Prescient building Operation utilizing Real Time data for Energy Dynamic Optimization

WP7 – Demonstrations in operational environment

D7.5 – Demo site report #4 Athens

v1.0

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PRELUDE CONSORTIUM PARTNERS

	Participant organisation name	Country
1	AALBORG UNIVERSITET	DK
2	TAMPEREEN KORKEAKOULUSAATIO SR	FI
3	ASOCIACIÓN DE INVESTIGACIÓN METALÚRGICA DEL NOROESTE	ES
4	POLITECNICO DI TORINO	IT
5	FORSCHUNG BURGENLAND GMBH	AT
6	UNISMART - FONDAZIONE UNIVERSITÀ DEGLI STUDI DI PADOVA	IT
7	BRUNEL UNIVERSITY LONDON	UK
8	EMTECH DIASTIMIKI MONOPROSOPI IDIOTIKI ETAIREIA	EL
9	CORE INNOVATION AND TECHNOLOGY OE	EL
10	ESTIA SA	CH
11	EUROCORE CONSULTING	BE
12	IREN SMART SOLUTIONS SPA	IT
13	LIBRA AI TECHNOLOGIES PRIVATE IDIOTIKI KEFALAIOUCHIKI ETAIREIA	EL
14	STAM SRL	IT
15	LA SIA SRL	IT
16	TREE TECHNOLOGY SA	ES
17	1A INGENIEROS S.L.P	ES

18	DIMOS ATHINAION EPICHEIRISI MICHANOGRAFISIS	EL
19	BLOK ARCHITEKCI SPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA	PL
20	CAISSE DE PREVOYANCE DE L'ETAT DE GENEVE	CH
21	INNOVACION Y CONSULTING TECNOLOGICOSL	ES
22	CORE INNOVATION CENTER NPO	GR

EXECUTIVE SUMMARY

Deliverable 7.5 is part of the WP7 activities related to the pilot implementation in the diverse sites of PRELUDE. It is a public report aiming to report the activities and tasks undertaken for the Athens pilot, as well as its current state and ongoing actions of Task 7.5 Demonstrations: Athens – DAEM (M04-30).

The report includes the preparation, implementation and overall execution of the pilot in the Estia of Athens building, the breakdown of tasks included in the process and the PRELUDE technical solutions and analysis for Athens' pilot.

TABLE OF CONTENTS

Contents

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

API	Application Programming Interface
BMS	Building Management System
BSEN	British Standards European Norm
CMS	Content Management System
CO2	Carbon dioxide
CV-RMSE	Coefficient of Variation of Root Mean Square Error
ECM	Energy Consumption Model
EMS	Energy Management System
EPIQR	Energy Performance, Indoor environmental Quality and Retrofit
IAQ	Indoor Air Quality
KPI	Key Performance Indicator
M&V	Measurement and Verification
NMBE	Normalised Mean Bias Error
URL	Uniform Resource Locator

1. INTRODUCTION

Deliverable 7.5 is part of the WP7 activities and tasks related to pilots implementation of PRELUDE. It is a public report aiming to depict the activities of the Athens pilot that were executed for Task 7.5 Demonstrations: Athens – DAEM (M04-30), hence the work undertaken in the Estia of Athens building. It was foreseen to install a central monitoring and actuation and more specifically sensors and monitoring were to be installed using low-cost options to collect real time data as in all PRELUDE sites. The overall process should depend on centrally controlled systems, while the special characteristics of this building in terms of social state of the occupants were taken into consideration. Namely, in the Athens pilot the challenging task of user engagement was highlighted from the beginning of the project. As a final outcome of PRELUDE after the end of the project, DAEM envisions to address the replicability of PRELUDE tools and solutions in other areas of Athens and Greece.

The objective of this document is to report on the activities that took place for Task 7.5 on the Athens pilot. Thus, the activities of DAEM are reported for the preparation, implementation and overall execution of the Athens pilot, as well as the technical monitoring system that was installed in the building of Estia and already integrated with the main PRELUDE platform FusiX. Also this document includes feedback from technical partners of PRELUDE that provided tools for the analysis of data from the Athens pilot until the deadline of this document M30. So the contributors are LIBRA, ESTIA and BUL while 1IA monitored the process as a WP7 leader.

In parallel, there are ongoing activities from EMTECH for the FusiX platform development as an overall integrator of all data collected and also from FB that is performing the analysis of the occupancy model. Hence, the document depicts the current outputs of the Athens pilot while after the submission of this document more tools are expected to be delivered to the Athens pilot and most importantly a software version of FusiX with login accounts for the pilot teams.

The deliverable is organised as follows:

- Section 2 includes an introduction of the Athens pilot with reports on the state-of-the-art, objectives, descriptions etc.
- Section 3 includes the preparation of the Estia of Athens building depicting the foreseen modifications for the PRELUDE pilot and the description of the system that was installed.
- Section 4 includes description and results from the Athens pilot site also with feedback from technical partners.
- Section 5 is a summary of the results and outputs with reference to the KPIs.
- The deliverable concludes with outputs in Section 6.

2. INTRODUCTION OF ATHENS PILOT

2.1 OBJECTIVES AND MOTIVATION

The Municipality of Athens has launched a Strategy for Climate Change Mitigation actions since 2019 and many initiatives are ongoing in that direction. Many aspects are defined to be tackled such as the reduction of CO2 emissions, reduction of traffic and air pollution and the target for cutting greenhouse gas emissions by 40% until 2030. Additionally, the city is working on:

- Collection of energy and environmental data for buildings of the municipality
- Adoption of actions for energy saving and reduction of expenditures
- Energy upgrade of the city's very old building stock, public lighting and promotion of sustainable mobility options.

The latter is included in the PRELUDE project and for the assessment of the overall performance of the building stock uses the "Estia of Athens" and it will be a reference building, as well, before expanding to more follow-up activities on behalf of the city.

Since the "Estia of Athens" is operating as a homeless shelter -hosting vulnerable citizens groups- the strong social aspect is of upmost importance. The effective engagement of such groups is not an easy process, although they are in need of healthy and comfortable indoor conditions. As such, the challenge and motivation in this case will be to guarantee comfort and quality of living, as well as to quantify the associated KPIs, while reducing energy consumption through limited user engagement. The latter shall be coherent to the shelter's use, that is short term housing for individuals and families while the city provides social services for their re-integration in the society e.g. labour counselling, food provision, medical support etc.

For the implementation of the Athens pilot, the actors involved are the residents of the building, the building administrators that are city employees and the city officials that under their responsibility is the management of "Estia of Athens", namely the president of board of directors and the Head of Homeless Shelter and the Head of Social Affairs Department.

2.2 USE CASE DESCRIPTION

The Athens pilot was designed to be implemented at the residential building of "Estia of Athens". Estia is a municipal building that is operating as a short-term hostel venue for housing mainly senior citizens or citizens that are under other groups of vulnerable population for example low financial resources, homeless, lacking social and family support etc.

Estia is located in a central area of Athens on Patission 221 str., operating since 2012 and currently administered by the Homeless Shelter Agency of the City (KYADA[1]). It has the capacity to host 52 citizens. The total cover area is 1080 m2 and it has the ground-floor, 5-storeys and a basement. Estia was initially erected in the 30s.

Apart from the residents that are hosted for free, the building includes municipal employees who are responsible for its operation and maintenance, social workers responsible for the care of the tenants and employees for the cleaning services. Also, there is a collaboration with an external catering service that delivers meals to the tenants, so that the personnel is not occupied with cooking and kitchen services.

[1] https://kyada-athens.gr/

Figure 1 Estia of Athens - pilot building

The building has undergone two major renovations for its maintenance and upgrade. In the period of 2005 - 2006 there were replacements in the infrastructure in order to increase the energy savings. Indicative upscaling included rooftop thermal insulation, installation of double aluminium windows to minimise thermal losses, replacement of outdated lighting with led lamps etc. Additionally, heating and hot water systems were upgraded to natural gas and boiler. The recent renovation of 2020 was mainly on the indoor spaces. The building was painted, common areas were renewed, a new modern dining room has been created for guests to eat on the ground floor, residential rooms were equipped with a TV etc. Finally, to summarize the main characteristics of the Athens pilot building that were mapped in order to design and prepare the pilot system installation it must be mentioned that there are 30 apartments (6 in each floor). The apartments are located equally 3 in the front surface of the building facing the main road and 3 at the back of the building facing the neighbouring houses. Apart from the 5 floors with apartments, Estia has a basement, roof and ground floor operating as a common space and kitchen. Currently 27-28 individuals are hosted. The building has installed Wi-Fi connection with a repeater on the 5th floor. The heating and hot water system operates with natural gas, the lamps are energy saving and all windows are double-glass aluminium. The apartments of the tenants are hotel-like rooms including room and bathroom with TV and fan, heating and cooling thermostat. Finally, apart from the ground floor main kitchen, the building has one small kitchen on each floor.

The profile of the tenants includes mainly senior citizens under the social groups mentioned above. Currently all are over 60 years old, hosted alone without family or children. The tenants are hosted in diverse durations, some are short term e.g. for 1 year while others remain in Estia long term as homeless.

Despite the renovations the building lacks digital tools for energy monitoring while its energy consumption is still at high levels. Prior to the PRELUDE project there were no sensors installed neither any measuring system nor automation.

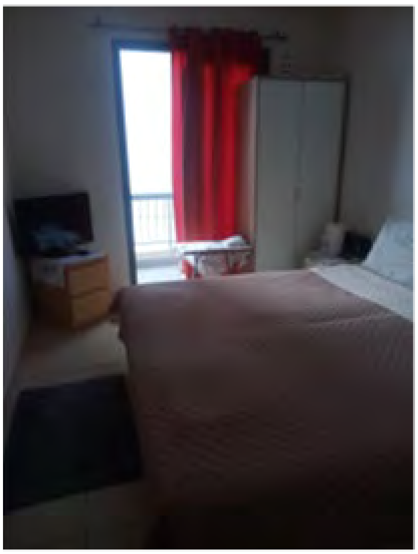


Figure 2 Internal room

Figure 3 Corridor of floor

The initial plan for the pilot implementation was to test the PRELUDE scenarios in 3 apartments (also described in the DoA) for indoor environmental conditions monitoring by the installation of a central monitoring system including BMS and EMS for near real-time data collection, a detailed description will follow in next sections. As it will also be reported below, this initial plan was leveraged to the whole building of Estia including all spaces, floors and rooms. In the images below there are indicatively depicted the blueprint of the ground floor - common space and kitchen - and the plan of a floor since all floors follow the same structure.

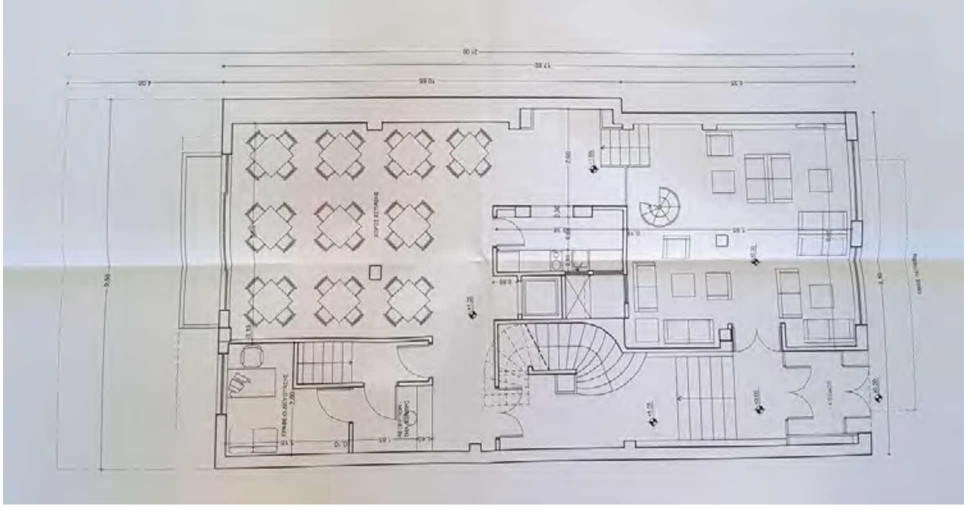


Figure 4 Blueprint of ground floor - common space, kitchen

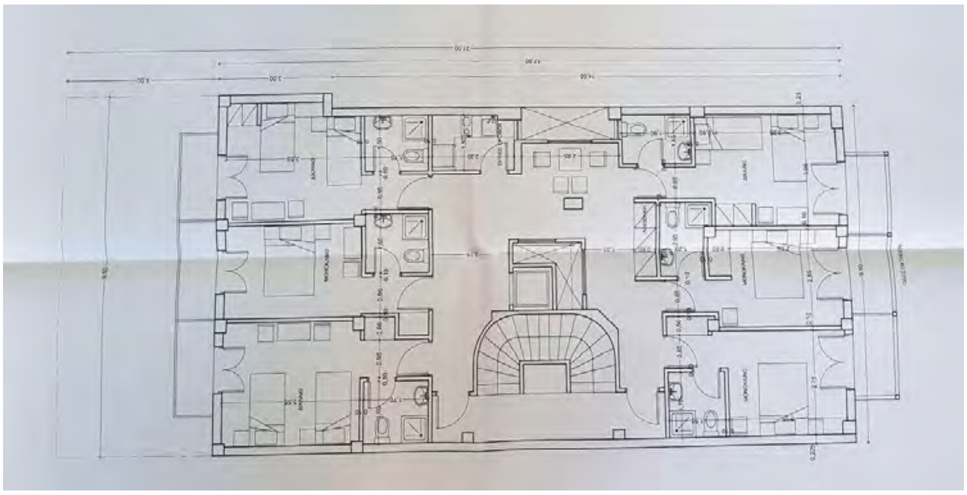


Figure 5 Blueprint of floor

Some sensitive aspects that should be under consideration for the Athens pilot are mainly:

- The high frequency of occupants coming and leaving, since they are hosted as a social support and as soon as they have the resources to have individual accommodation and the health capacity to live independently, they move out.
- The social aspect of the Athens pilot should also not be underestimated. Estia's basic aim was to provide short term housing for individuals and/or families that are affected by the social, economic or other difficulties. This approach coincided with the recent social and refugee crisis that affected Greece pressuring the citizens and incoming residents financially.
- The expected limited user engagement, since the building's occupancy features vulnerable groups, children and elderly, whom we cannot expect to effectively engage in research activities as they are lacking basic needs such as work, income, nutrition, housing etc. However such social groups are in need of healthy and comfortable indoor conditions.

In the following Table 1 there is a summary of Estia tenants in the recent years. Lately the building does not host families rather than individuals.

building	YEAR	NUMBER OF OCCUPANTS
ESTIA of ATHENS - DAEM	2018	34
	2019	31
	2020	29

Table 1 Number of tenants per year

Moreover, several scenarios are identified having three main actors: the Public Administration, the building managers and the end-users/tenants.

More detailed, city officials could have the overview of a baseline energy profile of the building, they could present an analysis of potential intervention for energy reduction and use the outcomes of this analysis for the monitoring of the cost effectiveness in this building particularly and its scalability to other municipal buildings.

From building managers' side that have the general administrative overview of the building the scenarios identified include several activities, namely, to have an interface for energy consumption monitoring, to be notified for energy excess consumption etc. From that perspective, they have the possibility to plan building common activities e.g. laundry or to recommend to tenants activities to reduce the energy consumption or even periodical maintenance actions.

Finally, from the tenants' side, possible scenarios to be adopted are to group them per floor suggesting them recommendations through an easy-to-use gamified application in order to improve health and well-being. Generally, the users' interface should also include useful and easy to interpret insights on the energy consumption e.g. the energy equivalent of an action etc. Similarly, a graphic depiction of the values of indoor conditions e.g. indoor humidity etc should be included in order for them to reflect on their correlation with health and well-being.

2.3 OVERVIEW OF LOCAL REGULATIONS AND STANDARDS - COMFORT AND ENERGY

In Greece the regulations and legislation related to buildings are centrally decided and voted from the relevant organisations and the Parliament of Greece. More specifically, the regulation that is active and should be followed for all buildings is the General Building Regulation. This regulation is formulated by the Technical Chamber of Greece (TCG)[2] that is an independent body monitored by the Ministry of Infrastructure, Transport and Networks. The General Building Regulation (in Greek[3]) was initially issued in 1985, then re-issued in 2000 and currently the newest version in operation is the new Regulation of 2012. However, this is a general standard referring to any building activity and also governing any action taken within a constructing area.

Additionally, to the above, the Ministry of Environment and Energy[4] launched in 2017 the Green regulation for the energy performance of buildings[5]. This regulation leveraged the standards of buildings in Greece by provisioning the increase of energy efficiency. More specifically in Article 2 is declared the goal of the Regulation as a guideline for the reduction of energy for heating, cooling and air-conditioning. Also, measures are foreseen for lightning, hot water and the assurance of internal conditions of comfort and quality for buildings. This regulation is valid and must be applied in all new buildings or any existing building under radical renovation that must follow the thresholds and ranges for emissions and energy

[2] https://web.tee.gr/en/

[3] https://www.e-nomothesia.gr/kat-periballon/oikodomes/n-4067-2012.html

[4] https://ypen.gov.gr/energeia/energeiaki-exoikonomisi/ktiria/kenak/

[5] https://ypen.gov.gr/wp-content/uploads/2020/11/KENAK_FEK_B2367_2017.pdf

consumption as reported. Finally, this regulation foresees the issuance of Energy Certificates for buildings that depict their energy consumption state-of-the-art. This certificate is also necessary to be issued for any actions on the property of the building e.g. in case it is rented, inherited etc.

