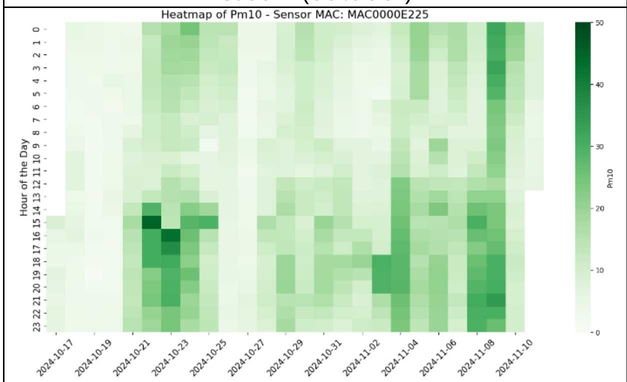
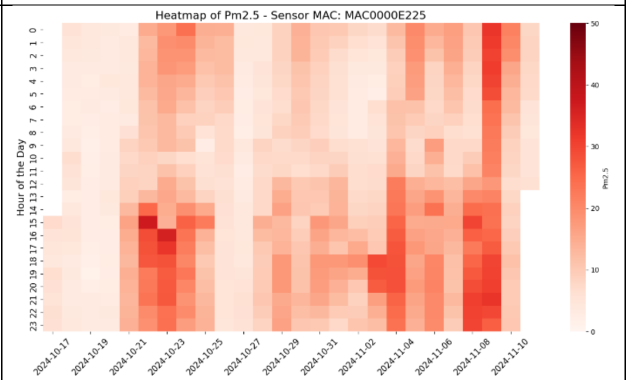
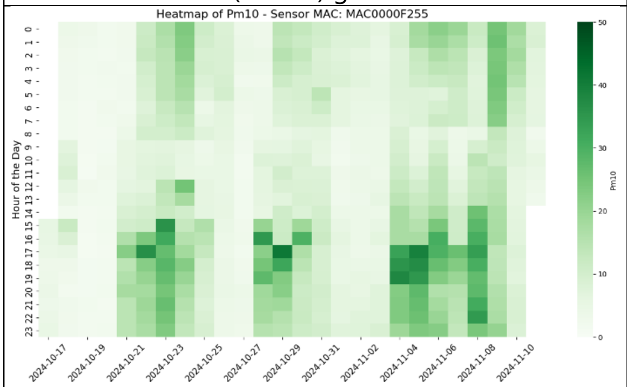
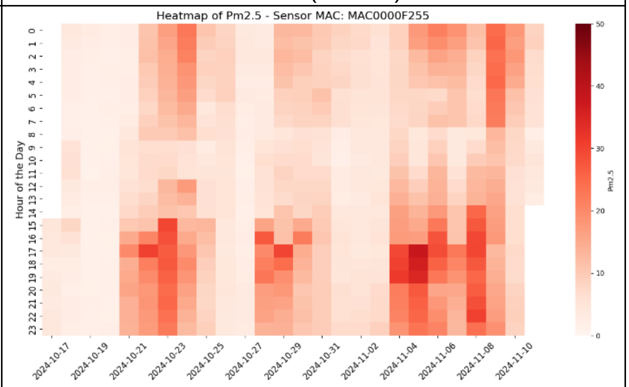


Figure 35 - TVOC (pink lines) VS CO_2 concentration (orange lines) in four sample rooms. (a) and (b) classrooms, (c) a chemical laboratory, and (d) a classroom with mechanical ventilation.

Considering particulate matter, **PM10** and **PM2.5** concentrations are measured in three schools, positioning a reference probe outside, on a rain-protected site, and the other(s) in a reference classroom(s). Carpet plots of both particulates are shown in Figure 36Figure 36. It can be underlined that indoor concentrations are lower in confined spaces compared to the outdoor environment because PM10 and PM2.5 productions do not arrive in school spaces. A high difference is measured between the PMx concentrations in the two locations outside the Turin metropolitan area (piedmont locations) and the concentrations in the Turin city site. In the latter, particulate matter concentrations are drastically higher, both inside and outside, as expected. Especially outside, PM10 and PM2.5 show a very bad condition, although the classroom IAQ is maintained lower, not underlining an excessive inflow of these pollutants from outside to inside spaces. Nevertheless, for crowded cities with high traffic and PMx production by heating and other systems, adopting particulate sensors may help balance ventilation when these indices are not at the maximum outdoor.

PM10	**PM2.5**
 Case 1 (outdoor)	 Case 1 (outdoor)
 Case 1 (indoor) ground floor	 Case 1 (indoor)
 Case 1 (indoor) first floor	 Case 1 (indoor)

