Sapienza
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Mining Sensor Data to Evaluate Indoor Environmental Quality of Public Educational Buildings

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Abstract

Public educational systems manage a large number of buildings from primary schools to universities. Each of the building has its unique architectural features, working schedule, and users' behaviour patterns. It is difficult to measure the operating performance of the building without data. In this work, we analyze the data collected during the past two years from sensors deployed in 15 different school buildings across the European continent. We use data mining techniques to detect abnormal conditions in the indoor environments and provide critical insights for the management personnel to evaluate the current operation, optimize the energy consumption and achieve better indoor environment quality

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1 Introduction

Public educational systems operate the school buildings at national level. These buildings are diverse in the architecture design, material, the building's location and orientation, age, size, the numbers of rooms, climate types, thermal pattern for indoor and outdoor, local culture, the cooling and(or) heating systems working time, users' habits and user activity patterns.

Each school building has unique requirements in contrast to commercial buildings or residential buildings. For example, indoor air quality and thermal comfort has to meet the request to fulfil the education purpose. The young students are more vulnerable to poor air quality or the temperature change. Classrooms lacking proper air ventilation or containing a high concentration of carbon dioxide or formaldehyde, can have a direct impact on the academic performance of the students. Frequent and widely fluctuating temperature could cause difficulties on the focus of the students on their study. The use of heating/cooling systems can control comfortable indoor conditions; however, their operation increases the total expenses during hot/cold seasons. Studies show energy costs being the second largest operating expense for school after the salary expense [1].

An interesting aspect of the energy efficiency in school buildings is that people believe this part of the cost is fixed and there is no space for improvement. However, recent research studies show that 20% to 37% of the energy expenses could be saved simply by engaging the students, the teachers and staff into energy saving activities, while maintaining the same quality of the environment for the study [2].

Research shows that energy consumption by heating and cooling could reach up to 20% out of the total energy cost of public school buildings in the US [3]. An important factor is the orientation of the buildings. It is not easy to change the orientation of the classrooms or the buildings, but changing users' behaviour or rearranging the interior, the room could be adjusted to have the most optimized natural light, comfortable air circulating, and maximize the effect from sunlight lighting up and heating the rooms. By utilizing the potential contributions of the sun, topography, and existing vegetation, it is possible to improve energy efficiency by reducing heat loss in winter and decreasing heat gain in summer [3].

In fact, this orientation of building research has been studied since the ancient times in China. Because of the lack of measurement for quantifying the result, Feng Shui becomes more philosophical than scientific. Without evidence on the performance of buildings such as the interaction of indoor-outdoor environment, strategic planning and sustainable operation of educational buildings becomes difficult. It is critical to provide real-world measurements on the actual conditions of classrooms and in general school buildings in terms of the ambient conditions [4]. Under this prerequisite, it is necessary to deploy an IoT infrastructure to provide the data for evaluating, redesigning and providing suggestions for the management of the effectiveness and optimization.

In this work, the data collected from the GAIA platform [5], an IoT infrastructure deployed in 3 countries (Greece, Italy, Sweden), 15 school buildings, are examined and analyzed in order to provide an evidence-based understanding of the energy consumption and indoor environmental conditions.

The data collected over a period of 2 years is analyzed in order to determine the indoor conditions of classrooms and provide insights on the operation of these educational buildings. This work establishes a comparative evaluation of different buildings and classrooms using quantitative measures. The analysis presented here can help building managers to quickly identify classrooms that do not have optimal indoor environmental conditions and proceed by conducting targeted interventions to improve the conditions. It can assist in reducing the energy consumption in the long-term and contribute towards the sustainability of public educational buildings.

The rest of the work is structured as follows:

- Chapter 2 presents the design principles, system architecture and sites of the IoT infrastructure deployed over a fleet of educational buildings.
- Chapter 3 examines the availability of data collected from the IoT infrastructure, conducts and analysis of the quality of the data and presents specific techniques to improve the quality and overcome the problem of missing data.
- Chapter 4 studies the thermal comfort of the classrooms and uses it to comparatively evaluate the performance of schools with similar characteristics. The indoor environmental conditions of classrooms are analysed in terms of thermal conditions and an automated method is presented to identify classrooms with poor thermal performance.
- Chapter 5 concludes the work and future research directions are provided.

2 Monitoring Public Educational Buildings

2.1 Overview

Public educational systems operate thousands of buildings with vastly different characteristics in terms of size, years of construction and preservation, location, thermal behaviour and user communities and behaviour patterns. The most significant cost to keep them operating is the energy consumption. This work is based on a real-world Internet of Things (IoT) deployment over a range of educational buildings across Europe. The real-world deployment is the result of an on-going research project called GAIA (http://gaia-project.eu) aiming to provide a method for quantitative performance of energy efficiency of school buildings and their users.