The above points summarize the main standards and regulations that are active in Greece and refer to the buildings in general.

2.4 IDENTIFICATION OF KEY REQUIREMENTS FOR THE USE CASE

The key requirements with regards to the PRELUDE technologies, refer mainly to data and information from the Estia of Athens building that are necessary for the implementation of the various PRELUDE tools, technical solutions and analysis.

As the state-of-the-art of the building in terms of data collection, sensors and energy monitoring system was not existing, since none of these technologies were present in the building, it was first decided to receive an offer and instal a Building management system with the respecting sensors and data collection points in order to have input for the PRELUDE solutions. These data included energy consumption from the electrical panels and all circuits of the whole building as well as other data necessary for PRELUDE tools such as occupancy, indoor temperature and humidity. The budget restrictions and the cost for the purchase and installation of such a system, resulted in the BMS that is described in next Section 3. Additional data e.g. water consumption or sensors for natural gas, were not possible to be collected since such monitoring systems would result in a budget exceeding the foreseen budget of DAEM in the project.

The data collected by the system described in Section 3 on the electric grid and others were required for the analysis for EPIQR, Climate Correlation Model, Measurement and Verification etc. Indicatively are mentioned the following required data:

- orientation of the building and geographical position for BUL analysis,
- weather data from external sources,
- measurements for CO2 concentration on the occupancy of the floors,
- data from the circuits of appliances,
- number of occupants,
- blueprints of the building,
- historical data of energy and natural gas consumption from the respective bills for the years 2018 until 2022,
- aggregated energy consumption real-time data per floor,
- photos for the current maintenance state of the building for the EPIQR analysis for diverse categories of elements e.g. external walls, internal lightning, pipes and wiring etc.

The afore mentioned and other data are stored in the PRELUDE common space[6] for the consortium convenience.

[6] https://aaudk.sharepoint.com/sites/PRELUDE/Delte%20dokumenter/Forms/AllItems.aspx?id=%2Fsites%2FPRELUDE%2FDelte%20dokumenter%2FWP7%2FAthens%20%28DAEM%29&viewid=cb27099b%2Df653%2D497c%2Da17e%2Dde596f502e06

3. PREPARATION OF THE DEMONSTRATION CASE

3.1 MODIFICATIONS CARRIED OUT IN THE BUILDING

In this section, the process of modifications and equipment installation in the building will be described.

For the preparation of the Athens pilot, DAEM organised meetings with the city officials and the building administrators, as well as visits and audits in the building in order to enlist and collect the available data as follows:

- Electricity consumption (2018-2022)
- Natural gas consumption (2018-2022)
- Water consumption (2018-2021)
- Blueprints
- Profile of occupants
- Number of appliances/devices in the building, status of windows, lighting, etc.

More detailly, the heating and the cooling is operating with gas. Every apartment has a meter for defining the temperature, individually. Also, there is a boiler for hot water operating with gas. Consumptions for electricity, gas and water of the recent years (2018-2022) are depicted below:

ELECTRICITY BILLS														
building	**YEAR**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**TOTAL (kWh)**
ESTIA of ATHENS - DAEM	**2018**	4240,00	3560,00	3360,00	2760,00	2440,00	2600,00	3200,00	3240,00	2840,00	2480,00	3600,00	4440,00	**38760,00**
	2019	4680,00	5640,00	4920,00	4480,00	3080,00	2520,00	2960,00	3240,00	2560,00	2440,00	3000,00	3840,00	**43360,00**
	2020		4280,00	4920,00	4760,00	2720,00	2840,00	8840,00			15480,00			**43840,00**
	2021		4400,00	4680,00	3880,00	2720,00	2840,00	3200,00	3280,00	2640,00	3520,00	3960,00	5520,00	**40640,00**
	2022	6360,00	5240,00	6560,00	3680,00	3280,00	3320,00	3640,00	3560,00	2880,00	3400,00	5040,00	4680,00	**51640,00**

Table 2 Electricity consumption

WATER				
building	**START PERIOD**	**END PERIOD**	**M3 PERIOD CONSUMPTION**	**LT PER DAY**
ESTIA of ATHENS - DAEM	October-17	January-18	524,00	6023,00
	January-18	April-18	541,00	6011,10
	April-18	July-18	543,00	5967,00
	July-18	October-18	576,00	6000,00
	October-18	January-19	494,00	5428,60
	January-19	April-19	442,00	5456,80
	April-19	July-19	468,00	5379,30
	July-19	October-19	473,00	5031,90
	October-19	February-20	473,00	4504,80
	February-20	June-20	652,00	5620,70
	June-20	September-20	621,00	6336,70
	September-20	November-20	475,00	6089,70
	November-20	February-21	453,00	5960,50
	February-21	May-21	518,00	5755,60
	May-21	August-21	655,00	7277,80
	August-21	November-21	524,00	5887,60
	November-21	February-22	479,00	5263,7
	February-22	May-22	504,00	5662,9
	May-22	August-22	603,00	6483,9
	August-22	November-22	657,00	7465,9
	November-22	February-23	692,00	7688,9
		TOTAL	**11367,00**	

Table 3 Water consumption

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL (kWh)
2018	37302,32	29118,05	27317,82	14651,23	6646,74	11028,44	24858,00	24466,00	15418,00	7458,00	21056,00	30434,86	**249755,46**
2019	37190,00	20808,00	17206,00	17179,00	3445,00	2626,00	16236,00	24460,00	13865,00	4922,00	12362,00	30206,00	**200505,00**
2020	36794,00	29879,00	16943,00	5766,00	5763,00	14571,00	29126,00	28698,00	18206,13	6113,00	21965,00	29563,00	**243387,13**
2021	56356,00		33483,00	18416,00	16943,00	7717,00	8167,00	12885,00	9815,00	9042,00	22360,00	16943,00	**212127,00**
2022	33718,00	27878,00	34398,00	18195,00	12695,00	17985,00	22806,00	26271,00	13389,00	6713,00	12233,00	23415,00	**249696,00**

Table 4 Natural gas consumption

As per the other data available, they could be summarised:

- Every apartment has a TV and a fan. There is a common fridge on every floor.
- On the ground floor there are two fridges. Since the food for the tenants is provided through a catering service in the common areas and the kitchen, the respective appliances are not used except for the microwave.
- On the basement there is a laundry
- All windows are new sliding with aluminium frame and double glasses and there is no shadowing facility in the building (tents, windows-blinds etc)
- The lamps are energy saving (Osram A or A++ or similar)
- There is an alarm facility.
- There is no air ioniser.
- Wi-Fi is available on the ground floor and there is a repeater on the 5th floor.
- A rooftop insulation installed after the renovation
- There are electrical panels for controlling different circuits. The basic and common ones are in the basement and ground floor, while each floor of apartments has also a dedicated panel.

Since the building has no sensors or additional equipment measuring CO_2, humidity, temperature and air quality, a supplier was identified so as to proceed with the energy BMS installation. The whole process included audits from the supplier's side in order to formulate an offer, a signed contract with DAEM, the purchase of the equipment required and of course the installation. More detailed, the equipment covered the whole building leveraging the initial planning of the pilot. During the offer stage there was a consideration of also purchasing the supplier's CMS for monitoring the data collected and the system. However, PRELUDE has committed to deliver a platform with the same functionalities - FusiX - hence the commercial CMS was not purchased.

For indoor conditions measurements, thus for CO2, humidity and temperature, 7 sensors in total are installed - one per floor. For outdoor conditions, one sensor is installed on the rooftop measuring external temperature and humidity. Also, smart meters are installed in the building's electric panels which are one general for the whole building and one per each floor. In the following Table 5 and Table 6, equipment installed per item is depicted.

The equipment has the capacity to measure the consumption of the electricity, such as lights, appliances and air-conditioning in real time (app. every 15' configurable) and is integrated already with the FusiX platform via API. Also, the system stores the data every 15 days, so in case of power failure or for historical purposes, data is always available.

In the following tables and figures, equipment installed in the building per item is depicted:

Figure 6 Boiler

Figure 7 Floor electric panel

BMS board				
Product		**Product code**	**Quantity**	**LOCATION**
SmartX Controller –AS-P-NL	Schneider Electric	SXWASPXXX10001	1	central panel
UI-16 16 Universal In	Schneider Electric	SXWUI16XX10001	1	central panel
PS-24V Power Supply 24VAC/VDC	Schneider Electric	SXWPS24VX10001	1	central panel
TB-ASP-W1 Terminal Base	Schneider Electric	SXWTBASW110002	1	central panel
TB-PS-W1 Term Base Pwr Sup W1	Schneider Electric	SXWTBPSW110001	1	central panel
TB-IO-W1 Term Base I/O W1	Schneider Electric	SXWTBIOW110001	1	central panel

Table 5 BMS board elements

Periphericals				
Product		**Product code**	**Quantity**	**LOCATION**
NSX100	Schneider Electric	EasypacT CVS100	14	each floor
PowerTag Energy 250A	Schneider Electric	LV434020	14	each floor
Powe LinkTag	Schneider Electric	A9XMWD20	1	central panel
Energy Meter iem3150	Schneider Electric	A9Mem3150	24	each apartment
SER8 Controller Temp & Humidity	Schneider Electric	SER8350A0B11	7	each floor
CO2 SE8000	Schneider Electric	VCM8001V5045	7	each floor

Outdoor SHO100-T	Schneider Electric	6902371	1	common area

Table 6 BMS periphericals

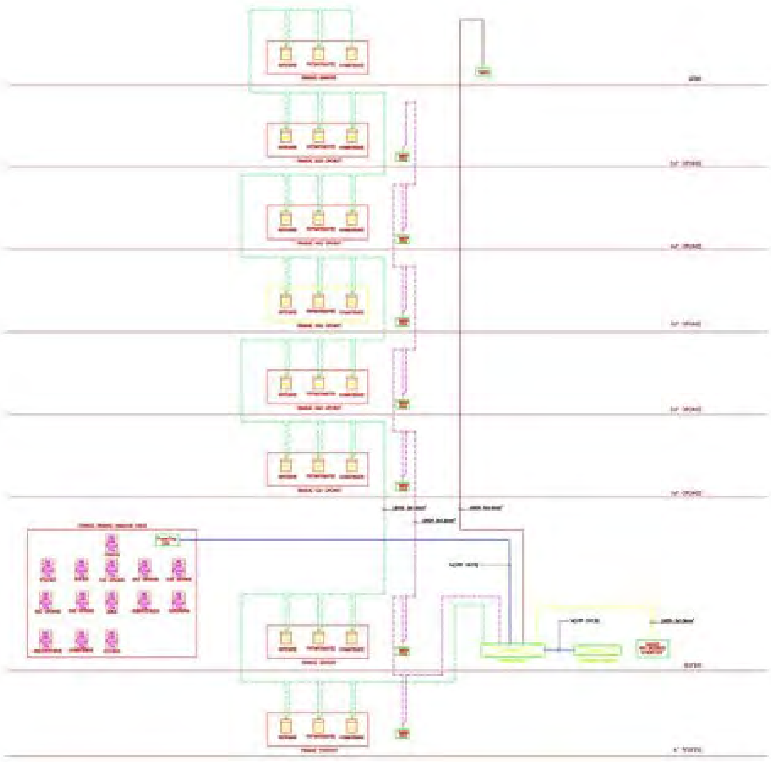


Figure 8 electrical blueprint of the BMS installed

Indicative examples from the measurements from the sensors of the BMS installed are mentioned below:

- For the 1st floor:
    - Air-conditioning: 70 Kwh
    - Lights: 107 Kwh
    - Electricity from appliances: 618,82 Kwh
- For the 3d floor:
    - Air-conditioning: 60 Kwh
    - Lights: 70 Kwh
    - Electricity from appliances: 73 Kwh

Indicative measurements of temperature and humidity are, for the ground floor humidity is about 60%, while the humidity per floor is about 58-62%. The temperature in the basement is 23°C.

Figure 10 BMS meters

Figure 9 General electric panel

Figure 12 BMS installation general panel

Figure 11 BMS floor meters

3.2 EVALUATION OF THE BUILDING

Section 3.2 aims at reporting the identification of good operation and also problems of the building with an exploratory data analysis and showcasing of data processing from the FusiX platform. By the submission of the current document M30, EMTECH has not delivered to the Athens pilot the FusiX platform with users' accounts in order to monitor and process the data that are collected from the Athens building. As it is reported in the previous sections the BMS system of Athens is integrated to FusiX and data are sent to the platform, hence as soon as EMTECH provides user accounts and a URL, the data will be analysed.

4. PLANNING AND IMPLEMENTATION OF PRELUDE SOLUTIONS

4.1 EPIQR FOR ATHENS PILOT

An EPIQR+ diagnosis of the Athens demo-case building was performed through the new EPIQRweb platform in order to determine the costs of two different renovation scenarios. The first one or "Diagnosis" scenario corresponds to the renovation works required to rehabilitate the building according to its current standard. The second one, named "Optimization", lists in addition to the interventions of the first scenario other ones corresponding to upgrades in terms of thermal envelope, summer comfort, use of local renewable energy and interior modernization.

The dimensional and cost coefficients, necessary inputs for the diagnosis, are mentioned in the Figure 13 Dimensional & cost coefficients - diagnosis inputs below.

Dimensional coefficients		
ERS Energy reference surface	999	m²
Wso Wall surface against the outsi…	1019	m²
Ws Window surface	180	m²
BS Built surface	169	m²
LSS Landscaped surroundings surf…	0	m²
FS Floor surface	1168	m²
Number of lift shaft modules	6	U
HS Habitable surface	640	m²
SS Secondary Surface	169	m²
Main circulation surface	359	m²
Dwelling count	30	U
Surface of viewed facades	0	m²

Cost coefficients		
Complexity Coefficient: Size of bui…	100	%
Complexity Coefficient: Working c…	100	%
Complexity Coefficient: Access	102	%
Building Cost Index	70	%
Engineering Fees	15	%
VAT	24	%
Miscellaneous and unforeseen	0	%

Figure 13 Dimensional & cost coefficients - diagnosis inputs

The results of the proposed interventions with their related costs for the two different scenarios are detailed in reports extracted from the web platform. Since the reports are extracted in pdf format, they are attached to the deliverable in the Appendix section.

To summarize, the "Diagnosis" scenario mainly takes into account the following works:

- Light repairs of plaster and/or metal siding of facades and balconies
- Replacement of few tiles and/or painting of walls and floors of the interior distribution
- Maintenance of the sanitary facilities
- Light reparation work on heat and cold and hot water distributions

The optimized scenario, in addition to the previous works, also considers:

- The addition of external blinds to help maintain a pleasant indoor climate during heat waves by blocking it before it enters the building and allowing in parallel some natural ventilation
- The modernization of the common and secondary surfaces and main ones (code 3 or replacement, apart from the kitchen and sanitary that are just maintained in the state)
- The implementation of a photovoltaic installation on the flat roof for local renewable energy
- The basement ceiling insulation.

The double-glazing aluminium windows and doors have been replaced in 2020 and are thus in a good condition with no relative work required. Regarding the facades, no thermal insulation is present, but no energy optimisation is currently planned on these. The roof and its covering were renovated in 2005-2006 with maximum 10 cm of thermal insulation. The electrical installations are relatively recent with smart meters and CO2 and humidity sensors installed last year. The building was connected to the natural gas city's network and added a new boiler in 2009.

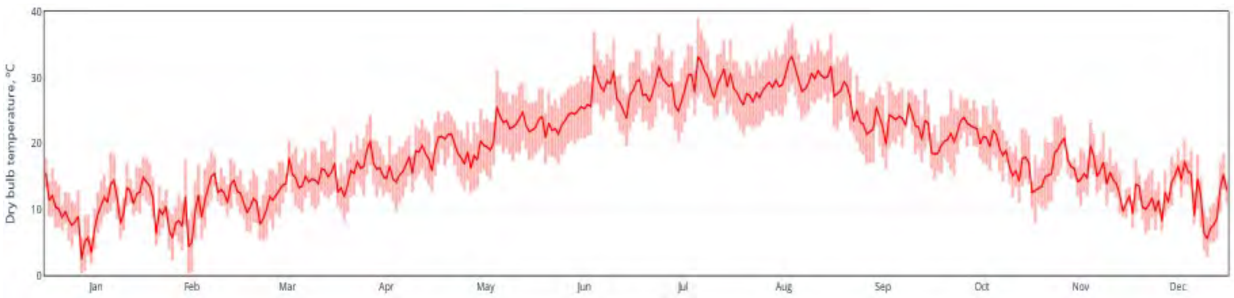
All taxes included, the optimized scenario costs about 684'000 euros which is approximately 2.8 times more expensive than the first one. However, it allows to increase indoor comfort and energy autonomy. A complementary study could permit to specify the photovoltaic project including its self-consumption rate as well as the cost effectiveness of this second scenario over time.

4.2 INDOOR CONDITION MODEL - CLIMATE CORRELATION MODEL FOR ATHENS PILOT

The climate correlation module predicts hourly internal environmental conditions from ambient climatic conditions by investigating the relationships between indoor and outdoor conditions in a building for its thermal comfort and indoor air quality. In Deliverable 3.4[7], the development of a climate correlation model was presented on how the indoor operative temperature and airflow can be predicted if the outdoor dry bulb temperature and wind speed are known. This exercise section demonstrates how the prediction model and equations are applied for different scenarios considering the variation in ventilation and cooling schedules which could be found in the operational environments for the Athens pilot building.