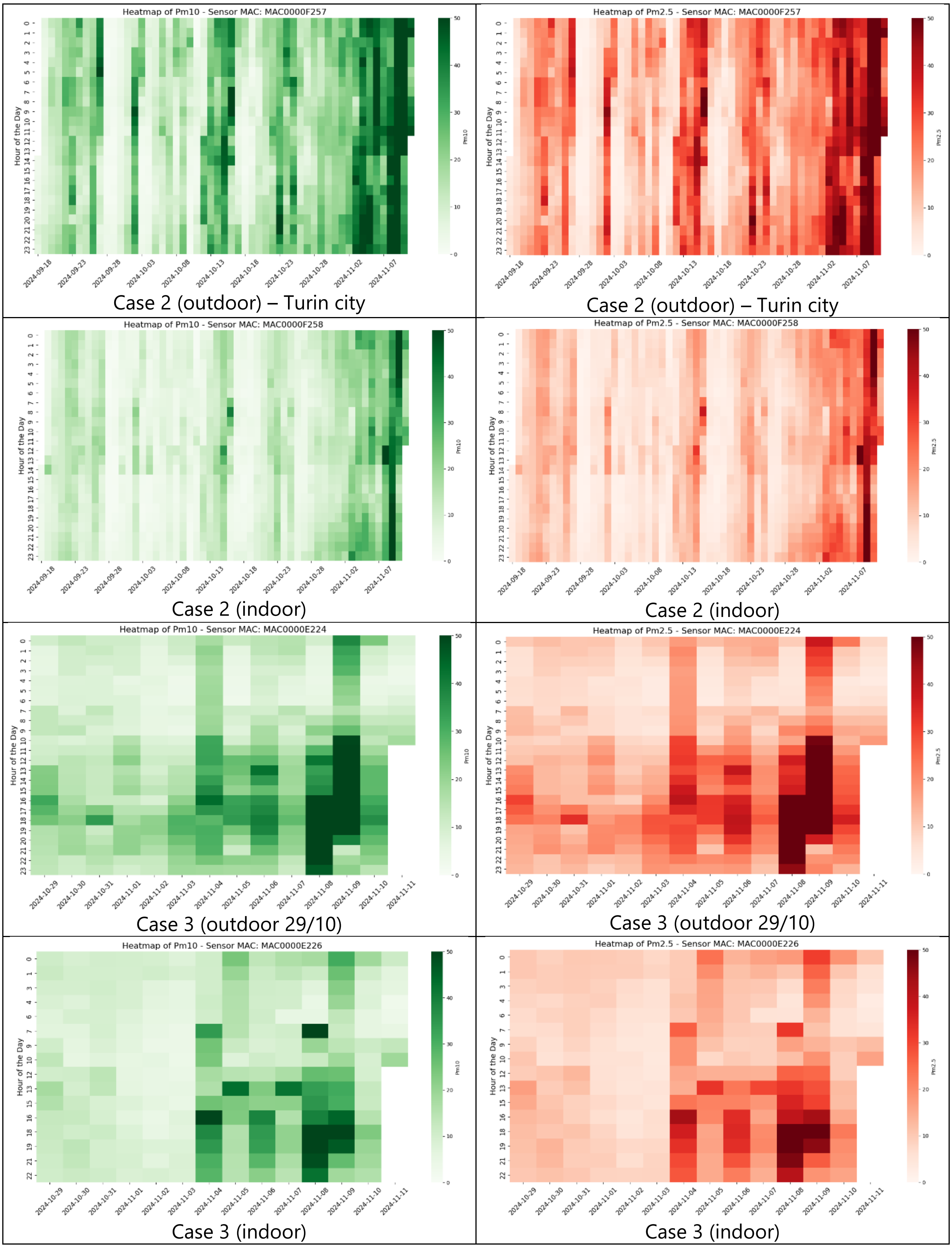


Figure 36 - Carpet plots representing the PM10 and PM2.5 concentrations. Outdoor conditions precede the relative indoor measurements.

Furthermore, Figure 37 plots the measured PM10 and PM2.5 values compared to CO_2 concentrations in the same enclosed space to discuss these indices' ability to describe air confinement. It can be mentioned that particulate matter behaviours are not aligned with the CO_2 ones, suggesting that these pollutants are independent of school occupation and that CO_2 looks to be more representative in supporting IAQ level control during occupation. During the occupation, PM growing trends are not correlated to the rise of the CO_2 concentration, which is a direct index of the indoor air confinement directly produced by the occupants, confirming this detachment. Nevertheless, it can be underlined how particulates grow after the school period in indoor spaces, suggesting that it is impacted by outdoor trends, e.g. traffic due to student family movements.

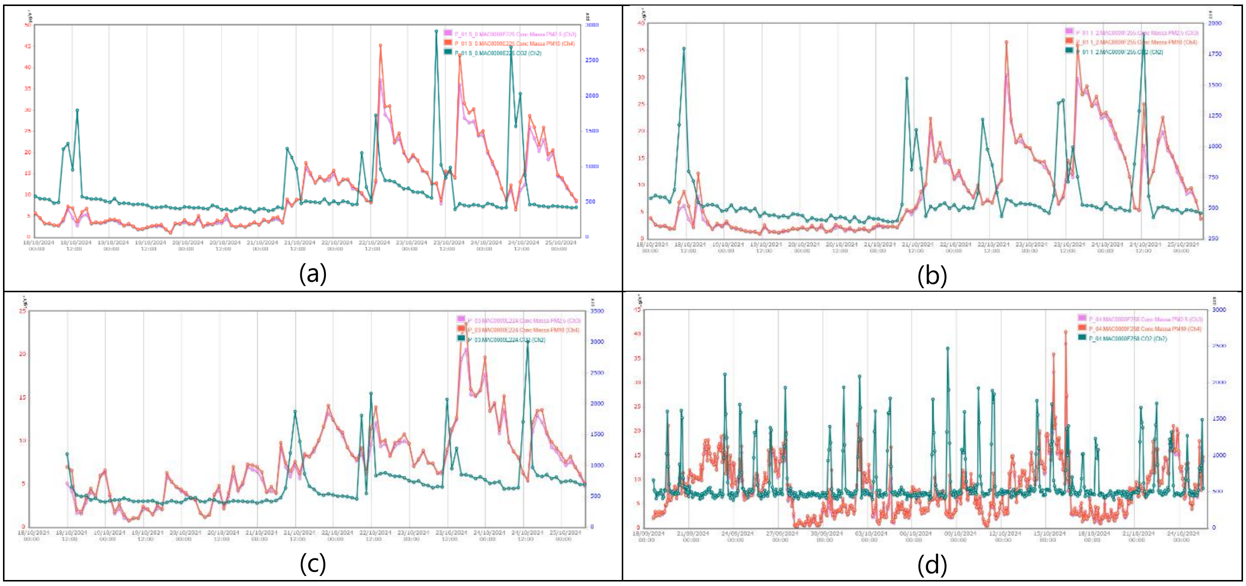


Figure 37 - PM10 and PM2.5 indoor concentrations VS CO_2 values in selected classrooms.

U-value

Finally, the thermal transmission cloud-connected set of sensors is analysed. In this case, measurements are conducted in a protected site, requiring the possibility of having access to both a free and homogeneous indoor and corresponding outdoor wall section. Figure 38 shows probe installation positions (indoor – an office room – and outdoor – a semi-confined space not heated). The U-value calculation result elaborated via the Capetti TMA (Transmittance Monitor and Analysis) software is shown in Figure 39. The measured wall, a not-insulated single-layer concrete block wall of medium to heavy weight (built-in 1996), is calculated to have a thermal transmittance of 2.086 W/(m^{2}K). This result is aligned with building physical expectations for the given material.

Figure 38 - the installed set of sensors to compute wall U-values

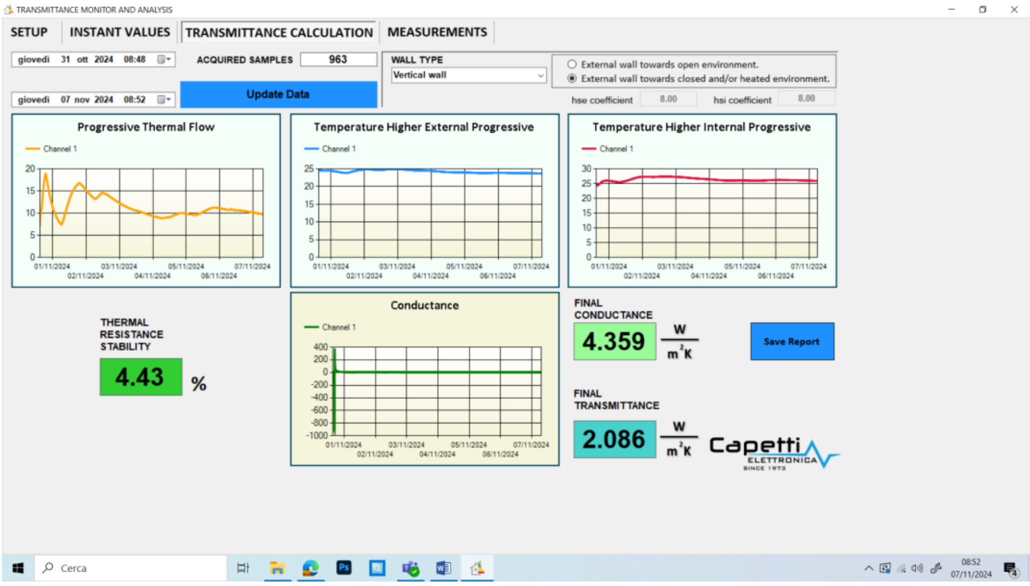


Figure 39 - results of U-value calculations performed via Capetti's TMA cloud-connected tool

4.5 Survey user feedback

The results of the smart building questionnaire submitted to students are summarised in this section. After filtering, the received voluntary questionnaires are 421, defining a representative amount of data to be elaborated. Considering the first question, only 30% of the students had a previous idea of a "smart/intelligent building". Hence, 70% of them have heard about smart buildings thanks to the citizen science initiative of PRELUDE. Similarly, 76% have never lived in a smart building, and 65% have never visited one of them. Among positive answers, 55% have visited or lived in a smart residential building, while 46% consider the school smart.