The IoT platform [6] focuses on the environmental sustainability and energy efficiency of school buildings. The core idea is that the availability of actual measurements of environmental parameters, such as energy consumption, indoor and outdoor luminosity, temperature, noise, pollution, etc., enables the conception and realization of diverse applications and scenarios. The goal is to provide a platform which will cater to the requirements of a broad variety of applications that will facilitate the educational sector towards improving the energy efficiency of school buildings. The ultimate goal is to involve the users (students, teachers, administrative personnel) in the process of improving the energy efficiency of the school buildings. This is achieved by attempting to affect the behaviour of the users by keeping them informed on the energy performance of their actions and helping them choose more efficient actions.

Figure 1 gives an overview of the architecture of GAIA; it is apparent that the IoT level and associated ecosystem runs through all of the architecture levels. It is important to outline the thinking behind the design of the IoT deployment and accompanied services and design philosophy of the main components of the GAIA platform.

Uniformity of design, replicability and reusability: all of the deployment sites follow similar design patterns regarding their infrastructure, even though they are applied in different environments, and based on different device types and vendors. This allows the IoT deployment to have great flexibility with respect to hardware, thus having an approach that is replicable and reusable, both in terms of hardware and software, since end-user applications can make the assumption that all sites feature similar capabilities.

Anonymity and Privacy: since the IoT deployment is dealing with very sensitive end-user groups in terms of privacy, the design needs to respect such aspects. The technologies and installations attempt to capture the activities of groups of people, rather than specific end-users, where possible.

Compatibility with school buildings design: the deployments try to adapt to the design and organization of school buildings; although there are several cultural differences in the way school buildings are designed in Sweden, Italy and Greece, there are many similarities as well. Also, school buildings have features that are in many ways very different than other public buildings, e.g., office buildings.

Compatibility with school daily activity and organization: the IoT infrastructure and ecosystem aim to become a part of the educational activity taking place at the participating schools. As mentioned above, the data originating from the IoT can potentially stir the interest of students and educators alike, and ideally make for a more personalized educational experience.