Athens climate and studied residential building

Athens Mediterranean climate (Köppen climate classification: Csa) represents a dominant alternation between prolonged hot and dry summers and mild, wetted winters with moderate rainfall. July and August are the driest months for Athens with the highest outdoor dry bulb temperatures (Figure 14). The dominant southwest wind comes with higher wind speeds (WS) to Athens throughout the year (Figure 15). The heating degree days and cooling degree days of Athens showed that the buildings in Athens need both heating and cooling for comfort. The Givoni bioclimatic chart (Figure 16) showed that about 20% of annual hours could be extended to be comfortable by applying natural ventilation in buildings. Adding sun shading could improve 14% of annual hours to be comfortable for a building. On the other hand, about 20% of annual hours need active heating and humidification, and 8-9% of annual hours need active cooling and dehumidification for thermal comfort in a building.



[7] D3.4: Indoor-outdoor correlation module, PRELUDE

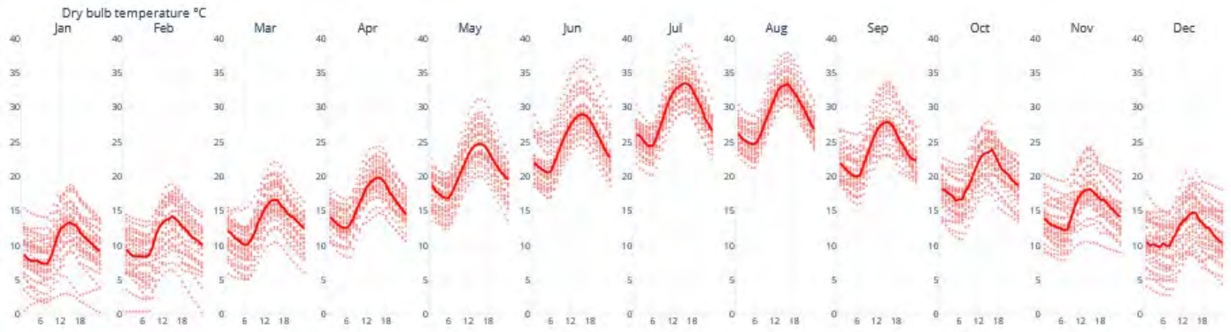


Figure 14 Daily outdoor dry bulb temperature profiles of Athens

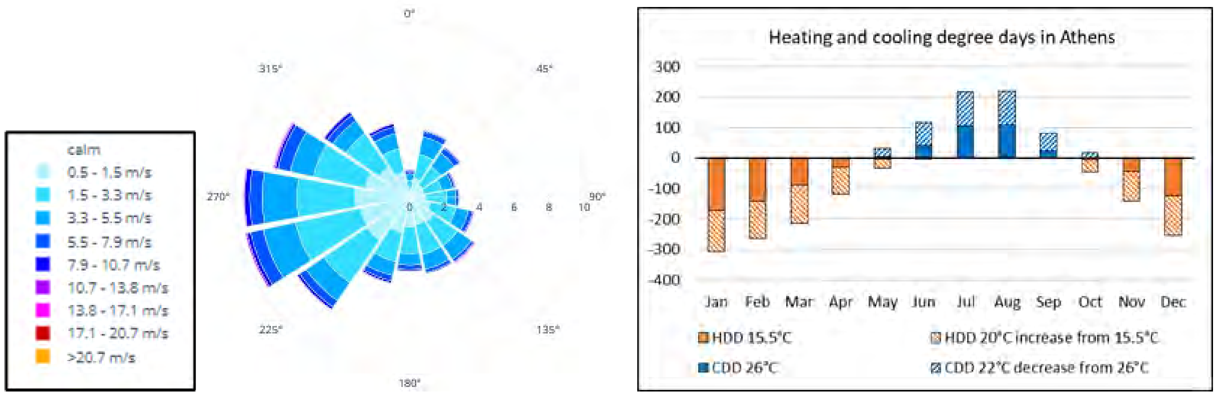


Figure 15 A wind rose, heating degree day and cooling degree day profiles of Athens

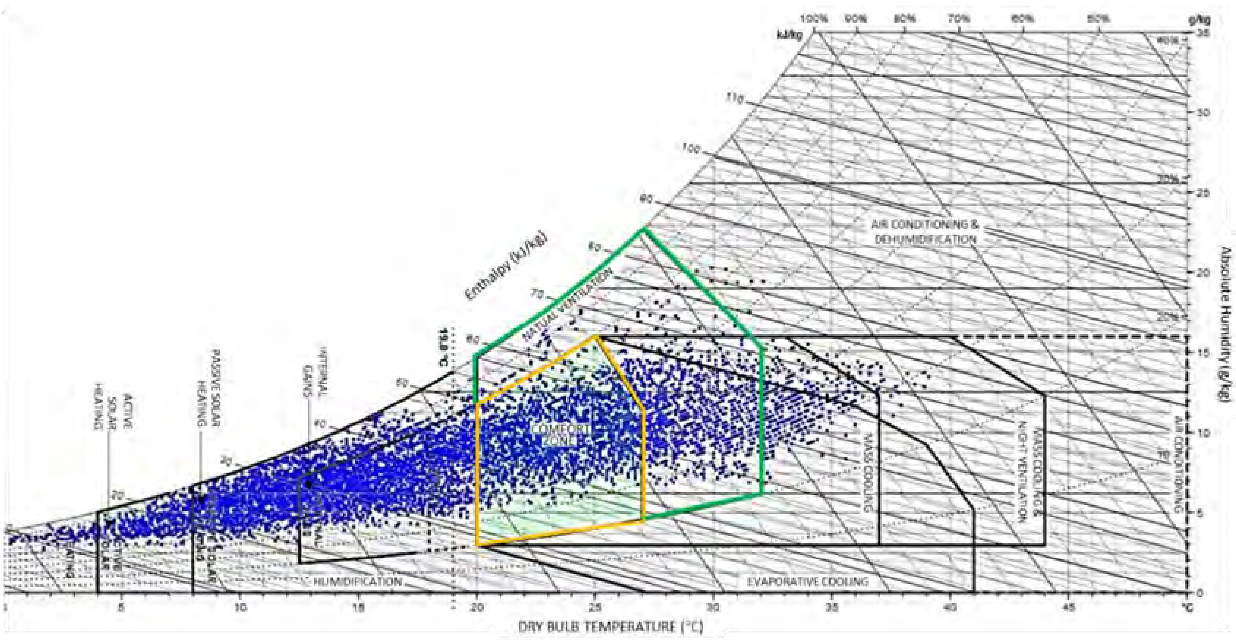


Figure 16 Givoni bioclimatic chart and psychrometric study for passive and active design strategies

The Athens pilot building is highly representative of low-rise multi-apartment buildings that were built during the 1960s and renovated by adding rooftop insulation. For this exercise, one "intermediate level", which is in between two levels and consists of 6 rooms, was chosen for further investigation. The single room (SR) is for one occupant and the twin room (TR) is for two occupants. Each room has one bath and there is a balcony with one window/door on either the east or west side. The room plan with each room area is presented in Figure 17.

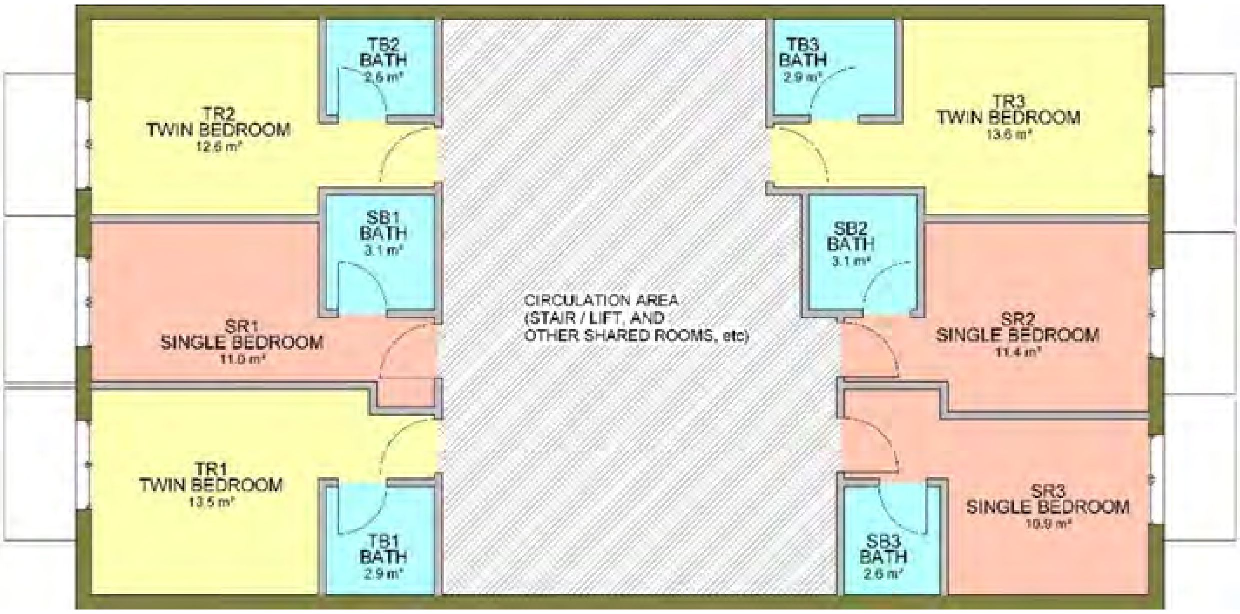


Figure 17 Studied rooms with their areas and orientation; SR1 and TR3 were selected for this study.

Methodology

The building schedules (occupancy fraction, appliance and lighting usage, etc) for a typical residential apartment recommended in the BSEN 16798[8] were used in this study. According to the occupancy for weekdays and weekends, the heating hours, window opening hours and mechanical ventilation time were applied. As the climate of Athens needs both active heating and cooling, according to BSEN 16798, heating and cooling were considered to operate if the indoor temperature is lower than 20°C or higher than 26°C. The heating schedule was run from 05:00 to 23:00 except window opening hours; heating was turned off during weekdays considering lower occupancy. The cooling schedule was run according to occupant presence. Two different window-opening scenarios were considered in this work. One was that the window-opening time was proposed for two hours a day (morning and evening), and the other was to open the window during occupied hours if the indoor temperature is above 22°C. Figure 18 presents the schedules used in this study; 0 represents no activities, and 1 represents fully operated or active for one hour.

[8] BS EN 16798-1 (2019) *Energy performance of buildings. Ventilation for buildings. Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. Module M1-6.* UK: BSI.

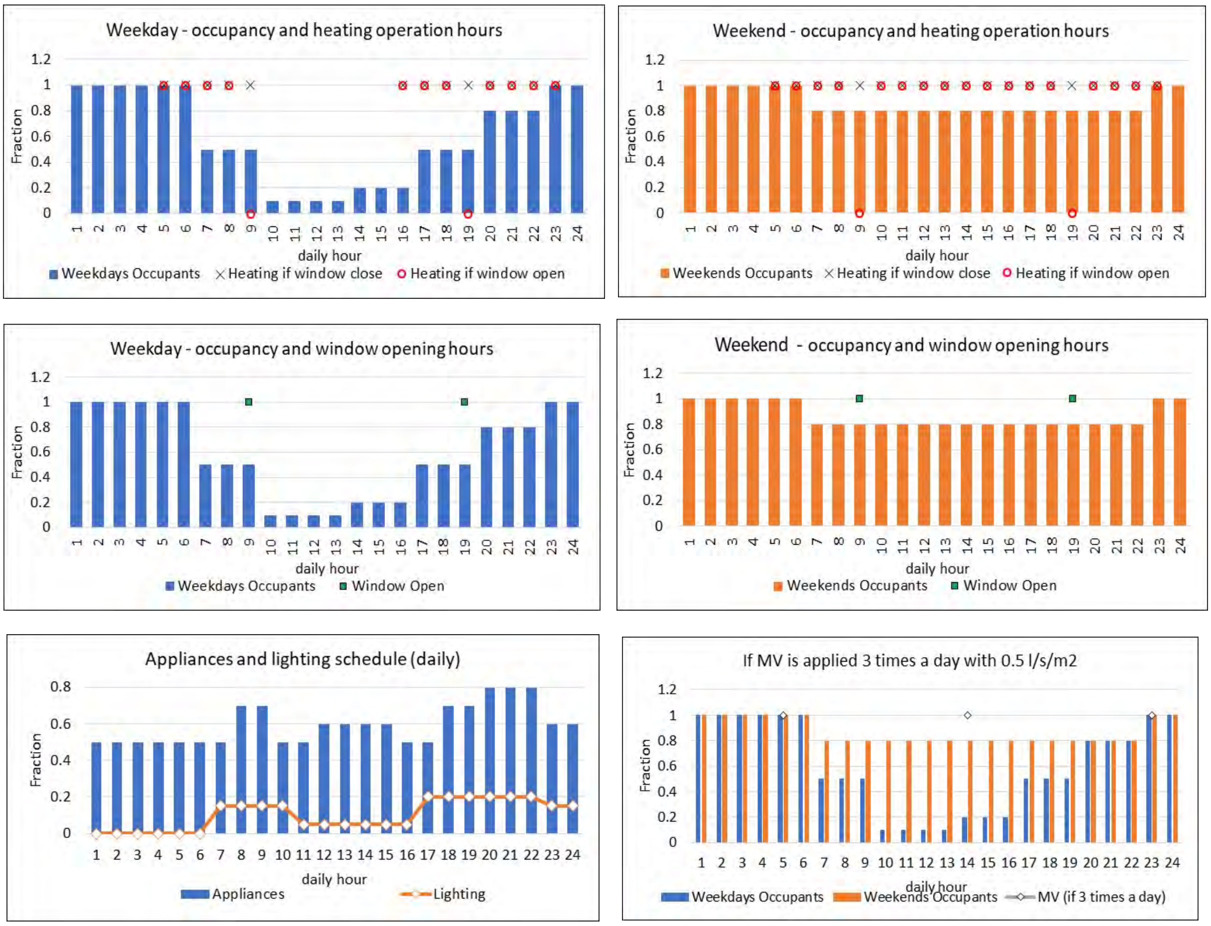


Figure 18 Occupancy, appliance, lighting, heating and ventilation schedules were used in this study

Figure 17 presents the studied level consisting of six rooms - three twin rooms and three single rooms. From this, two rooms were selected for a comparative study. The single room (SR1), which has west-facing window and is sandwiched between two rooms, was selected. The twin room (TR3), which has an east-facing window, and is exposed to the north and shared party wall at the south wall, was selected. As the selected level was in between two levels, the internal floors are exposed to below and above levels. In this work, the U-values of 1.8 W/m^{2}K for exterior walls, 2.03 W/m^{2}K for party walls and partitions, 1.83 W/m^{2}K for internal floors and 2.55 W/m^{2}K for window glazing were considered. The internal heat gains of 3W/m2 were considered when the appliance schedule was run. A minimum mechanical ventilation rate of 0.28 l/s/m^2 per person was considered to remove indoor CO_2 concentration during occupied hours. If the mechanical ventilation was run three times a day, the ventilation rate of 0.5 l/s/m^2 was considered. It was assumed that each room has a 1600mm width and 1400mm height window with 40% of the window openable area. In order to test different ventilation and cooling schedules, six cases shown in Table 7 were considered to test simulations in DesignBuilder / EnergyPlus using a typical weather file of Athens. Night-purge ventilation was considered in case 2N by opening windows from 20:00 to 08:00.

Cases	Window opening mode	Cooling	Mechanical Ventilation	Heating
1	Close all time	No	No	

2	Open for selected hours, close the other time	No	No	Applied as per the schedule if T<20°C
2N	Open from 20:00 to 08:00 during the summer	No	No	
3	Same as case 2	Apply if T>26°C	No	
4	Open if T>22°C during occupied hours	No	No	
5A	Close all time	No	Min. fresh air 0.28 l/s/m^2 during occupied hours	
5B	Same as case 2	No	Fresh air 0.5 l/s/m^2 - 3 hours a day	

Table 7 Test cases used in this study

Simulation results - Monthly

The monthly indoor temperature results showed that cases 1, 2, 5A and 5B were closely aligned to each other while the window close all-time (case #1) had the highest indoor temperatures. As the active cooling was applied in case #3, its summertime temperatures were lower than outdoor temperatures. Opening the window if the indoor temperature is above 22°C (case #4) could reduce indoor temperatures against outdoor as the windows were opened during night time to flush warm air out of the building and cool the building envelope (particularly if it has a high thermal mass) for the next day. Therefore, night purge ventilation was considered in case #2N by opening windows from 20:00 to 08:00 during summer (from 1 May to 30 September). Cases 5A and 5B showed very similar results for indoor temperatures; however, higher relative humidity values were found in case 5B. Therefore, constant minimum mechanical ventilation could maintain lower humidity in the room than applying a slightly high ventilation rate three times a day. The indoor humidity could be trapped if the windows were closed at all times. Average humidity above 60% was found even though the windows were open 2 times a day (BSEN 16798[9] suggest max. relative humidity of 60% for residential settings). Applying mechanical ventilation - either 3 times a day with 0.5 l/s/m^2 or a minimum rate of 0.28 l/s/m^2 during occupied hours could help to maintain the humidity between 40-60%.