Looking at the importance of knowing the real-time building conditions, only 3% of the students consider this point totally or generally not important. In comparison, 44% think it is medium important, and 53% consider this point essential or very important. Considering question 6, 9% do not consider it necessary to use innovative technologies in their school. In comparison, 34% feel this point is of medium importance, and 57% think it is essential or very important – see Figure 40.

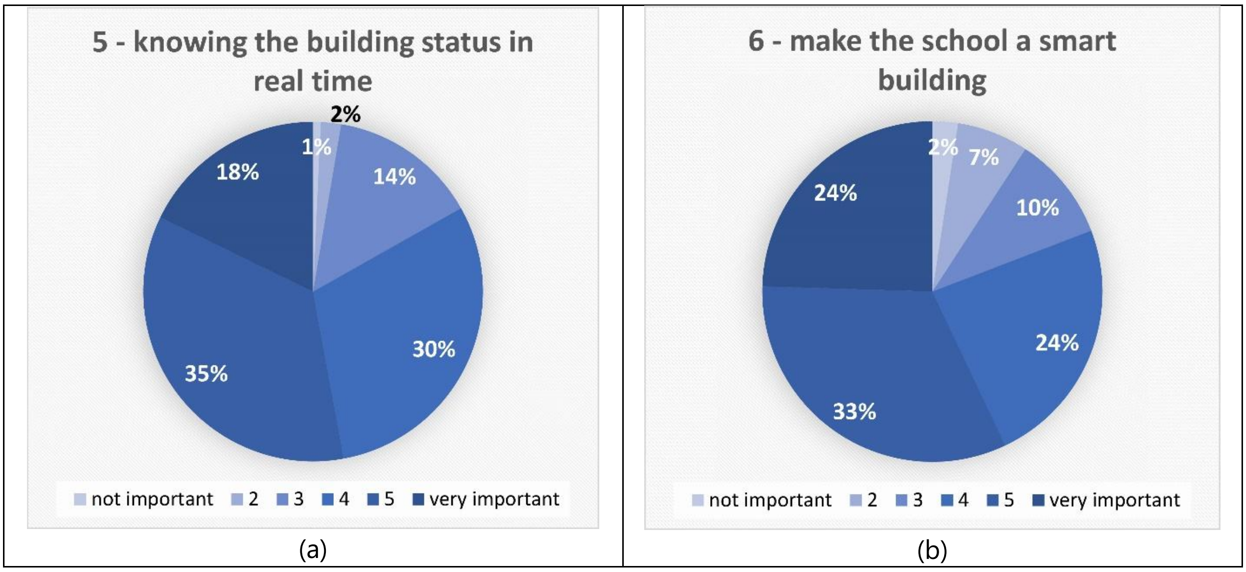


Figure 40 - (a) answers to Question 5; (b) answers to Question 6

Focusing on the aspects more essential to be measured and visualised (Question 7), 78% of the answering students identified energy consumption, followed by IAQ levels (46%) and air temperatures (39%). At the same time, 22% are interested in illuminance levels and 12% in the relative humidity of the air (more than one answer is allowed). Only 38% of the students had heard about thermal comfort issues (Question 8), mainly at home (50% of them), via the media (25%) or at school (24%). This underlines the positive impact of the various citizen science lectures in disseminating general information about building IEQ and IAQ topics, including measuring and actuating solutions. Differently, IAQ is generally known by 80% of the students (Question 9), thanks to school (62% of the students), home (30%), and media (14%) (more than one answer is allowed). Hence, it underlines how students have heard more about IAQ than the whole IEQ domain. This high number of students knowing IAQ issues is very welcome, supporting a positive integration of smart solutions in a context in which the general purpose of citizen science is already shared.

Focusing on the IAQ levels in the classes, 31% of the students are happy about their starting conditions, 52% are neutral, and 17% are unhappy or unsatisfied (Question 10). Indeed, the people involved in citizen science show a general interest in improving the IAQ of their spaces.

Finally, considering Question 11, 78% of the students are very interested in managing the window openings based on the real-time monitored indoor air quality level. In comparison, another 19% are generally interested, and only 3% do not seem interested. Hence, citizen science focuses on a challenge recognised by the audience – see Figure 41Figure 41.

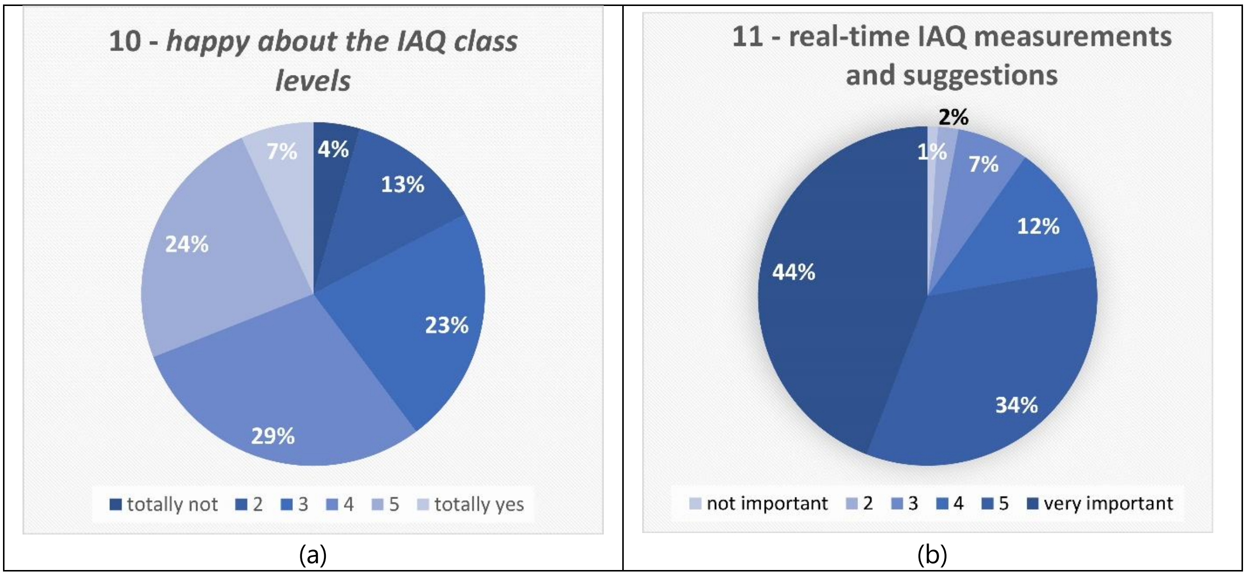


Figure 41 - (a) answers to Question 10, and (b) answers to Question 11

5. Final Educational Activity Event

A final educational activity event is organised, including the following two activities:

- A final lecture/conference, continuing the educational event series, opening the public exhibition (see the following point) and resuming and debating the citizen science action (20th November 2024), hosted in the Salone d'Onore, Valentino Castle, Turin, Italy (see section 5.1);
- A public exhibition (20-22 November 2024) hosted in the Sala delle Colonne, Valentino Castle, Turin, Italy (see section 5.2);

A network business aperitif follows the latter activity.