[9] BS EN 16798-1 (2019) *Energy performance of buildings. Ventilation for buildings. Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. Module M1-6.* UK: BSI.

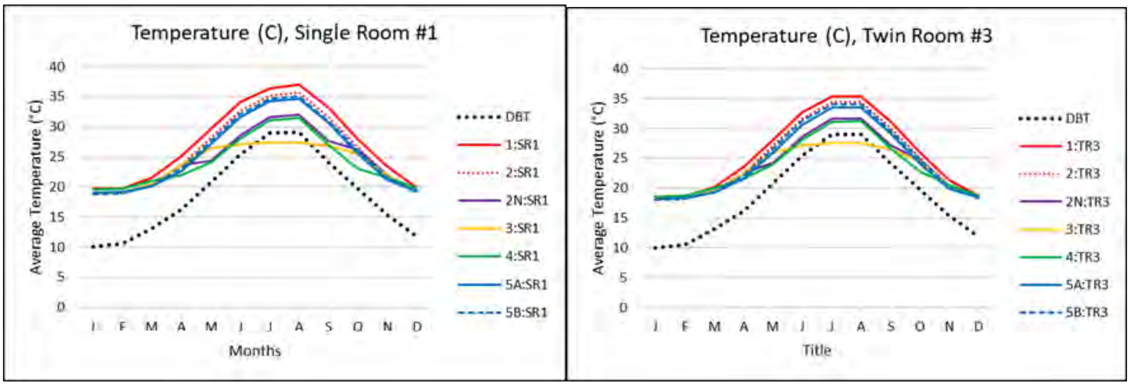


Figure 19 Monthly indoor air temperatures for single room SR1 and twin room TR3

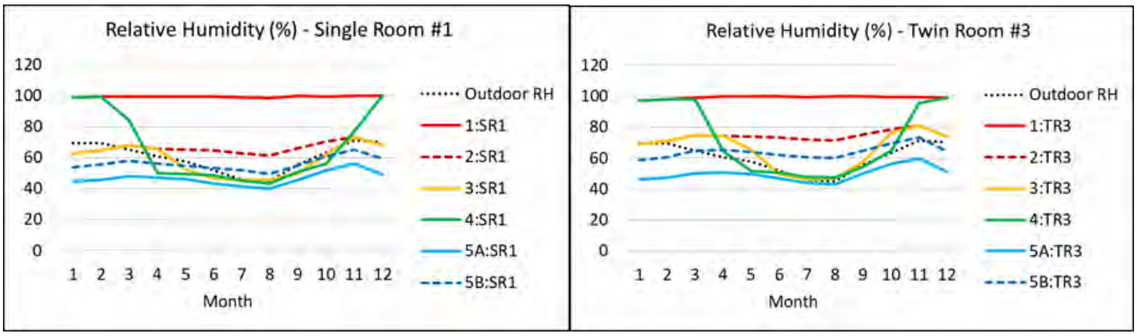


Figure 20 Monthly indoor humidity for single room SR1 and twin room TR3

As active heating was applied if the indoor temperature is below 20°C, all rooms showed similar temperature results. However, the north-exposed wall with the east-facing TR3 room consumed double the amount of heat load than the west-facing SR1 room. Opening the window daily for 2 hours increased the heat load as the energy consumption for heating was traded to achieve the required ventilation for the rooms. Cases #1 and #4 found similar results as no heat load contribution by opening windows as the windows were opened when the indoor temperatures were above 22°C. Cases #2 and #3 found similar results as no heat load contribution as the cooling was operated when the indoor temperatures were above 26°C (case #3). Applying higher mechanical ventilation could increase heat loads slightly (cases 5A and #5B).

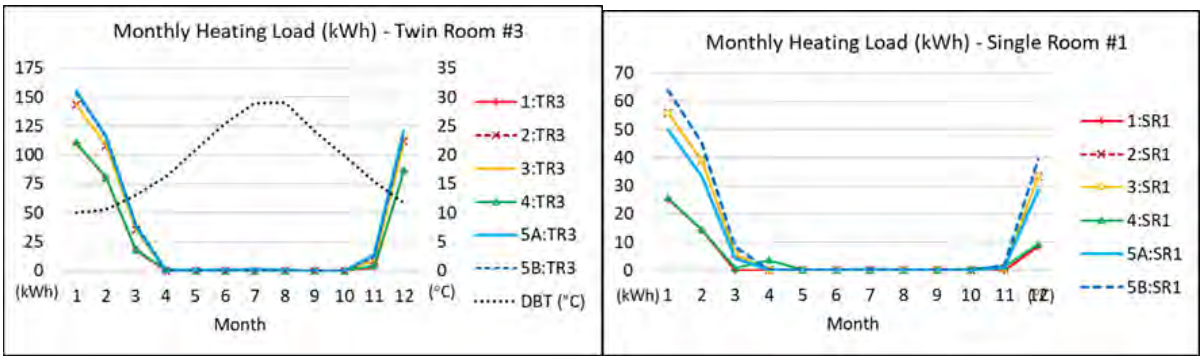


Figure 21 Monthly heating load (kWh) for single room SR1 and twin room TR3

Closing windows (case #1) and opening windows during the summertime if the indoor temperature is 22°C (case #4) could cause higher indoor CO_2 concentrations. Applying active cooling during summertime by closing windows also could increase indoor CO_2 concentration. Applying constant mechanical ventilation of 0.28 l/s/m^2 during occupied hours (case #5A) could reduce more CO_2 concentration than applying higher mechanical ventilation 3 times a day with 0.5 l/s/m^2.

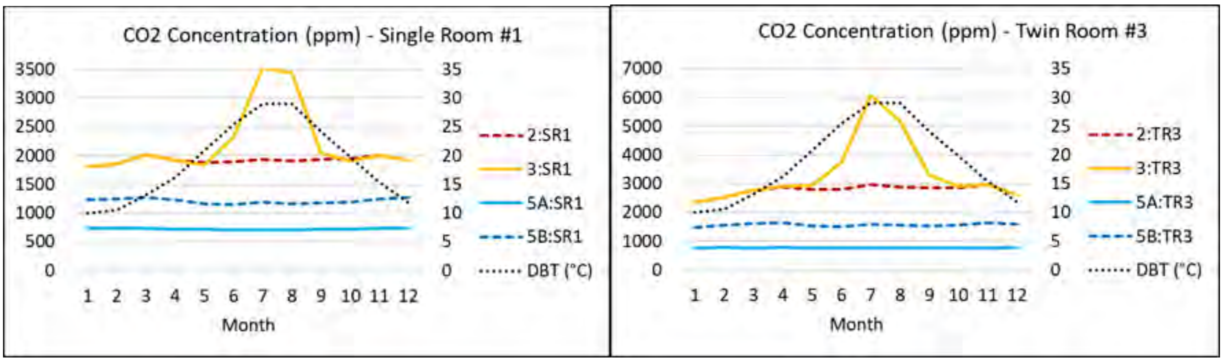


Figure 22 Monthly indoor CO2 concentration (ppm) for single room SR1 and twin room TR3

Simulation results – Annual heating demand

Figure 23 presents the annual heating demand of different rooms for six cases. It can be seen that closing windows at all times (case 1) and opening window only if the temperatures were above 22°C (case 4) had the lowest heating load despite those cases showing the worst case for indoor air quality. Whilst applying mechanical ventilation could improve indoor air quality, it could also bring higher heating demand for all rooms. Applying higher mechanical ventilation 3 times a day could bring the highest heating demand. Figure 24 presents how the heating demand could increase by opening windows or applying mechanical ventilation.

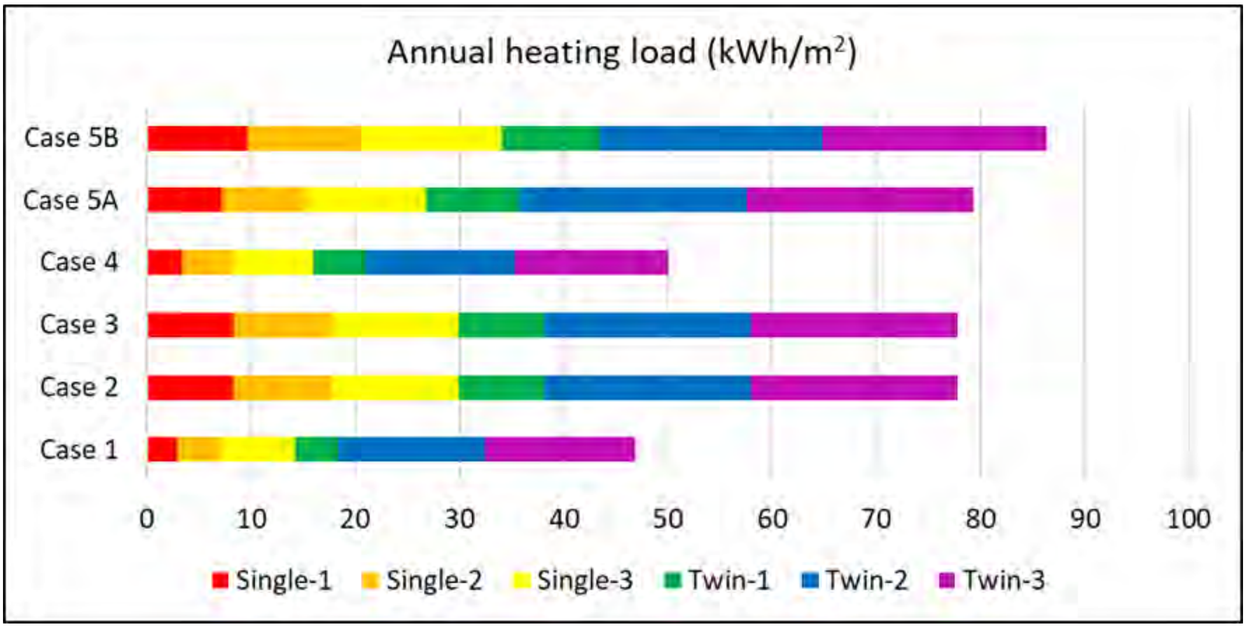


Figure 23 Annual heating demand for all rooms in different cases

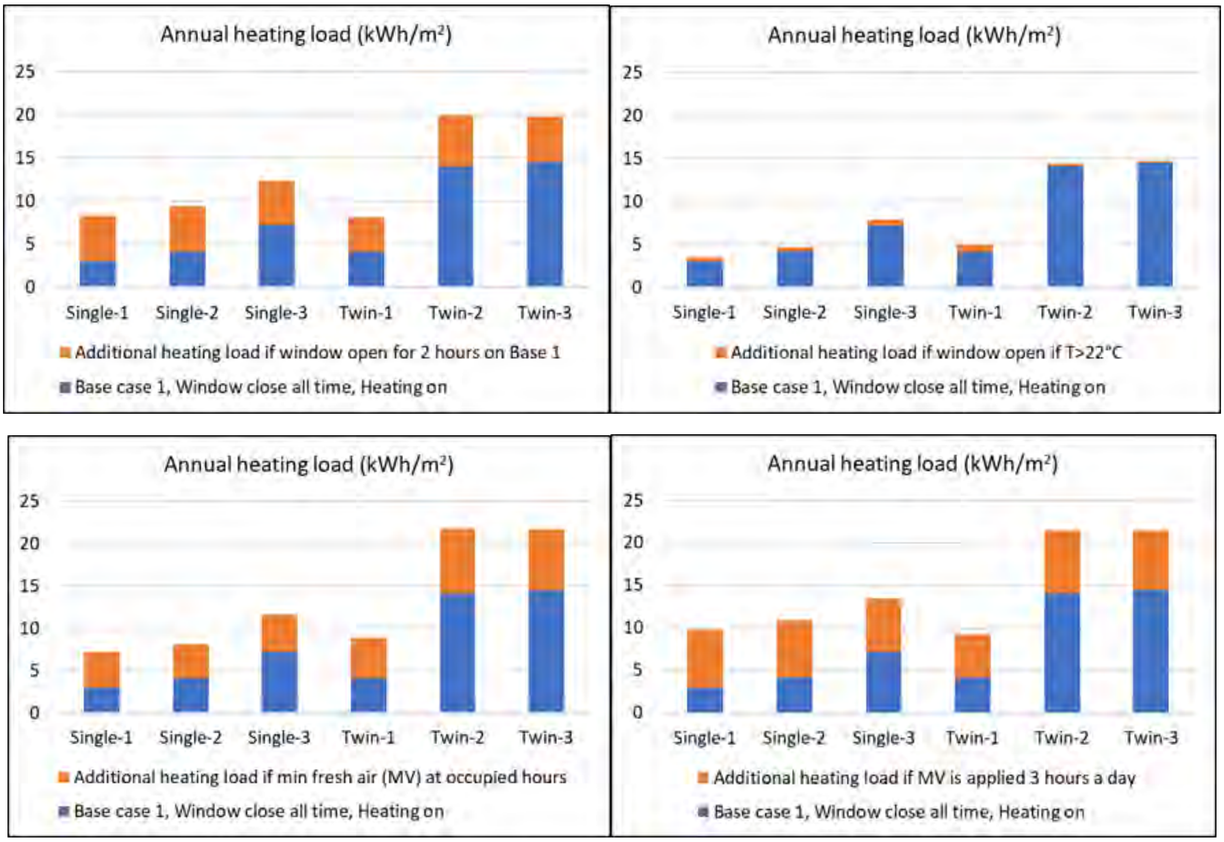
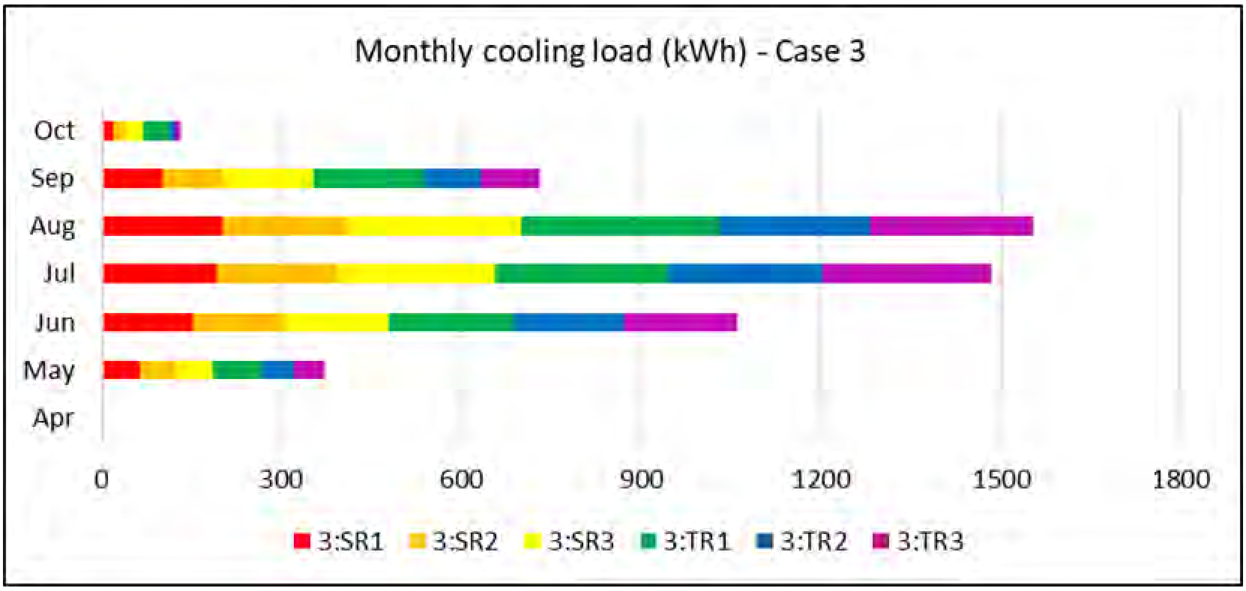


Figure 24 Heating demand changes if the windows are opened or MV was applied.

Simulation results – Annual cooling demand and fan load

Similar heating loads for cases 2 and 3 were observed in Figure 24. Active cooling was considered in case 3; therefore, its monthly cooling load can be seen in Figure 25. As July and August are the hottest months in Athens, cooling demand for those months was higher than the others. East-facing single room SR3 and west-facing twin room TR1, whose walls are exposed to the south, required more cooling than the others. Whilst case 5A showed the best case with acceptable indoor CO_2 concentration (Figure 22), the fan loads for case 5A were five times higher than case 5B (Figure 26) as the fan schedules were considered during occupied hours in case 5A. Therefore, the heating demands of case #5A were lower than case #5B, but the fan loads of case #5A were higher than case #5B.



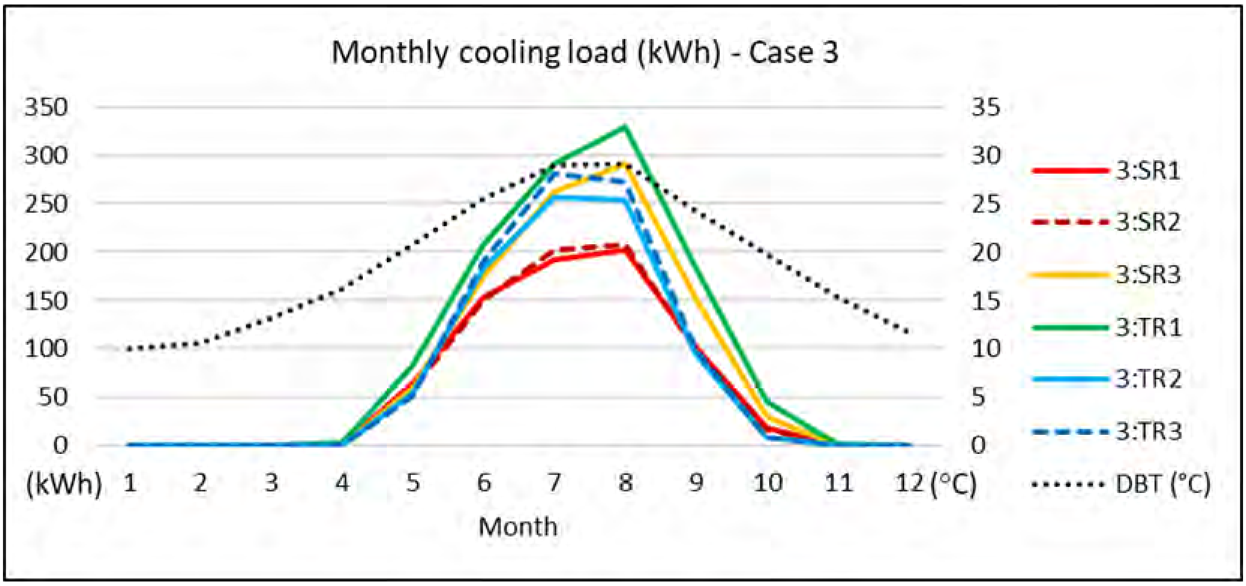


Figure 25 Monthly cooling demand for all rooms in case 3.

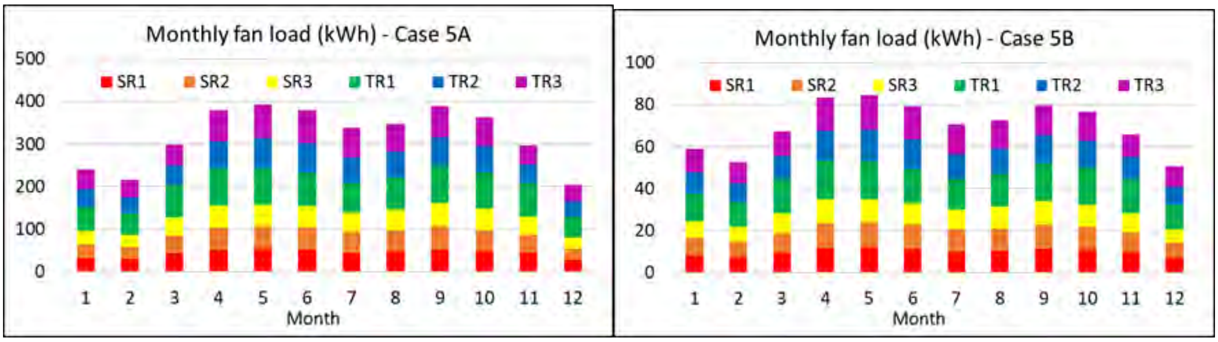
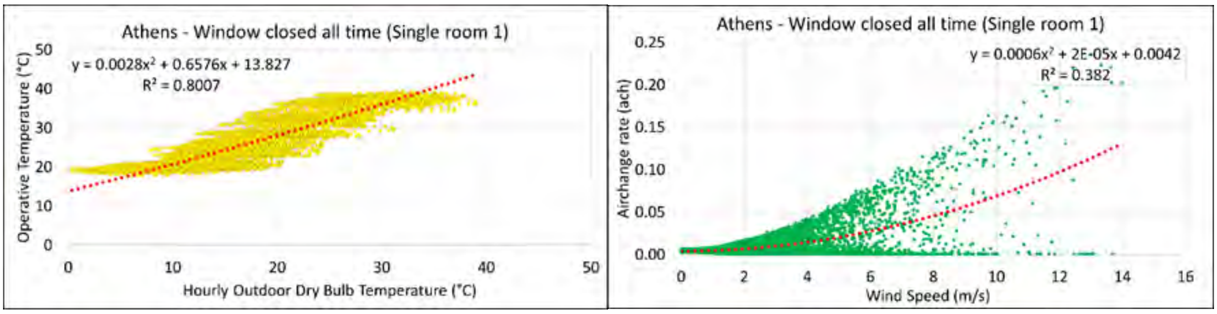


Figure 26 Monthly fan load for mechanical ventilation

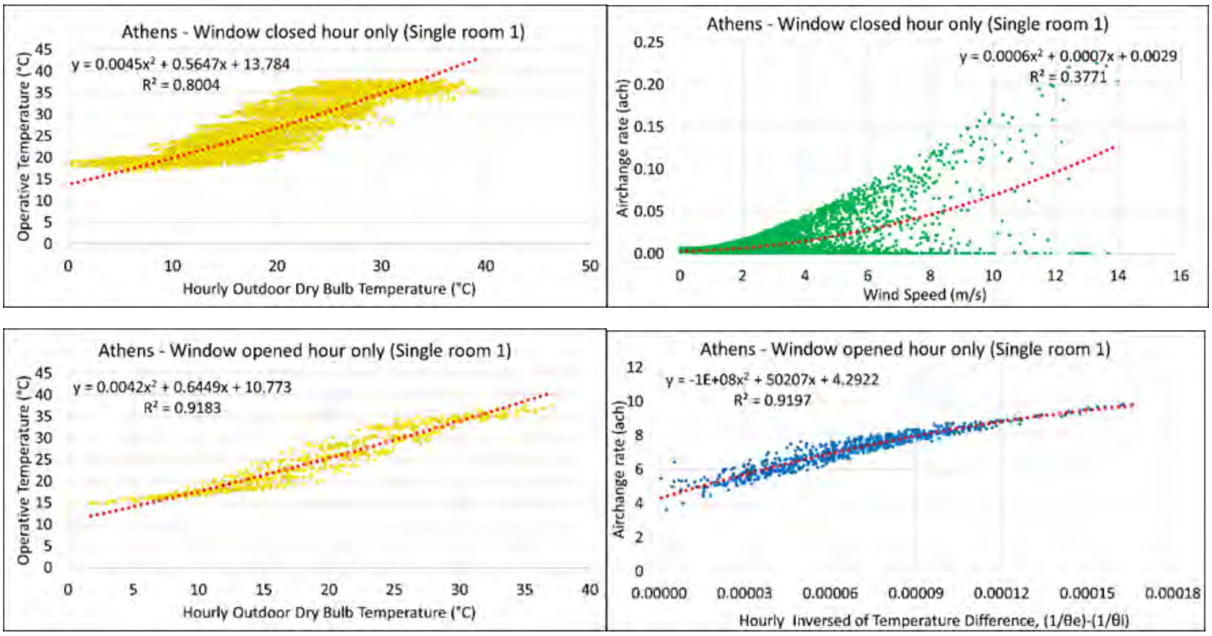
Simulation results – Correlation model

Figure 27 presents the correlation between indoor temperature, air change rate and outdoor weather of the single room SR1. It can be seen a strong correlation between indoor and outdoor temperatures if the window is opened. A strong correlation between air change rate and the inversed temperature differences between indoors and outdoors was observed if the windows were opened. Similar results for the twin room TR3 were found in Figure 28.

Case 1: If the windows were closed at all times



Case 2: If the windows are opened two hours (morning and evening) daily and close the other hours



Case 2N: If the windows are opened from 20:00 to 08:00 for night-purge ventilation in summer

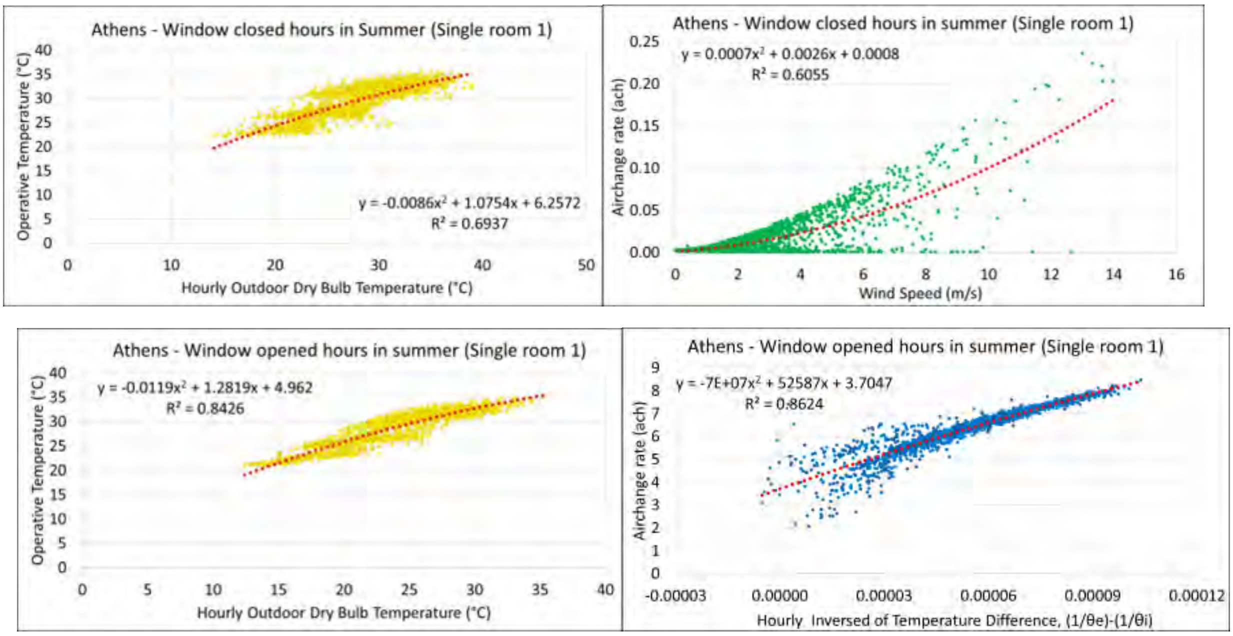
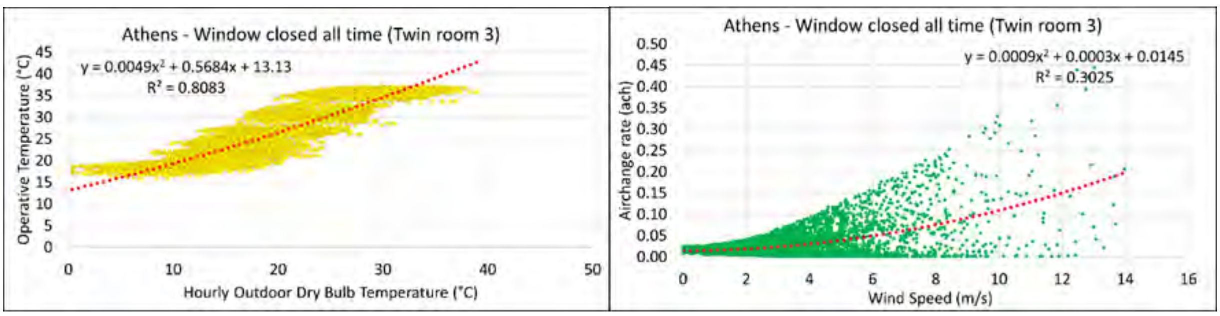
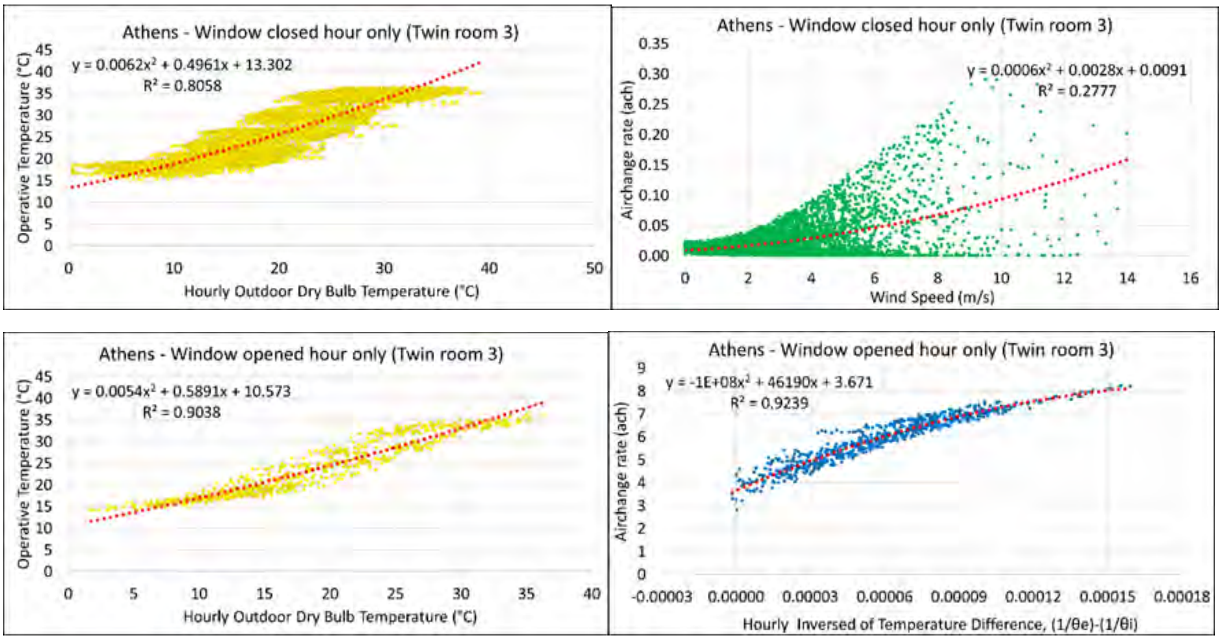


Figure 27 Correlations between indoor temperature, air change rate and outdoor weather for single room SR1 from secondorder (quadratic) polynomial equations.

Case 1: If the windows were closed at all times



Case 2: If the windows are opened two hours (morning and evening) daily and close the other hours



Case 2N: If the windows are opened from 20:00 to 08:00 for night-purge ventilation in summer

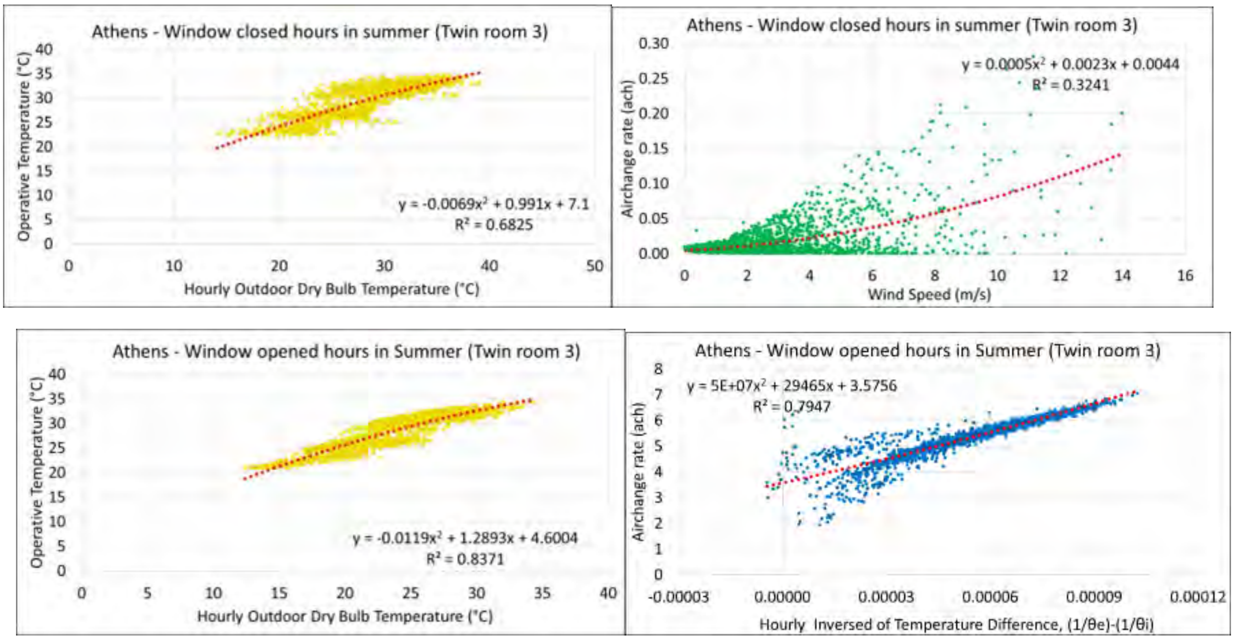


Figure 28 Correlations between indoor temperature, air change rate and outdoor weather for twin room TR3 from second-order (quadratic) polynomial equations.

The correlation equations shown in Figure 27 and Figure 28 were generated from second-order (quadratic) polynomial equations for indoor temperatures and air change for their relationships to the outdoor weather. A quadratic polynomial function is a second-degree function and always produces a parabola. The profile of the correlation scatters plots showed that the correlation trend can be calculated from a cubic polynomial function, which is a third-degree function and usually comes with two critical points (points where the line changes direction). Table 8 presents the summary of correlation equations gathered from the scatter plots.