5.1 PRELUDE final educational lecture/conference

The final lecture/conference is subdivided into two main parts: one in English debating the T9.5 educational activities touching all the three actions and introducing the PRELUDE project, and a second part, in Italian, discussing the citizen science with the Piedmont Region, relevant stakeholders, and participants.

The programme is:

Part A- *Institutional welcome and PRELUDE project outcomes (ENG) – final educational event*

14:30 – Welcome, institutional greetings and event introduction (expected participants: Prof. M.Bonino, Head of the Department of Architecture and Design, POLITO; Prof. T.Bianchi, responsible for the M.Eng. in ICT for Smart Society, POLITO DET; Piedmont Region)
14:40 – Michal Pomianowski, PRELUDE project coordinator, Aalborg University, Denmark | Introduction to the PRELUDE projects and primary outcomes
15:00 – Giacomo Chiesa, PoliTO, Italy | PRELUDE project educational activities and citizen science – final exhibition
15:20 – Q&A

Part B- *Attività educative e citizen science per le sfide energetico-ambientali (Educational and citizen science activities on energy and environmental challenges – final educational workshop) (ITA)*

15:30 – Tavola rotonda, coordina Giovanni Borgarello, Regione Piemonte / Workshop, coordinated by G.Borgarello, Piedmont Region
15:30 – Giovanni Borgarello (Regione Piemonte), introduzione/introduction
15:40 – Giacomo Chiesa (Polito), PRELUDE citizen science: organizzazione, attività, risultati / organisation, activities, results
15:55 – PRELUDE citizen science: voci dalle scuole partecipanti / participant school voices | intervengono/participate: ITIS Pininfarina (Antonio Spano e Anna Braccia), IC Luserna (Francesco Calliero), Liceo Valdese (Nicola Massucco), and others
16:10 – ITIS Avogadro (Alfonso Carlone), L'esperienza delle Scuole EcoAttive / the EcoActive school experience
16:25 – Erasmo da Rotterdam (Rossella Seren Rosso), L'esperienza del Protocollo Abitare Sostenibile / the Sustainable living protocol experience
16:40 – Q&A
16:50 – Conclusioni / Conclusions
17:00 – Networking catering event & opening of the PRELUDE final education exhibition

The event flyer is shown in Figure 42.

Figure 42 - Flyer of the final educational workshop/conference (8th Educational event)

5.2 PRELUDE project educational exhibition

Figure 43 - Flyer of the final educational exhibition

The exhibition hosted the second student educational group project poster exhibition – see Section 3 – including the ten project posters and some of the developed prototypes, a recap of the 7th lectures/conferences of the educational event series, and a series of posters resuming the citizen science action and the results. The supplementary posters, in addition to the ones reported in Section 3, are shown here below. The previous Figure 43 shows the exhibition flyer, while Figure 44 is the exhibition opening poster to which the PRELUDE media released poster is added – see the project site[12].

Figure 44 – The introductive poster

[12] https://prelude-project.eu/media-corner/resource/

5.2.I Citizen Science posters

The Citizen science posters report the results of the citizen science action, including a general introduction, main results and a recap of the conclusions.

PRELUDE T9.5 | *educational activities & citizen-scientist*

Politecnico di Torino

Introduction of

Citizen-Science Actions

Objectives

The citizen science aiming at involving students of middle and high schools and their teachers in studying and improving the Indoor Environmental Quality (IEQ) with particular regard to the Indoor Air Quality (IAQ) of selected school environments. It has disseminated PRELUDE and smart building correlated topics to a large audience, thanks to installing sensor networks, activating LED alerting for CO2 thresholds, and focused lectures/discussions with students or teachers to support the self-actuation exercise.

More focused actions have been defined for middle schools, such as directly giving lectures to students. In contrast, in high schools, with the exclusion of one case, the communication level stays at the teaching level, involving school professors in activating their students when the IAQ level overpasses the given threshold, suggesting starting space ventilation.

Methodology

Citizen science actions are based on the use of measurement solutions that can monitor typical building variables to detect indoor air and environmental quality and retrieve potentially typical key performance indicators aligned with the PRELUDE project ones. A series of monitoring systems have hence been acquired and installed in the participating schools, reproducing real solutions in line with the ones adopted during the project.

To cover all needed requirements and to ensure an approach acceptable to all schools, the installed sensors have been selected among commercial solutions. Sensors are described in the following sub-sections, while the expected data elaborations are mentioned afterwards.

Monitoring systems need to be easily installed, considering a flexible network configuration that allows the addition and the reduction in the number of sensors in each building to follow citizen science requirements and to support a fast installation process. Sensors are required to measure IEQ, especially IAQ Key Performance Indicators (KPIs), which help user engagement when a specific threshold is overpassed.

Considering these requirements, the Capetti Winecap system was selected, which is in line with the measuring solutions adopted in some of the Italian PRELUDE demos. In each school, they have been installed a SIM gateway and a series of probes able to cover at a minimum 3 classrooms or other didactical spaces with sensors including LED alerting. Additional sensors (e.g. TVOC, particulate matter) were defined with each school aligning with specific activities and local interests.

Sensors are used to detect indoor environmental variables related to IAQs. In particular, the users will be activated based on IAQ levels, assuming CO2 as the reference gas – e.g. [1–4], requiring lighting alerting when certain thresholds are overpassed. In addition, air temperature and relative humidity are also detected for potentially covering a large IEQ spectrum of KPI, which is also correlated to thermal comfort conditions. In specific cases, e.g. chemistry labs in a high school or sample classrooms in middle ones, TVOC probes are included to potentially underline the difference among the use of CO2 or other pollutant sensors, showing the differences in graphical restitutions. Furthermore, 7 PM10-PM2.5 sensors have also been installed, focusing on indoor and outdoor conditions to detect potential peaks. Adopting multi-IAQ variables allows us to check several indices in school environments, considering the large number of variables suggested in these cases. However, CO2 has been chosen as the tracking IAQ gas to support citizen science alerting.

Involved schools

Six schools have participated in the project, answering the open call shared by the Piedmont Educational Division via the Eco-active school group. Among them, three are high schools ("Scuola secondaria di secondo grado", in Italy) and three middle schools ("Scuola secondaria di primo grado", in Italy). Additionally, three are positioned outside Turin, while the other three are in the Turin extended city area.

IC "Luserna S. Giovanni" (Middle school), Luserna S.Giovanni, Italy [3 classes 2023-24, 3 thematic classes 2024-25];

IC "Foscolo" (Middle school), Turin, Italy [5 classes 2024-25 (4 classes mute sensoring in 2023-24)]

IC "Gianni Rodari" (Middle school), Torre Pellice, Italy – note: former demo B2.1 of the E-DYCE EU H2020 co-funded project [9 classes 2023-24, 2 new classes + 6 classes (continuation) 2024-25]

ITIS Pininfarina (High School), Moncalieri (Turin extended city area), Italy [6 laboratories with multi-sensors, 1 classroom 2024-25]

Liceo Valdese (High School), Torre Pellice, Italy – note: former demo B2.2 of the E-DYCE EU H2020 co-funded project [8 thematic classes and 1 office both 2023-24 and 2024-25]

IIS Ettore Majorana (High School), Turin, Italy [4 thematic classes 2024-25]

Citizen-Science Pipeline

A methodological citizen-science pipeline is defined by identifying five operative steps. In **step 1**, sensors are installed in the selected rooms, including a discussion with representative teachers. Secondly, in **step 2a**, sensors are left monitoring the actual conditions without any alerting activations to define a benchmark. Retrieved 2-3 weeks of data, **step 2b**, a lecture is given to involved students (middle schools) discussing building IEQ and IAQ topics, the PRELUDE project, and the citizen science action; a survey on smart building topics is also distributed. During this moment, LED alerting is started, defining the set thresholds with students. The lecture in Step 2b can be substituted (high schools) with specific communication with the teaching staff. The following **step, 3** (3-8 weeks), is the self-actuation period during which students will look at sensors to activate manual window operation when the IAQ overpasses the threshold of acceptability. After 3-4 weeks, a slight reset of the thresholds may be defined together with teachers, especially in one of the schools where personalised ambitious thresholds were defined during the first year of activity, requiring too many actions. In **step 4**, data are partially elaborated to communicate to teachers the advancement of the action, and optional restitution is given to the involved classes. Finally, in **step 5 (optional)**, the activity will continue maintaining the sensor system active for more extended periods (end of the school year), allowing for verification of the long-term impact of self-actuation actions.

Step 1; Sensor Installation

POLITO has installed sensors in all schools. In order to reduce potential damages, sensors have been positioned in several cases at about 2 m from the ground instead of the suggested 1.5 m height. Nevertheless, they guarantee a sufficient distance from room ceilings. Additionally, they are placed on the wall opposite the window side, or laterally in limited cases, to avoid direct exposure to the direct solar radiation.

Step 2; Introductory Lecture

An introductory lecture has been prepared for the involved Middle Schools and further customised for the different schools to align with specific local requirements. The lecture was performed in all middle schools and a scientific high school, excluding the other two high schools, which directly participated in the self-actuation exercise for a total of 26 frontal didactical hours, reaching 33 classes. The lecture's main treated topics are:

Climate changes and energy efficiency (reminder/introduction) – e.g. the ecological footprint, some contents from T8.5;

Step 3; Self-actuation Exercise

In all involved schools, CO2-installed sensors host a luminous blinking alerting LED allowing them to be remotely controlled by setting specific activation thresholds. When the CO2 concentration overpasses the given threshold, the light alerts occupants that the IAQ level is not optimal, suggesting that they manually self-actuate windows or ventilation systems to exchange the indoor foul air.

Step 4; Restitution of Results

Results have been communicated to participating middle schools and students via a devoted second lecturing moment or sharing a presentation file with relevant teachers to be disseminated to students. In all cases, all students using the monitored rooms were directly engaged with their teachers in the self-actuation activity.

The PRELUDE project - Prescient building Operation utilising Real-Time data for Energy Dynamic Optimization – aims to support advanced innovative, smart, low-cost solutions supporting intelligent buildings and proactive optimisation services. Among the others, the project pursues the minimisation of energy uses, the maximisation of self-consumption and renewable sources balance, and the improvement of comfort conditions supporting the maximisation of free-running building potentials. PRELUDE includes an extensive multi-year educational and citizen-scientist action - T9.5 - involving students at different school levels in developing and/or testing simple simulation and monitoring platforms and facilities, including developing apps, web services and IoT sensoring solutions, following and disseminating different PRELUDE topics during educational activities. The work involves the Regional educational division (Piedmont Region), part of the project advisory board. Additionally, activities of the PRELUDE T9.5 includes an educational event series based on the organisation of lectures/conferences on smart building issues, climate-free-running building design, and operational solutions.

Keywords: *PRELUDE, smart building, intelligent monitoring, IoT, DIY, digital twin, dynamic building simulation, climate design, building optimisation.*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement N° 958345

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prelude-project.eu @PreludeEu prelude-project

Figure 45 - Citizen Science Introduction

PRELUDE T9.5 | *educational activities & citizen-scientist*

Politecnico di Torino

Results of

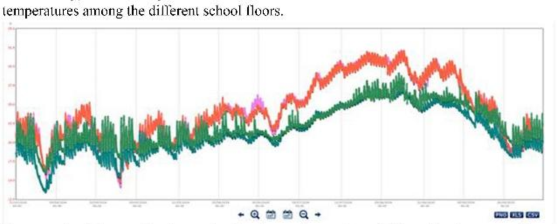
Citizen-Science Actions

IEQ; Air temperature, U-value, and Thermal comfort

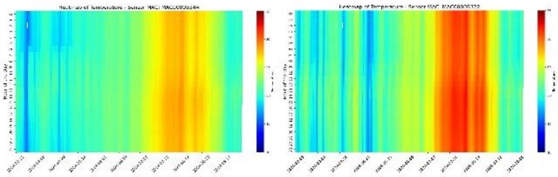
Results

Air temperature

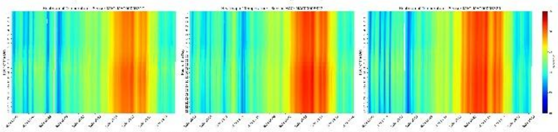
Air temperatures are measured and are used for a preliminary check on the thermal comfort behaviours. Considering the educational purpose of the study, carpet plots were elaborated, allowing for discussion of the temperature differences measured among the different building constructive typologies of the involved schools, i.e. the summer free-running and un-occupied behaviours of a recent building (built around the '70s) and a historic building (built during the XIX century). Additionally, measurements also allow to discuss the thermal stratification of temperatures among the different school floors.



Representation of the same behaviours using a line chart to increase the readability of the phenomenon. Orange and pink lines represent sensors positioned in a '70s building block, while lines green and blue-green are of an XIX-century building. Continuous differences higher than 5-6°C can be underlined for a long summer period.



Temperature carpet plots in rooms positioned on the left; a building of the '70s (6 cm of insulation, medium weight walls) and on the right; a building of the XIX century (no insulation, high thermal mass). The differences in summer temperature behaviours allow to discuss the impact of thermal masses.



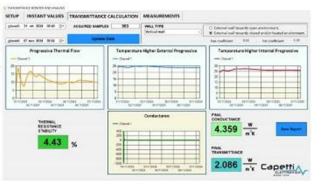
Temperature carpet plots showing the differences among different floors (sensors are positioned respectively on a ground floor, first, and second-floor room from left to right). This analysis helps students discuss the thermal gradient concept, solar access, and obstacle-brought shadings.