Scenario code	Correlation Parameters		Coefficient of determination (R^2)		Correlation Equation for Thermal Comfort and Ventilation	
	x = Outdoor	y = indoor	Window Close	Window Open	Window Close	Window Open
Case 1 (window always closed), Single Room 1	DBT	OT	0.8007	n/a	$y = 0.0028x^2 + 0.6576x + 13.827$	n/a
	WS	ACH	0.382		$y = 0.0006x^2 + 2E\text{-}05x + 0.0042$	
	IVT	ACH	0.0157		$y = 330501x^2 - 119.17x + 0.0184$	
Case 2 (window opened for 2 hours, used for winter), Single Room 1	DBT	OT	0.8004	0.9183	$y = 0.0045x^2 + 0.5647x + 13.784$	$y = 0.0042x^2 + 0.6449x + 10.773$
	WS	ACH	0.3771	n/a	$y = 0.0006x^2 + 0.0007x + 0.0029$	n/a
	IVT	ACH	0.0197	0.9197	$y = 422074x^2 - 135.02x + 0.018$	$y = -1E+08x^2 + 50207x + 4.2922$
Case 2 (window opened 20:00-08:00, used for summer), Single Room 1	DBT	OT	0.6937	0.8426	$y = -0.0086x^2 + 1.0754x + 6.2572$	$y = -0.0119x^2 + 1.2819x + 4.962$
	WS	ACH	0.6055	n/a	$y = 0.0007x^2 + 0.0026x + 0.0008$	n/a
	IVT	ACH	n/a	0.8624	n/a	$y = -7E+07x^2 + 52587x + 3.7047$
Case 1 (window always closed), Twin Room 3	DBT	OT	0.8083	n/a	$y = 0.0049x^2 + 0.5684x + 13.13$	n/a
	WS	ACH	0.3025		$y = 0.0009x^2 + 0.0003x + 0.0145$	
	IVT	ACH	0.0038		$y = 456006x^2 - 115.17x + 0.0296$	
Case 2 (window opened for 2 hours, used for winter), Twin Room 3	DBT	OT	0.8058	0.9038	$y = 0.0062x^2 + 0.4961x + 13.302$	$y = 0.0054x^2 + 0.5891x + 10.573$
	WS	ACH	0.2777	n/a	$y = 0.0006x^2 + 0.0028x + 0.0091$	n/a
	IVT	ACH	0.0021	0.9239	$y = 443202x^2 - 88.192x + 0.0244$	$y = -1E+08x^2 + 46190x + 3.671$
Case 2 (window opened 20:00-08:00, used for summer), Twin Room 3	DBT	OT	0.6825	0.8371	$y = -0.0069x^2 + 0.991x + 7.1$	$y = -0.0119x^2 + 1.2893x + 4.6004$
	WS	ACH	0.3241	n/a	$y = 0.0005x^2 + 0.0023x + 0.0044$	n/a
	IVT	ACH	n/a	0.7947	n/a	$y = 5E+07x^2 + 29465x + 3.5756$

Table 8 Correlation equations from scatter plots for comfort and ventilation prediction

Predictions – Indoor air temperatures

The outdoor climatic parameters (x value on the horizontal axis of scatter plots) are independent variables; therefore, the dependent variables which are indoor condition parameters (y value on the vertical axis of scatter plots) are predicted. Therefore, the indoor operative temperatures can be predicted if the outdoor dry bulb temperatures are known. The predicted values of internal operative temperature for thermal comfort can be evaluated using the adaptive thermal comfort model and equations (BS EN 16798-1[10], 2019) to determine whether comfort is achieved.

Figure 29 and Figure 30 present the prediction results of the SR1 and TR3 rooms for one normal summer day and one normal winter day. Scenario 1 and scenario 2N were selected for summer; scenario 1 and scenario 2 were selected for winter. It was found that the predicted indoor temperatures were within adaptive limits.

[10] BS EN 16798-1 (2019) *Energy performance of buildings. Ventilation for buildings. Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. Module M1-6.* UK: BSI.

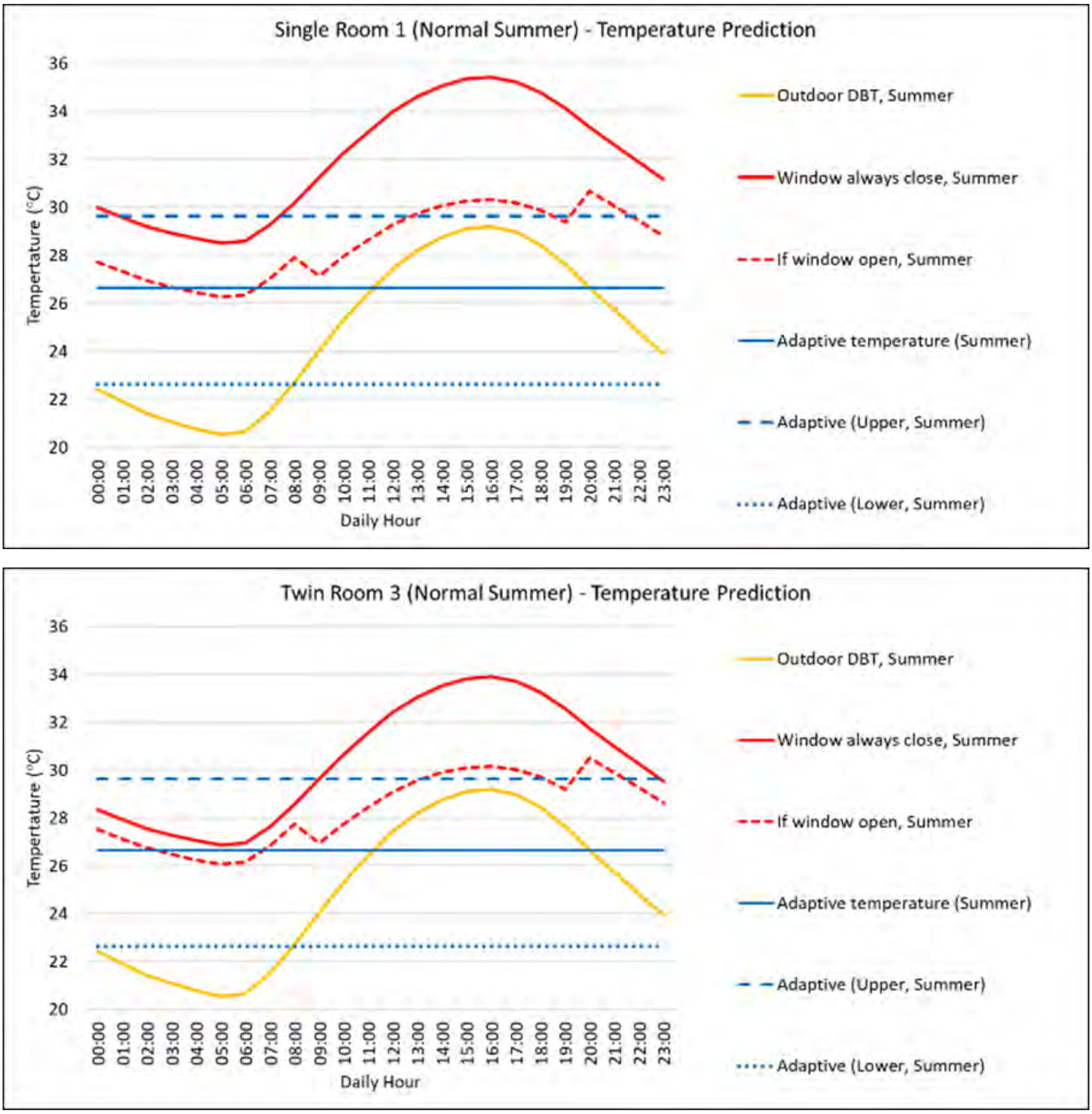
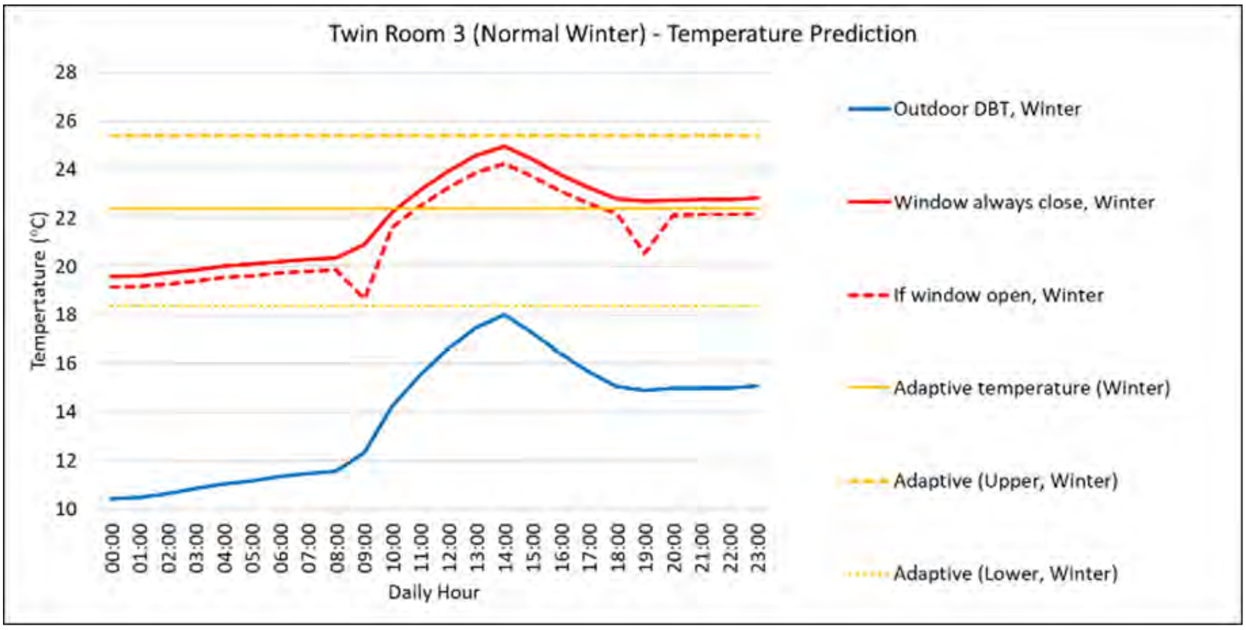


Figure 29 Indoor temperature prediction for (normal) summer days



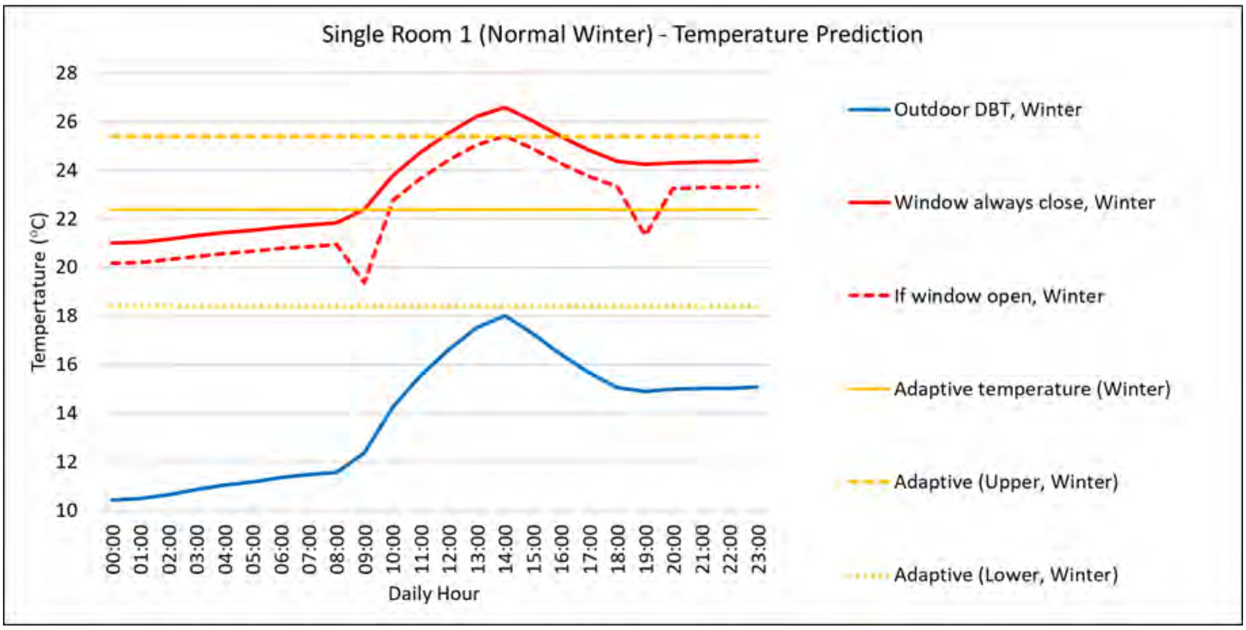


Figure 30 Indoor temperature prediction for (normal) winter days

Predictions – Indoor CO_2 concentration

The predicted values of airflow were evaluated by the single-zone mass balance equations which give the relationship between ventilation rate and wind/temperature differences. The indoor air carbon dioxide (CO_2) concentration, which is often used as an indicator of indoor air quality (IAQ) and one of the main drivers for ventilation requirements, was also selected to investigate the impacts of airflow on indoor air quality. Furthermore, space-specific indoor CO_2 concentration was calculated from the airflow prediction equations (Persily and Polidoro, 2019[11]). The evaluation process of this approach can be found in the PRELUDE report D3.4 and D6.1. The CO_2 concentration varied according to the occupancy schedules assigned for weekdays and weekends. Needless to say, the indoor air CO_2 concentration could trap in the

[11] Persily, A. and Polidoro, B.J. (2019) *Residential application of an indoor carbon dioxide metric.* https://www.aivc.org/sites/default/files/D2_S9A-03_1.pdf: 40th AIVC Conference., pp. 15.

room by closing windows all time both at weekends (yellow line) and weekdays (black line). Whilst the number of occupancies has a direct impact on indoor air CO_2 concentration, the concentration removal rate which is influenced by the air change rate and the air volume of the room also could alter the results of indoor air CO_2 concentrations. Figure 32 shows that the air change rates of the single room SR1 were significantly lower than the twin room TR3, and also showed window close cases. Therefore, the indoor CO_2 concentrations in the single room SR1 were significantly high (yellow lines) although it had only one occupant (Figure 31). On the other hand, the indoor CO_2 concentrations in the twin room TR3 were significantly high (blue and green lines) due to its higher occupancy (Figure 31). Applying mechanical ventilation could reduce CO_2 concentration (Figure 33), for instance, by adding an exhaust fan in the bathroom. To do so, further assessment for heating demand changes would be required (Figure 24).

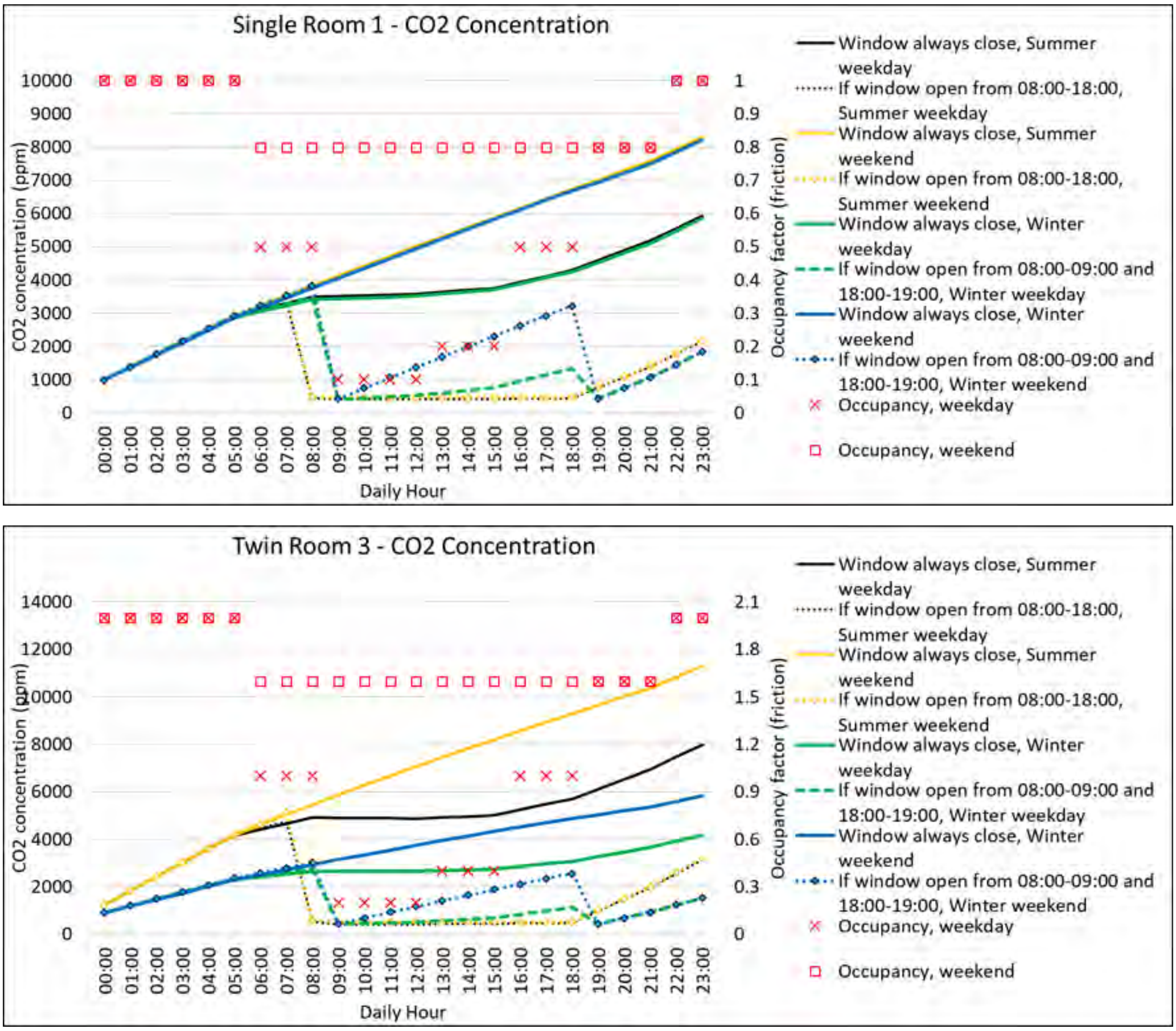


Figure 31 Indoor CO2 concentration in the window close at all times and the window open cases