U-Value

Then, the thermal transmission cloud-connected set of sensors is analysed. In this case, measurements are conducted in a protected site, requiring the possibility of having access to both a free and homogeneous indoor and corresponding outdoor wall section. The figures on the right show probe installation positions (indoor – an office room – and outdoor – a semi-confined space not heated). The U-value calculation result elaborated via the Capetti TMA (Transmittance Monitor and Analysis) software is shown in figure on the left. The measured wall, a not-insulated single-layer concrete block wall of medium to heavy weight (built in 1996), is calculated to have a thermal transmittance of 2.086 W/(m2K). This result is aligned with building physical expectations for the given material.

results of U-value calculations performed via Capetti's TMA cloud-connected tool (right)

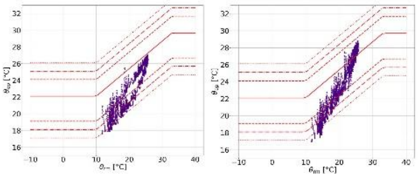
Capetti's U-value sensor isntallation (top left and bottom left)



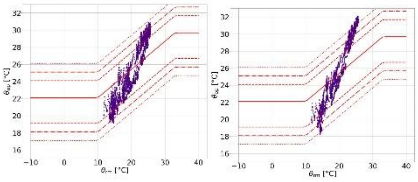
Thermal Comfort

For ten sensors by five buildings, the data measured during the 2024 neutral and summer seasons (01/05/2024 – 30/09/2024) are elaborated via PREDYCE to produce the EN 16798-1 correlated adaptive thermal comfort charts. External temperatures are retrieved by locally installed meteorological stations, including the PRELUDE Turin demo one. The following figures compare the results of the five schools with summer 2024 temperature-monitored data. Also in this case, it is possible to underline the effect of different technical characteristics of the envelope being the high mass uninsulated building of case (a) characterised by low summer temperatures due to the high inertia, while cases (b, c, d) have sensibly higher temperatures. Case (b) has a cavity wall with a 6-cm insulation layer and two bricks, slightly better than the others, double windows, and all classrooms are south-facing. Finally, case (e) has reduced solar gains due to the recent retrofitted windows and to different exposures not directly facing south.

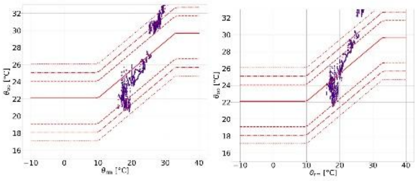
(a) XIX century building Piedmont Site left (ground floor) right (first floor)



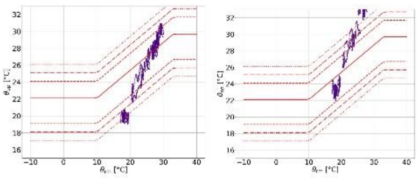
(b) '70s building, Piedmont Site left (ground floor) right (second floor)



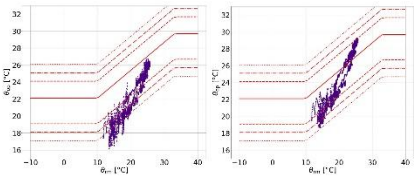
(c) '50s building Turin Site left (central floor) right (last floor)



(d) second half of the XX century building Turin Site left (ground floor) right (second floor)



(e) partially retrofitted building Piedmont Site left (ground floor) right (first floor)



**Running mean temperatures are based on local weather stations.*

The PRELUDE project - Prescient building Operation utilising Real-Time data for Energy Dynamic Optimization – aims to support advanced innovative, smart, low-cost solutions supporting intelligent buildings and proactive optimisation services. Among the others, the project pursues the minimisation of energy uses, the maximisation of self-consumption and renewable sources balance, and the improvement of comfort conditions supporting the maximisation of free-running building potentials. PRELUDE includes an extensive multi-year educational and citizen-scientist action - T9.5 - involving students at different school levels in developing and/or testing simple simulation and monitoring platforms and facilities, including developing apps, web services and IoT sensoring solutions, following and disseminating different PRELUDE topics during educational activities. The work involves the Regional educational division (Piedmont Region), part of the project advisory board. Additionally, activities of the PRELUDE T9.5 includes an educational event series based on the organisation of lectures/conferences on smart building issues, climate-free-running building design, and operational solutions.

Keywords: *PRELUDE, smart building, intelligent monitoring, IoT, DIY, digital twin, dynamic building simulation, climate design, building optimisation.*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement N° 958345

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Figure 46 - Citizen science results: thermal comfort

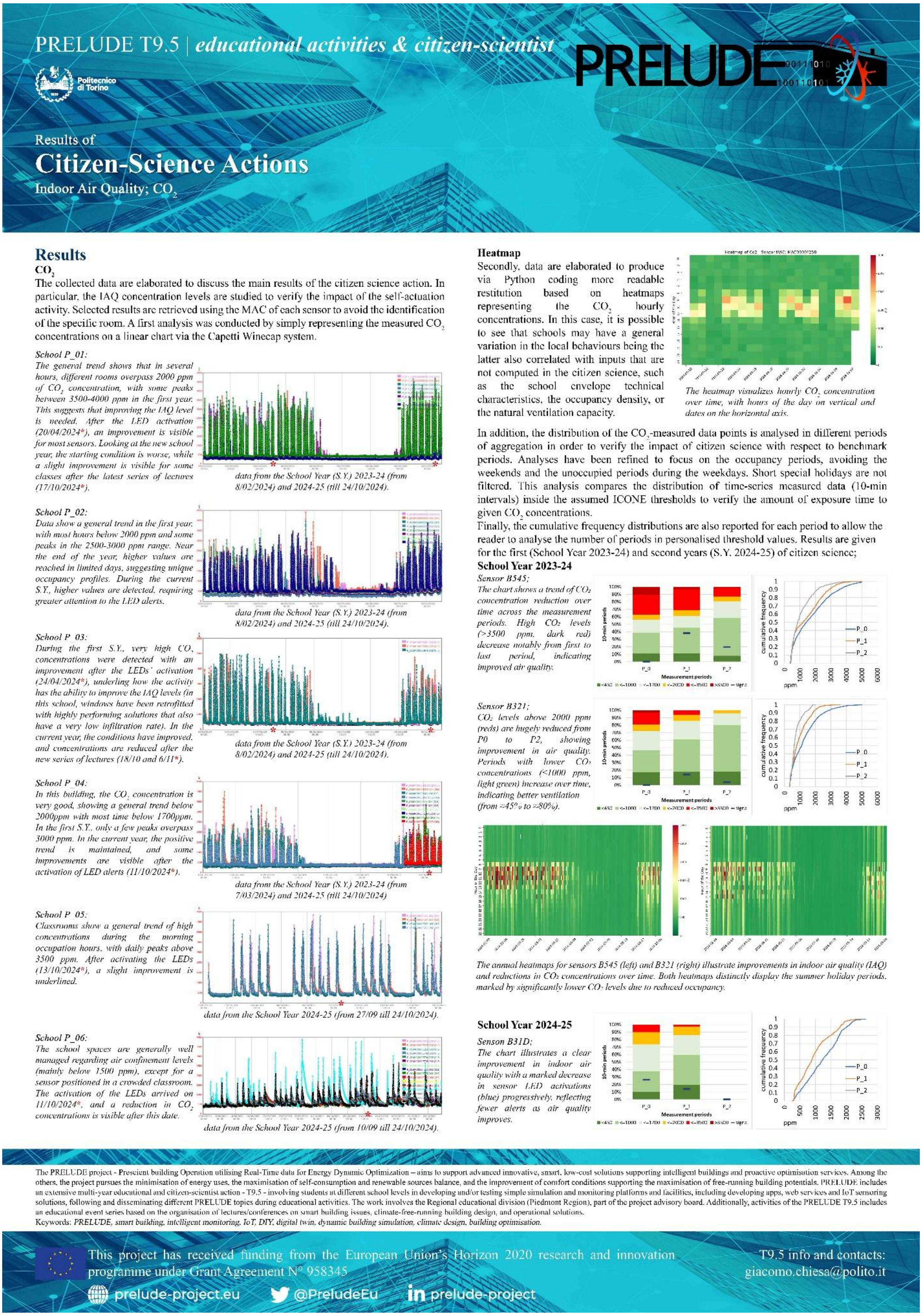


Figure 47 - Citizen science results: IAQ, CO2 analyses

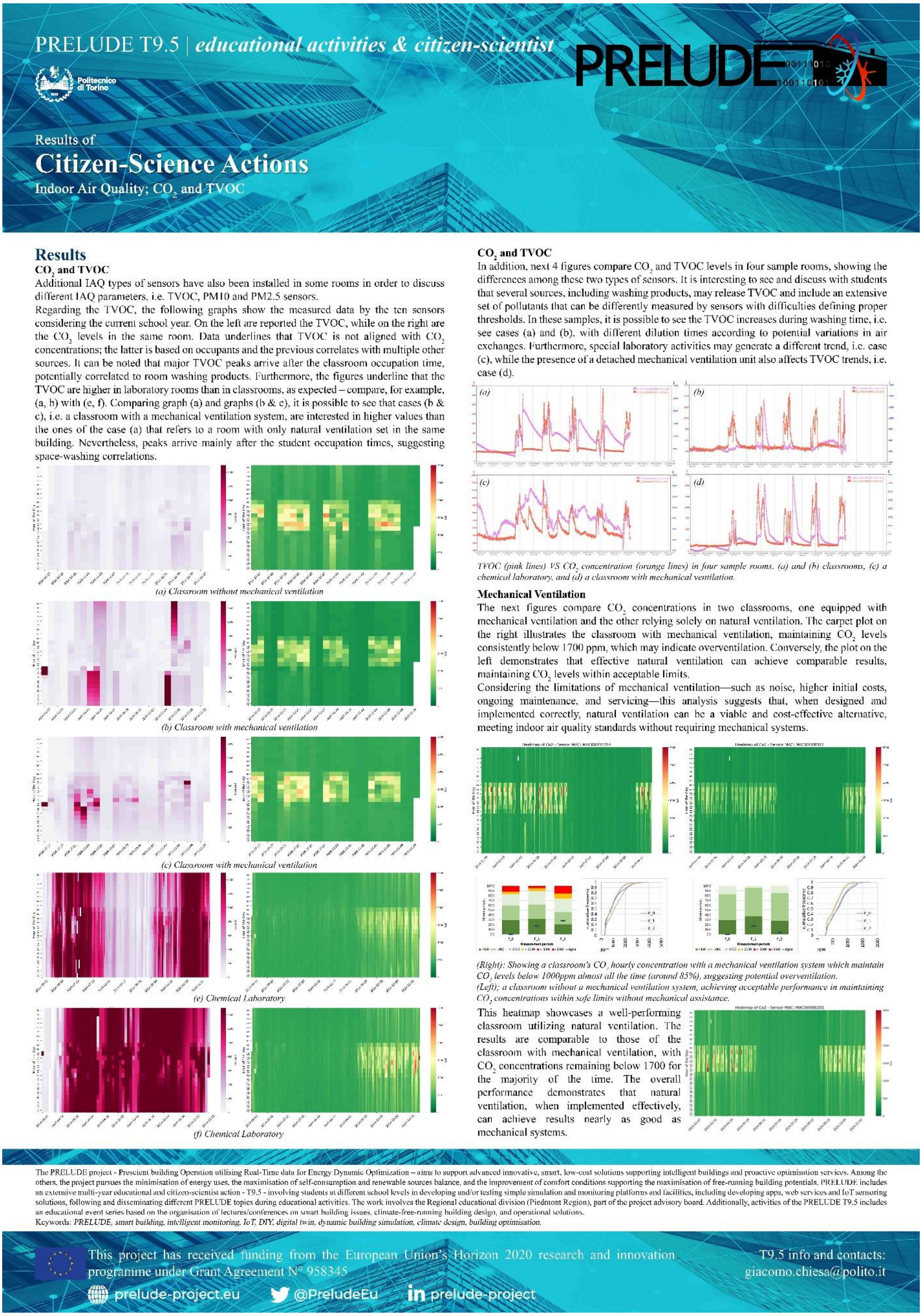


Figure 48 - Citizen science results: IAQ, TVOC and CO2 analyses

PRELUDE T9.5 | *educational activities & citizen-scientist*

Politecnico di Torino

Results of

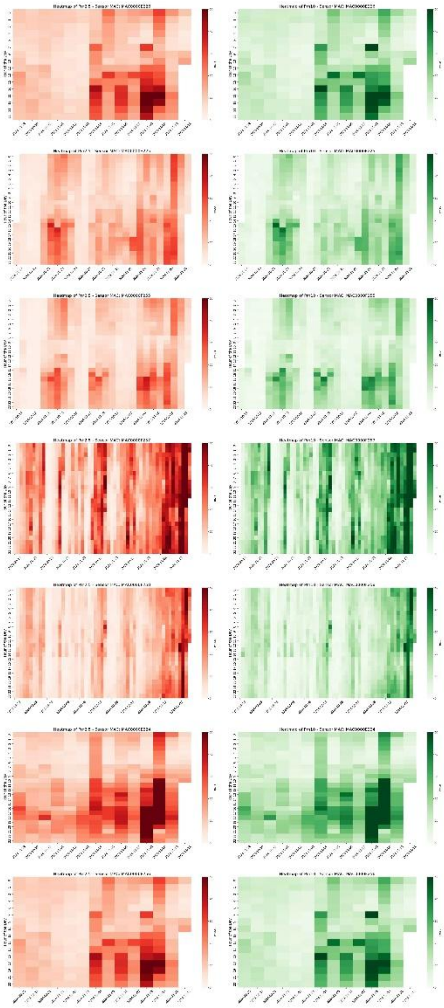
Citizen-Science Actions

Indoor Air Quality; CO_2, PM_{10}, and $PM_{2.5}$

Results

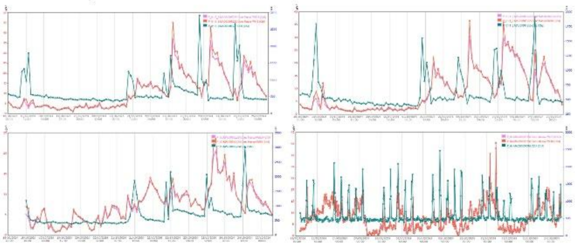
PM_{10} and $PM_{2.5}$

Considering particulate matter, PM10 and PM2.5 concentrations are measured in three schools, positioning a reference probe outside, on a rain-protected site, and the other(s) in a reference classroom(s). It can be underlined that indoor concentrations are lower in confined spaces compared to the outdoor environment because PM10 and PM2.5 productions do not arrive in school spaces. A high difference is measured between the PMx concentrations in the two locations outside the Turin metropolitan area (piedmont locations) and the concentrations in the Turin city site. In the latter, particulate matter concentrations are drastically higher, both inside and outside, as expected.