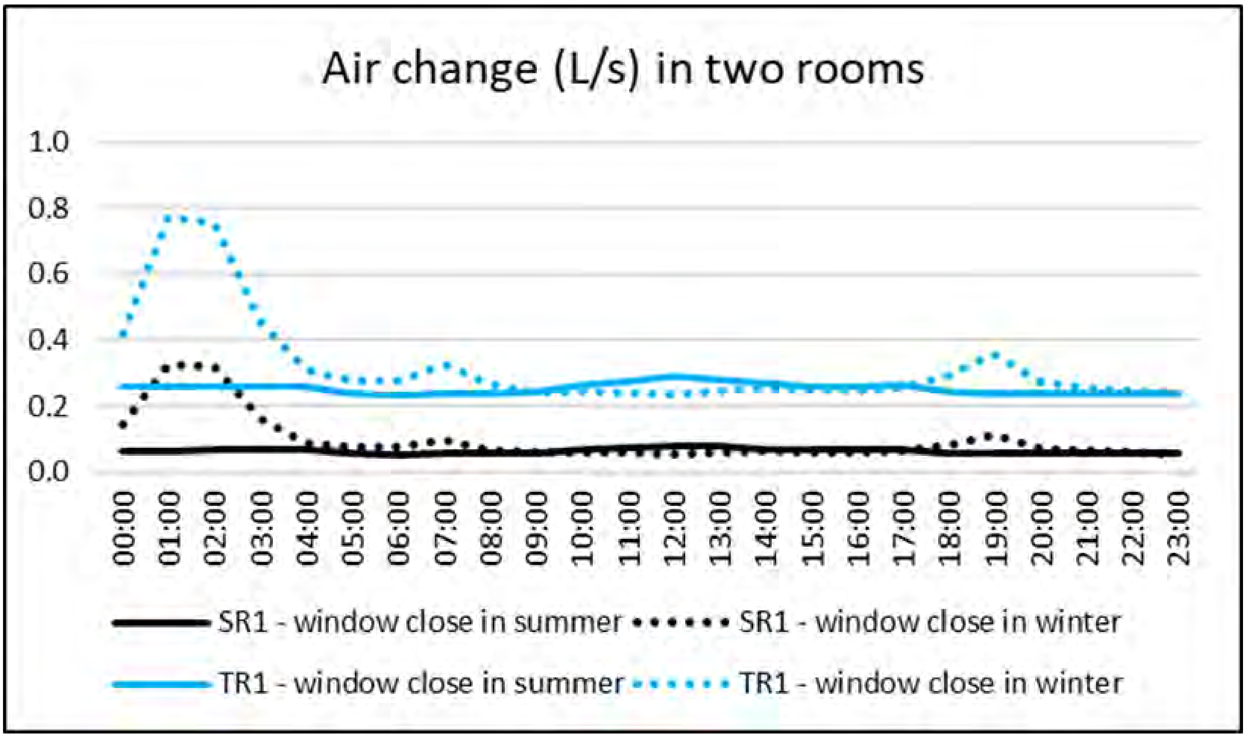


Figure 32 Air change in the single room SR1 and twin room TR3.

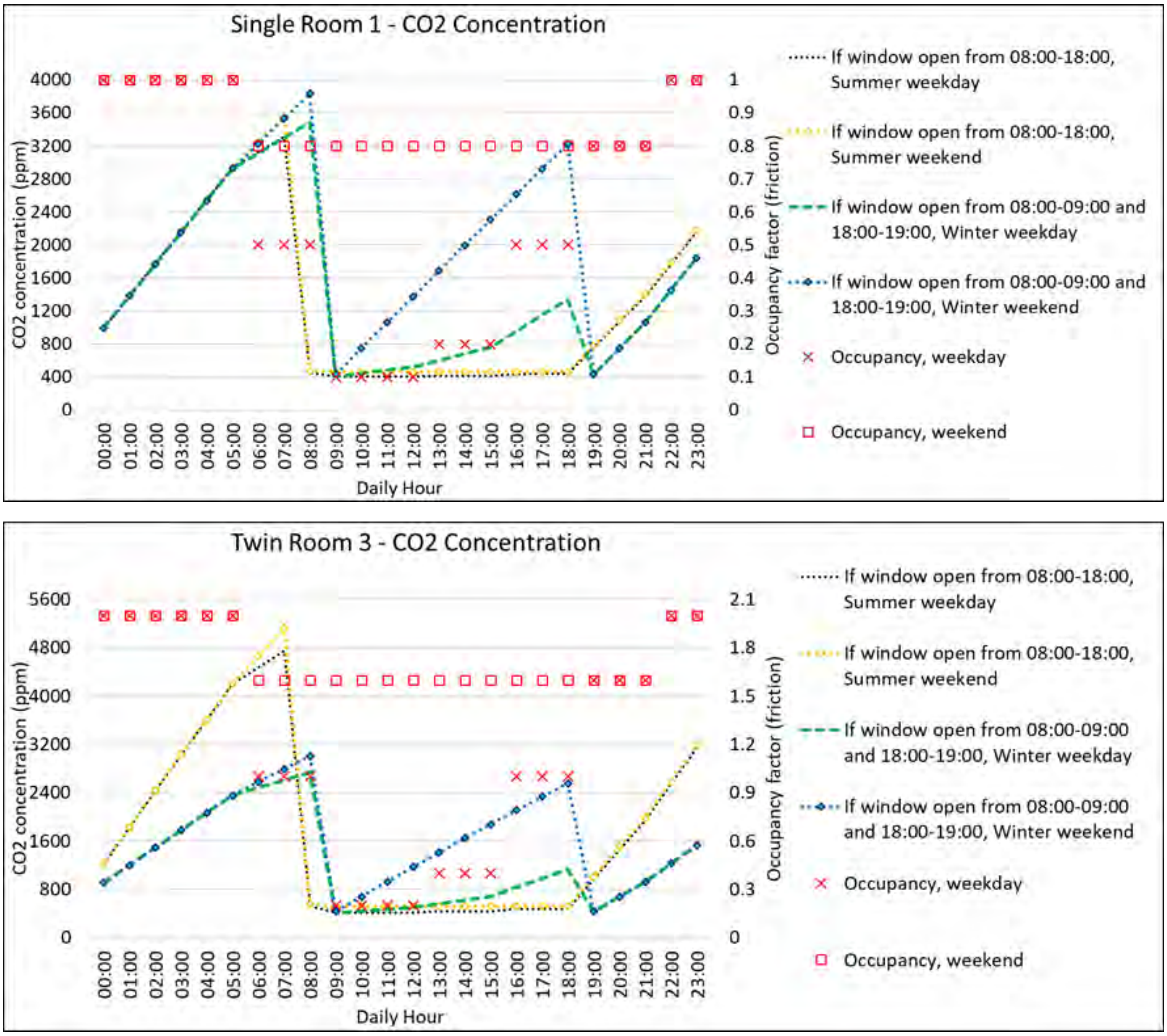


Figure 33 Indoor CO2 concentration in window-open cases

Discussion and implementation

This exercise carried out under WP7 demonstrates how the prediction model and equations are applied for different scenarios considering the variation in ventilation and cooling schedules which could be found in the operational environments. In sum, the following processes were used in this exercise.

- The studied climate was reviewed using the psychrometric chart in terms of its applicability to natural ventilation.
- One case study was selected to differentiate the impacts of different orientations and the number of occupancies.
- Building operation schedules, i.e., heating, cooling, ventilation, occupancy, internal gains generation from appliances and lighting, etc., were defined to develop test cases.
- Cases were proposed to investigate using correlation models for indoor condition predictions, considering night-purge ventilation, mechanical ventilation and window opening hours.

- Following the steps developed in PRELUDE D3.4[12] and D6.1, the temperature and air change rate (ventilation) were predicted using polynomial equations generated from scatter plots.
- The indoor air quality was evaluated to present how natural ventilation can be utilised differently for summer and winter days.

The indoor-outdoor correlation model can be used to inform residents on how to operate their windows so that thermal comfort and acceptable indoor air quality can be achieved through natural ventilation for the periods that this is possible (considering the outside conditions).

The model is implemented in the pilot by making forecasts for a few days and informing the residents on what to do regarding the opening of windows. This is a low tech solution which utilises the ability of the residents to control their environment correctly through taking appropriate actions. It will contribute to energy use reduction as heating, cooling and mechanical ventilation can be minimised by exploiting external prevailing conditions.

4.3 M&V METHODOLOGY AND BASELINE MODELS FOR ATHENS PILOT

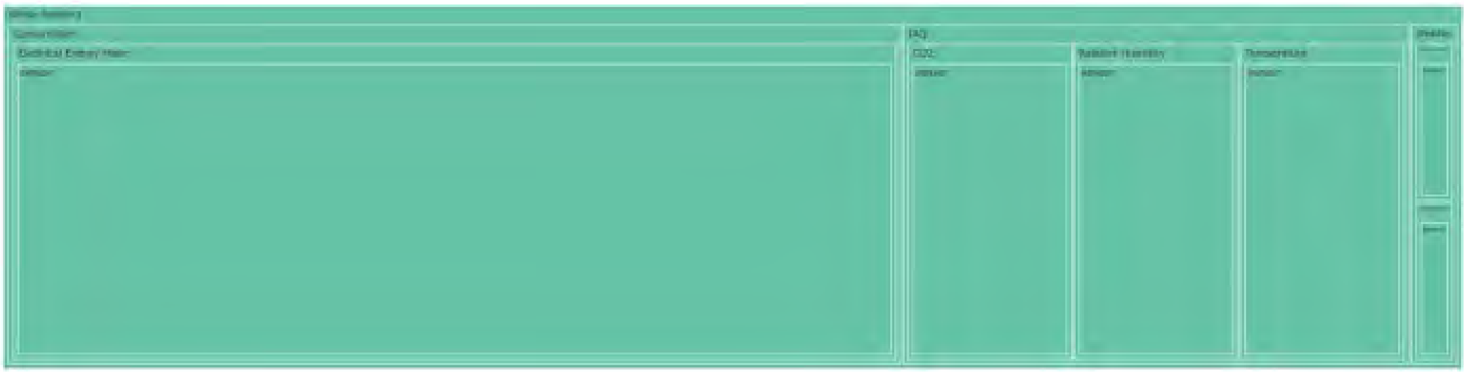
Overview of the proposed solution for building

The M&V framework developed in PRELUDE is presented in detail in deliverable 4.3 and refers to the M&V methodology developed in Task 4.3 of WP4 (Proactive optimization functions). However, as per the current plan, there are no plans to introduce a PRELUDE solution at the Athens demo site that could affect thermal energy consumption, and therefore there is no need to implement the M&V methodology. Instead, LIBRA has developed a methodological process for the Athens demo site that is in line with the M&V framework proposed in PRELUDE. The plan focuses on creating an adjusted baseline model which can be used in the future when interventions are made. Also, the adjusted baseline model can be used to forecast energy consumption.

Technical specifications of the proposed solution

As the demo site's characteristics are considered, the input source for the data will be the gas billings provided by the demo site's representative. Based on the gas billing information, the data resolution is monthly. The demo site's representative specifies all this input offline. The next step involves evaluating the data quality. All data points, non-routine adjustments, and demo site characteristics are available from 2018 to 2022, encompassing the pre-intervention period and providing essential information about the measurement boundary. Following a thorough analysis and mapping of the available data sources and the Athens demo site's characteristics, Figure 34 has been created.

Figure 34 Mapping of the distribution of the central devices in Athens.



[12] D3.4: Indoor-outdoor correlation module, PRELUDE

Despite the implementation of an extended monitoring solution in Athens, there is an absence of submetering sensors for monitoring thermal energy. This hinders the ability to formulate an energy flow chart with relevant data points. Moreover, the applied methodology requires weather data, specifically outdoor air temperature, which is obtained from the Meteostat Python library[13]. Necessary calculations are carried out to meet the minimum requirements for creating the adjusted baseline model.

Implementation plan

According to the current plan, there are no immediate plans to implement a PRELUDE solution at the Athens demo site that would impact thermal energy consumption. Therefore, implementing the M&V methodology is not necessary at this time. Instead, LIBRA aims to create an adjusted baseline model that conforms to the M&V framework and can be utilized in the future when interventions are made. This approach will result in the development of an adjusted baseline model that can also be used for forecasting energy consumption.

The input source for this calculation would be the gas billings provided by the demo site owner. Figure 35 displays the monthly gas consumption data for the years 2018 to 2022. After examining the data, we have decided to use the entire period from 01/01/2018 to develop the adjusted baseline model.

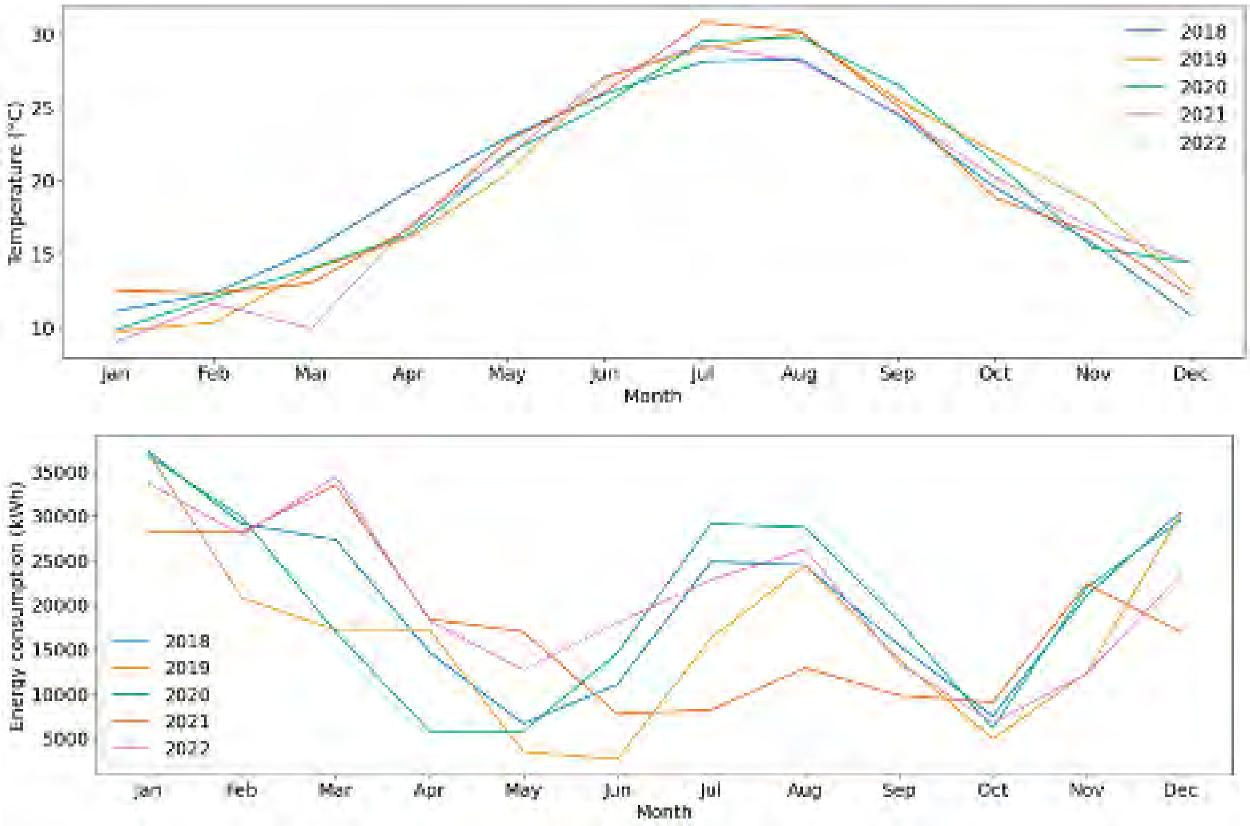


Figure 35 Monthly average temperature and gas consumption for the Athens Demo site for the years 2018 till 2022

The energy consumption of the entire building is evaluated based on its characteristics and available data, which corresponds to Option C (Whole Facility) in the M&V methodology. This cross-reference is only applicable if an ECM is applied in the future. Based on Athens' pilot energy consumption, which is measured monthly from gas billings, the appropriate training data for calculating the adjusted baseline model will be

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

selected from 01/01/2018 to 31/12/2022. The adjusted baseline model will be produced and presented in the final deliverable, to be used in the future if there are any energy conservation measures implemented.