CO_2 and PM_X

Following figures plot the measured PM10 and PM2.5 values compared to CO2 concentrations in the same enclosed space to discuss these indices' ability to describe air confinement. It can be mentioned that particulate matter behaviours are not aligned with the CO_2 ones, suggesting that these pollutants are independent of school occupation and that CO_2 looks to be more representative in supporting IAQ level control during occupation. During the occupation, PM growing trends are not correlated to the rise of the CO_2 concentration, which is a direct index of the indoor air confinement directly produced by the occupants, confirming this detachment. Nevertheless, it can be underlined how particulates grow after the school period in indoor spaces, suggesting that it is impacted by outdoor trends, e.g. traffic due to student family movements.



PM10 (Orange line) and PM2.5 (Pink line) indoor concentrations VS CO_2 (Green line) values in selected classrooms.

Conclusion

Many schools agreed to participate while demonstrating a high level of involvement by teachers and students during the activities. Results are very interesting, allowing on the one side to produce didactical outcomes that can return information related to building IEQ and IAQ indicators and the intelligent building dimension to students at different school levels. Additionally, the IAQ level improved in most measured spaces, showing that the involved people followed the manual self-actuation actions suggested by the LED alerts. The study also had the opportunity to reach more than 2000 students indirectly and more than 1400 students directly involved in the self-actuation, half of which also followed devoted lectures, introducing them to topics like building energy needs, climate change, smart buildings, thermal and indoor air quality comforts, and supporting the dissemination of a general background and knowledge (civic education) about IEQ and the need to reduce energy consumptions and correlated GHG emissions. Almost none of the involved students had previous knowledge of these topics. On the contrary, in the end, nearly all of them demonstrated great attention and the acquisition of general information about building-correlated topics during the restitution phase. The study also identifies potential criticalities and positive behaviours of general school buildings in the territory, suggesting future research lines and the importance of disseminating IEQ and IAQ smart monitoring solutions to improve comfort conditions.

Among the potential lessons learnt (citizen science), we can mention:

- IAQ levels can be improved via self-actuation actions involving young generations, allowing in schools where the level of attention is maintained high, e.g., thanks to specific teachers' involvement, to minimise or avoid high CO_2 concentrations, drastically limiting peak values and minimising continuous exposures to high concentrations.
- The possibility of controlling IAQ levels via manual window openings is confirmed, allowing the increase and control of IEQ quality in classrooms even when mechanical ventilation is not present, such as in typical Italian and Mediterranean buildings, and its installation is not feasible.
- CO_2 is a significative gas tracker compared to other air pollutants, being on the one side directly correlated with the occupancy, e.g. TVOCs are mainly associated with other activities, not allowing, for example, to ventilate during the occupation. Using CO_2 allows to manage the air age when people are exposed to potential pollutants. Additionally, this choice aligns with most available sensors, supporting the expansion of intelligent monitoring and alerting systems in public buildings.
- Disseminating smart building, IAQ, low-energy building, and IEQ topics and correlated challenges is fundamental, as underlined by the student survey topics that are not generally known, suggesting the importance of preparing new generations for digital technologies in the building domain and understanding the energy and the IEQ domains.

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Figure 49 - Citizen science results: PMx and conclusions

6. CONCLUSIONS

The educational activities of the PRELUDE project (T9.5) have reached for all three main actions representative results. Regarding the educational event series, all the lectures/conferences were followed by a large number of people who demonstrated a high level of interest, allowing the dissemination of PRELUDE topics and results to a technical audience mainly composed of university students, supporting the discussion and the education of the next generation of engineers and professionals working in the transdisciplinary building domains.

Lectures treated innovative aspects correlated to different topics, including smart buildings – e.g. adoption of machine learning techniques, advanced building monitoring and actuation systems including challenges and barriers, and building management platforms –and low-energy, climate and free-running building management. The high number of speeches, 25 plus introductions, and the number of involved lecturers from different countries, universities, research institutions, and companies also represent the dissemination potentialities.

Considering the educational projects, all the developed projects, both the group works and the thesis ones, have reached innovative results, supporting the potential development of future publications after the project conclusion. At the same time, one of the projects has been published in an international paper in the open-access journal Sustainability, reaching (30/10/2024) 9 Scopus quotations and more than 3460 visualisations. A very high impact for an educational project! The latter demonstrates how all the developed works focused on innovation and beyond the state-of-the-art topics, answering current challenges in PRELUDE correlated arguments. Students were delighted, and they received a high appreciation when disseminating the results.

The citizen science action also reached relevant results. On the one hand, many schools agreed to participate while demonstrating a high level of involvement by teachers and students during the activities. Results are very interesting, allowing on the one side to produce didactical outcomes that can return information related to building IEQ and IAQ indicators and the intelligent building dimension to students at different school levels. Additionally, the IAQ level improved in most measured spaces, showing that the involved people followed the manual self-actuation actions suggested by the LED alerts. The study also had the opportunity to reach more than 2000 students indirectly and more than 1400 students directly involved in the self-actuation, half of which also followed devoted lectures, introducing them to topics like building energy needs, climate change, smart buildings, thermal and indoor air quality comforts, and supporting the dissemination of a general background and knowledge (civic education) about IEQ and the need to reduce energy consumptions and correlated GHG emissions. Almost none of the involved students had previous knowledge of these topics. On the contrary, in the end, nearly all of them demonstrated great attention and the acquisition of general information about building-correlated topics during the restitution phase. The study also identifies potential criticalities and positive behaviours of general school buildings in the territory, suggesting future research lines and the importance of disseminating IEQ and IAQ smart monitoring solutions to improve comfort conditions.

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Furthermore, potential criticalities to be faced in future experiences are:

- The need to attentively plan all school involvement, considering longer required time than the ones previously planned;
- The potential interest in considering activating the entire school teaching staff or the definition of alternative solutions, i.e. monthly recaps, to support students in maintaining a high level of interest and attention to the alerts in the long-time spam;
- Potentially consider the use of local monitors or GUIs to give back results to students in an automatic way, supporting gamification and increasing their attention while giving teachers the possibility to analyse the class performances in aggregated periods;
- Eventually, consider using additional alerting systems, e.g. a larger LED or an acoustic signal, when a very high ICONE IAQ level is overpassed, e.g. 3500 ppm of CO_2.

In conclusion, the educational activities demonstrated the importance of disseminating PRELUDE-correlated topics to a large audience, the interest of younger generations in the treated points and the possibility of involving students in significant testing actions. Considering the citizen science, this approach was instrumental in retrieving not only specific improvements in local comfort conditions but also in testing general PRELUDE outcomes (e.g. the importance of monitoring, the potential use of informed self-actuation actions in low smartness building to support improvements), discussing large replicabilities and identifying potential challenges or further development branches.

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