Performance assessment of the implemented solution

For measuring the performance of the adjusted baseline model for the demo case, two metrics were selected: the Coefficient of Variation of Root Mean Square Error (CV-RMSE) and the Normalised Mean Bias Error (NMBE). Using both metrics together provides insight into the model's performance. The model performs better when the CV-RMSE value is the lowest, as this metric is used to calculate the introduced uncertainty. However, the NMBE is an ancillary metric used to support model evaluation but not utilized for model selection since positive bias can counteract negative bias, and the primary goal is to minimize the uncertainty in the modelling process.

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

Given the current status of the implemented PRELUDE solutions, there will be no energy savings to assess from applying the M&V methodology. The steps outlined in D4.3 regarding the M&V framework after the installation of ECMs cannot be carried out. However, an adjusted baseline model will be developed based on the demo site's current status and will be used for energy forecasting. This approach is a prerequisite step for a potential Saving Quantification and Performance Evaluation, which will have to be employed in case an ECM is implemented in the future. It is important to note that if any additional ECMs are installed, the M&V methodology will be adjusted accordingly to evaluate the energy savings accurately.

4.4 FUSIX TOOL FOR ATHENS PILOT

Section 4.4 aims at reporting the outputs and results from the analysis of the data collected by the Athens pilot in the FusiX tool. As mentioned also in a previous section, by the submission of the current document M30, EMTECH has not delivered to the PRELUDE pilots the FusiX platform with user accounts in order to monitor and process the data that are collected from the Athens building. Hence, these results are considered as still an ongoing process.

4.5 OCCUPANCY MODEL FOR ATHENS PILOT

Apart from the aforementioned results and analysis on the Athens pilot data, during the submission of this deliverable there is an ongoing analysis of the occupancy model from FB. The model is fed by the CO2 data that are collected by Estia building in Athens. As presented above, there are 7 sensors installed in the building measuring CO2 (as well as temperature and humidity) located in the common space of each floor. The results of the analysis are not possible to be reported here, since it is still ongoing; however, they will be available in the next months of the project.

5. SUMMARY OF RESULTS AND EXPECTED IMPACTS

According to the analysis that are performed so far in the project there are important results and outputs to be reported in this section and also to be correlated with the KPIs addressed on the expected impact of the PRELUDE pilots.

On the domain of maintenance cost, it was foreseen to have a study on the pilot location in order to analyse the data and the situation of the building envelope and status. For the maintenance the EPIQR tool was used and two scenarios were produced, the first for the potential renovation of Estia according to the up-to-date standards and the second for an optimization scenario that foresaw wider interventions in the building leveraging it to an advanced state and modernization. The second option was 2.8 times more costly (684k euros) than the first scenario which was approximately 242k euros. However, there is a need for an additional study in order to specify the cost effectiveness of the photovoltaic investment in the second option. These both studies foresee both other costs such as the architect fees, VAT etc.

In the case of the basic maintenance it mainly includes small scale repairs on the facade of Estia, a replacement of tiles and refreshment in all the walls, upgrade of sanitary facilities and on the distribution of the water and gas within the building. The performance of this potential proactive approach is estimated to depict a reduction in the unscheduled maintenance costs by 50%. For example an unexpected incident in the water distribution piping as it is now, would mean for the building administration the replacement of all the water distribution system for a 5-storey building in addition with complementary costs for the workers, hardware, etc would exceed 100k euros.

In the project description it was foreseen that PRELUDE will achieve an overall reduction in maintenance costs of minimum 20% through the proposition of a proactive maintenance approach rather than reactive. This approach under the scope of municipal buildings has the potentiality of being much more cost effective since the parallel scheduling of maintenance works in more than one building can have better financial planning and reduction of costs from external construction suppliers resulting in a lower investment. As an example the replacement of tiles could be calculated to be applied not only in Estia but also in other municipal buildings, hence resulting in less price for the material and work.

Hence in total the PRELUDE tools related to maintenance and the results of the Athens pilot are estimated to meet the KPIs as described in the DoA.

Maintenance						
PM reduction to Unscheduled	PM reduction to scheduled	Total PM reduction	PRELUDE O&M costs	Total cost reduction	Original costs per household	PRELUDE annual savings per household
48%	27%	154.95 €	240.05 €	39%	694 €	272 €

Table 9 Maintenance KPIs

Regarding the energy consumption of the Athens pilot, the Estia building is differentiated from the PRELUDE pilots as it offers social housing for free to vulnerable populations and the data that are integrated in FusiX are subject to limited user engagement.

The building is subject to overheating risks both in summer and winter, given the lack of monitoring and only central heating and cooling control is available. The consumption of the building prior to the PRELUDE project was calculated as 89.6 kWh/m2 , around 25% of which was cooling. The total saving of energy was foreseen to represent 1200 euros annually. At the moment the lack of monitoring in the FusiX data makes it difficult to report whether these KPIs can be met.

In parallel, the M&V model is currently developing a model for the forecasting of energy consumption in terms of thermal energy.

Energy consumption							
Current consumption (kWh/m2a)	Total heated area (m2)	Occupant behaviour (kwh/ m2a)	Proactive optimization (kwh/ m2a)	Final consumption (kwh/ m2a)	% Improvement	Annual energy savings (€)	Savings per household (€/a)
66.36	1080	14.60	13.52	36.55	45%	56,392 €	1199.83€

Table 10 Energy consumption KPIs

Regarding the domain of Indoor Air Quality (IAQ) for the Athens pilot - more so than the other use cases - it is much more important to achieve consistent comfortable conditions due to the vulnerable groups that are hosted. Most importantly the tenants are usually in poor health conditions and seniors, so the importance of the climate correlation model is critically high since it combines the orientation of the building, data from the blueprints and CO2 occupancy, as well as weather conditions and proposes different schemes of natural ventilation combined with mechanical ventilation with the aim to reduce the percentage of the latter.

The Climate Correlation model tackles the KPIs for indoor air quality and also proposes solutions on natural cooling schedules e.g. during night hours, that as well contribute to energy consumption reduction. In total the proposed schemes increase the quality of indoor conditions in terms of ventilation and temperature, have different application cases for the summer and winter period and increase comfort of temperature and living.

The overall accuracy of the assessment is high and utilises indoor factors and thermal indicators. Other factors under consideration are the outside weather conditions and the orientation of the tenants rooms in the building since this differentiates the solar gains, the thermal/cooling effect from the outside conditions, the habits of the tenants etc.

IAQ KPIS	
Minimum cooling loads addressed	Annual overheating hours
85%	< 8%

Table 11 IAQ KPIs

Finally, a non tangible impact of the PRELUDE implementation in the Athens pilot is the potentiality of replication of the solution and the evaluation of its scalability. More specifically in Athens there are hundreds of municipal buildings and a study on the cost effectiveness of PRELUDE could provide an exploitation potential of PRELUDE generally for cities. At the moment of this deliverable the complete toolkit of PRELUDE is not delivered to the pilots, hence currently this potentiality cannot be reported.

Nonetheless, the starting point for the Athens pilot was a non-digitized building with lack of monitoring tools so the purchase and installation of a costly system was necessary. Further analysis of the data that are collected and how they can be utilized on energy efficiency is still ongoing.

6. CONCLUSIONS

This deliverable is a detailed public report of the Athens pilot designed and implemented in the building "Estia of Athens". In the first sections a description of the building, the available data and requirements, an overview of equipment installed and sensors' measurements were presented.

The following sections are dedicated to solutions provided to all pilot sites from the technical partners. Regarding the Athens pilot, the EPIQR+ diagnosis of the Athens building was presented from ESTIA, the climate correlation model form BUL University and the M&V framework developed by LIBRA were described as well.

Finally, the results and the KPI's to be addressed and their impact on the whole process is of upmost importance. The evaluation of the results of Estia of Athens is interesting since the demo case of Athens has a social aspect taking into consideration that the building hosts vulnerable groups of population.

APPENDIX

EPIQR Diagnosis Report

Work cost Estimation

Diagnosis Cost index : 70.00

Diagnosis

Summary of cost

Wa Facades and balcony	54 800
Wi Windows and doors	0
Ro Roofs	11 100
Ss Common and secondary surfaces	58 400
Ms Main surface	9 600
El Electricity	0
He Heating	9 500
Ve Ventilation and Air conditioning	0
Sa Sanitary	24 000
Mi Security, transport, miscellaneous	2 300
Works cost (without fees and without VAT)	170 000
Architect's fees (without VAT) calculated on the basis of 15 % of the works cost	25 000
Sub-total of works and fees (without VAT)	195 000
Misc. and unexpected's fees (without VAT) calculated on the basis of 0% of the sub-total	0
VAT on the basis of 24% of the sub-total and misc. and unexpected	47 000
Total cost for renovation (with VAT)	242 000

1 / 5

Work cost Estimation

Diagnosis — Cost index : 70.00

	%	Element-Type	Degradation	Intervention	Cost excl. taxes
Wa		**Facades and balcony**		**0**	**54 800**
1.1	50%	External wall - Rendering	❶○○	■□□	12 700
1.7	50%	External wall - Wood or metal cladding	❶○○	■□□	15 100
3.1		External wall thermal insulation - Absence of thermal insulation	○○❸	□□□	0
5.1	50%	Balconies and galleries - Concrete / masonry railing	❶○○	■□□	16 900
5.2	50%	Balconies and galleries - Metal / wood railing	❶○○	■□□	10 100

	%	Element-Type	Degradation	Intervention	Cost excl. taxes
Wi		**Windows and doors**		**0**	**0**
1.2		Windows - Aluminum or PVC windows	○⓪○	□□□	0
3.2		External doors - Manual wood or metal doors	○⓪○	□□□	0
2.5		Shutters and solar protection - External blinds	○○❸	□□□	0
2.6		Shutters and solar protection - Internal solar protection	○⓪○	□□□	0

	%	Element-Type	Degradation	Intervention	Cost excl. taxes
Ro		**Roofs**		**0**	**11 100**
1.4		Roof covering - Flat roof with access	❶○○	■□□	8 200
1.5		Roof covering - Flat roof without access (to residents)	❶○○	■□□	2 900
3.3		Roof thermal insulation - Flat Roof	○⓪○	□□□	0

	%	Element-Type	Degradation	Intervention	Cost excl. taxes
Ss		**Common and secondary surfaces**		**0**	**58 400**
3.2		Floor thermal insulation - Thermal insulation basement-ground floor	○○❸	□□□	0
2.1		Interior doors - Wood interior manual doors	❶○○	■□□	6 100

2 / 5

	%	Element-Type	Degradation	Intervention	Cost excl. taxes
4.1		Common premisses - In basement including distribution	3	■■■	0
1.1		Main distribution - Interior distribution - housing	1	■□□	52 300

Ms		Main surface		0	9 600
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
4.1		Kitchen - Equipped kitchen	0	□□□	0
5.1		Sanitary premisses - Toilets in bathroom	1	■□□	9 600
7.1		Interior carpentry - Interior carpentry	0	□□□	0
1.3		Floor finishings - Tile covering	0	□□□	0
2.8		Interior walls and wall finishings - Generic	0	□□□	0
2.5	30%	Interior walls and wall finishings - Ceramic tiles	0	□□□	0
3.8		Ceiling coating - Generic	0	□□□	0
3.3	50%	Ceiling coating - Rendering	0	□□□	0
3.4	50%	Ceiling coating - Plaster suspended ceiling	0	□□□	0

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

He		Heating		0	9 500
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.2			0	□□□	0

	Heating central production plant - Oil or gas boiler - more than 1500m2 HRA resp. 100kW			
2.1	Sanitary hot water production - Central boiler with heat exchanger	○⓪○	□□□	0
3.1	Heating distribution network - Apparent heat distribution	❶○○	■□□	9 500
4.2	Heating and cooling terminal units - Radiators - generic	○⓪○	□□□	0

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

Sa	**Sanitary**		**0**	**24 000**
%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1	Water connection and metering - Connection and water distribution battery	○⓪○	□□□	0
2.1	Sewage pipes - Wastewater pipes	❶○○	■□□	700
3.1	Sanitary water distribution - Cold water and hot water pipes	❶○○	■□□	23 300

Mi	**Security, transport, miscellaneous**		**0**	**2 300**
%	Element-Type	Degradation	Intervention	Cost excl. taxes
0.0	Lift and extinguisher - summary - Elevator	○⓪○	□□□	0
1.1	Lifts - Lift	❶○○	■□□	2 300
2.1	Gaz connection to the city network - Connection to natural gas	○⓪○	□□□	0

Works cost (without fees and without VAT)	**170 000**
Architect's fees (without VAT) calculated on the basis of 15 % of the works cost	**25 000**
Sub-total of works and fees (without VAT)	**195 000**
Misc. and unexpected's fees (without VAT) calculated on the basis of 0% of the sub-total	**0**
VAT on the basis of 24% of the sub-total and misc. and unexpected	**47 000**
Total cost for renovation (with VAT)	**242 000**

4 / 5

EPIQR Optimization Report

Work cost Estimation

Optimization Cost index : 70.00

Optimization

Summary of cost	
Wa Facades and balcony	54 800
Wi Windows and doors	27 500
Ro Roofs	11 100
Ss Common and secondary surfaces	216 900
Ms Main surface	138 300
El Electricity	28 900
He Heating	0
Ve Ventilation and Air conditioning	0
Sa Sanitary	0
Mi Security, transport, miscellaneous	2 300
Works cost (without fees and without VAT)	480 000
Architect's fees (without VAT) calculated on the basis of 15 % of the works cost	72 000
Sub-total of works and fees (without VAT)	552 000
Misc. and unexpected's fees (without VAT) calculated on the basis of 0% of the sub-total	0
VAT on the basis of 24% of the sub-total and misc. and unexpected	132 000
Total cost for renovation (with VAT)	684 000

1 / 4

Work cost Estimation

Optimization

Cost index : 70.00

Wa		Facades and balcony		0	54 800
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1	50%	External wall - Rendering	❶○○	■□□	12 700
1.7	50%	External wall - Wood or metal cladding	❶○○	■□□	15 100
3.1		External wall thermal insulation - Absence of thermal insulation	○○❸	□□□	0
5.1	50%	Balconies and galleries - Concrete / masonry railing	❶○○	■□□	16 900
5.2	50%	Balconies and galleries - Metal / wood railing	❶○○	■□□	10 100

Wi		Windows and doors		0.00	27 500
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.2		Windows - Aluminum or PVC windows	○⓪○	□□□	0
3.2		External doors - Manual wood or metal doors	○⓪○	□□□	0
2.5		Shutters and solar protection - External blinds	○○❸	■■■	27 500
2.6		Shutters and solar protection - Internal solar protection	○⓪○	□□□	0

Ro		Roofs		0	11 100
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.4		Roof covering - Flat roof with access	❶○○	■□□	8 200
1.5		Roof covering - Flat roof without access (to residents)	❶○○	■□□	2 900
3.3		Roof thermal insulation - Flat Roof	○⓪○	□□□	0

Ss		Common and secondary surfaces		0.00	216 900
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
3.2		Floor thermal insulation - Thermal insulation basement-ground floor	○○❸	■■■	16 300
2.1		Interior doors - Wood interior manual doors	❶○○	■■■	27 000

4.1		Common premisses - In basement including distribution	3	■■■	0
1.1		Main distribution - Interior distribution - housing	1	■■■	173 600

Ms		Main surface		0.00	138 300
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
4.1		Kitchen - Equipped kitchen	0	□□□	0
5.1		Sanitary premisses - Toilets in bathroom	1	■□□	9 600
7.1		Interior carpentry - Interior carpentry	0	■■■	31 600
1.3		Floor finishings - Tile covering	0	■■■	39 500
2.8		Interior walls and wall finishings - Generic	0	■■■	29 600
3.8		Ceiling coating - Generic	0	■■■	14 600
3.4	50%	Ceiling coating - Plaster suspended ceiling	0	■■■	13 300

El		Electricity		0.00	28 900
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
5.1		Lighting appliances - Lighting Fixtures	0	□□□	0
6.1		Individual electricity production - Photovoltaic panels	3	■■■	28 900
1.1		Electrical power supply and main electrical panel - Without induction current compansation	0	□□□	0
2.1		Pannels and secondary electrical distribution - Low power distribution pannels	0	□□□	0
4.1		Lighting wiring and plugs - Power supply for outlets and lights	0	□□□	0
3.2		Emergency lighting - Centralised power supply	0	□□□	0

He		Heating		0	0
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.2		Heating central production plant - Oil or gas boiler - more than 1500m2 HRA resp. 100kW	0	□□□	0
2.1		Sanitary hot water production - Central boiler with heat exchanger	0	□□□	0

3 / 4

3.1	Heating distribution network - Apparent heat distribution	1		0
4.2	Heating and cooling terminal units - Radiators - generic	0		0

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

Sa	Sanitary		0	0
%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1	Water connection and metering - Connection and water distribution battery	0		0
2.1	Sewage pipes - Wastewater pipes	1		0
3.1	Sanitary water distribution - Cold water and hot water pipes	1		0

Mi	Security, transport, miscellaneous		0	2 300
%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1	Lifts - Lift	1		2 300
2.1	Gaz connection to the city network - Connection to natural gas	0		0

Works cost (without fees and without VAT)	**480 000**
Architect's fees (without VAT) calculated on the basis of 15 % of the works cost	72 000
Sub-total of works and fees (without VAT)	**552 000**
Misc. and unexpected's fees (without VAT) calculated on the basis of 0% of the sub-total	0
VAT on the basis of 24% of the sub-total and misc. and unexpected	132 000
Total cost for renovation (with VAT)	**684 000**

4 / 4