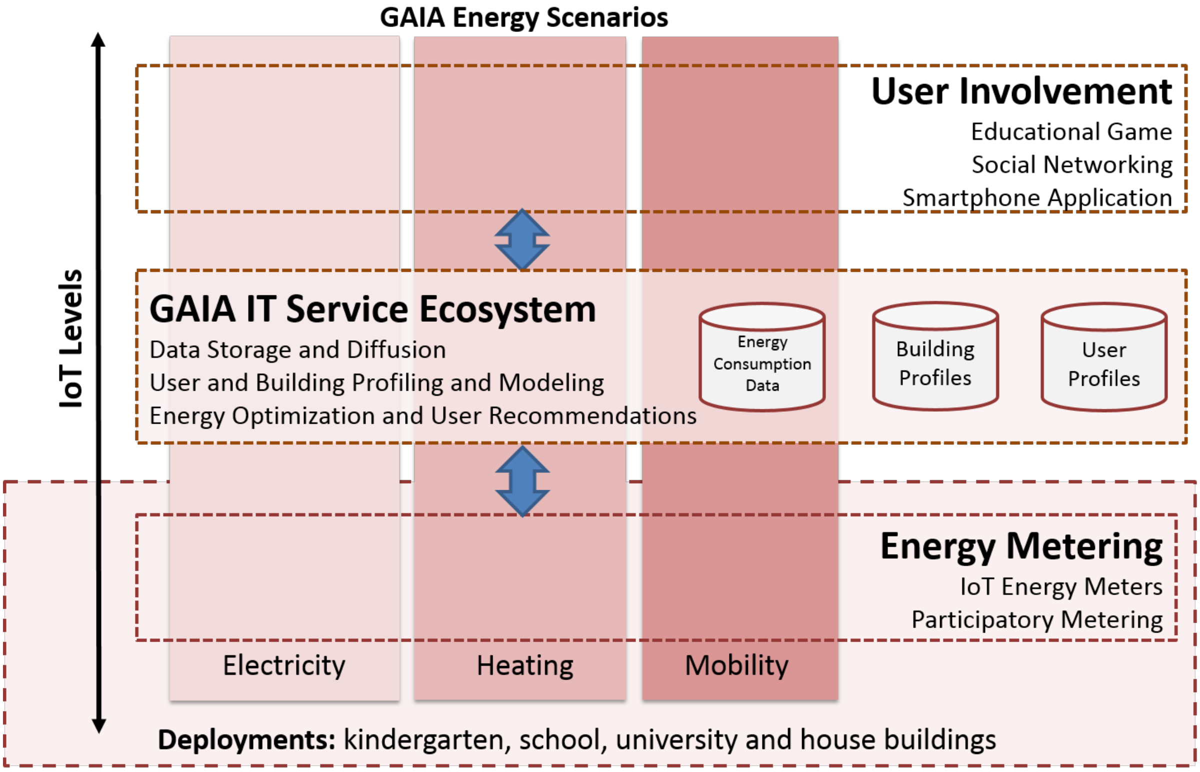

Figure 1: GAIA architecture design overview

Open source approach: a main goal of the system is to be expandable and easy to interface with other systems or components. Towards this end the system utilizes open standards and components.

Conformance with existing standards: It is reasonable to expect a diverse set of device providers working under the same interoperability framework. Due to this, the software infrastructure is hardware independent: sensors from different manufacturers interoperate with the cloud based services. IoT ecosystems are composed of a variety of business players that collaborate towards bringing together a diverse set of devices for real-time monitoring and management of school buildings. Therefore, the concept and scope of the IoT as defined by ITU-T in 2012 [ITU-T] are adopted.

Non-invasive installation: another critical point is the non-invasiveness of the IoT infrastructure; as it is crucial that no significant changes are involved in installing new IoT devices inside classrooms, i.e., no significant costs are incurred. As an additional advantage, equipment can be easily relocated to other building spots for convenience.

Minimal operational costs: apart from the installation costs, there are the operational costs associated with the IoT infrastructure. The use of standard hardware components like low-power microcontrollers limits the energy consumption of such devices to several watts, thus the overall energy consumption of the IoT infrastructure for a building amounts to less than the consumption of a single light bulb.

Monitoring-only infrastructure with no actuation capabilities: the design reflects the fact that real-world deployment is dealing with a sensitive sector. It is also a product of the fact that end-users should be included in the feedback-action loop; an ecosystem that acts completely in a transparent manner to the end-users does not help in keeping them engaged in the whole process.

2.2 A typical deployment of Internet of Things devices

The IoT deployment monitors in real-time electricity consumption, indoor and outdoor environmental conditions and atmospheric condition over two years, shown in Figure 2:

- Power consumption devices are situated on the general electricity distribution board of each building to measure the power consumption of each one of the 3-phase power supply.
- Indoor environmental comfort devices measure various aspects such as thermal (satisfaction with surrounding thermal conditions), visual (perception of available light) comfort and overall noise exposure. They also monitor room occupancy using passive infrared sensors (PIR).
- Outdoor weather stations devices and atmosphere stations devices monitor measure weather conditions including wind speed and direction and atmospheric pressure and concentration of selected pollutants (to provide insights on the pollution levels).

All of the aforementioned IoT devices communicate wirelessly with each other, eliminating almost all dependency on wired connectivity, apart from the gateway devices. Specific details on networking technologies and protocols used are included in subsequent chapters, but in general the IoT deployment relies on IEEE 802.15.4 and ZigBee in most cases, as well as WiFi. In several cases where wireless connectivity within the building sectors is difficult, due to network topology or building characteristics, we additionally utilize 3G-enabled devices.

For the majority of the school buildings, a typical actual installation so far consists of the following:

- 1 or 2 power meters, installed inside the school's central electricity distribution panel or one that controls a discrete building sector or floor.
- 5 or 6 IoT sensor boxes, installed inside classrooms dedicated to a specific class, or ones that are share among many different classes. A typical example in Greece is the computer lab classroom, which is shared among all classes of a school.
- 1 weather station installed on the building roof.
- 1 smart plug, which can be moved from room to room by staff or students.

This kind of typical setup enables the IoT deployment to do the following:

- Have a detailed idea of the overall electricity consumption of the building, general patterns in consumption, irregularities, establish energy consumption baselines and extract other useful data.

- In many cases, have a view of how a specific floor or building sector fares in terms of energy consumption against the energy profile of the building.
- Using energy consumption disaggregation techniques, identification of specific devices/procedures can be performed.
- Detailed environmental data from the IoT sensor boxes can give a clear picture of what is actually taking place in classes; if rooms are occupied, how specific parts of the building behave in terms of end-user thermal and visual comfort, etc.
- The IoT weather stations give a precise picture of what is happening outdoors and within the schools areas' microclimates. Such data can be utilized to make detailed studies regarding the buildings' behavior in aspects related to e.g., insulation or even how well procedures such as heating are adjusted to environmental parameters.

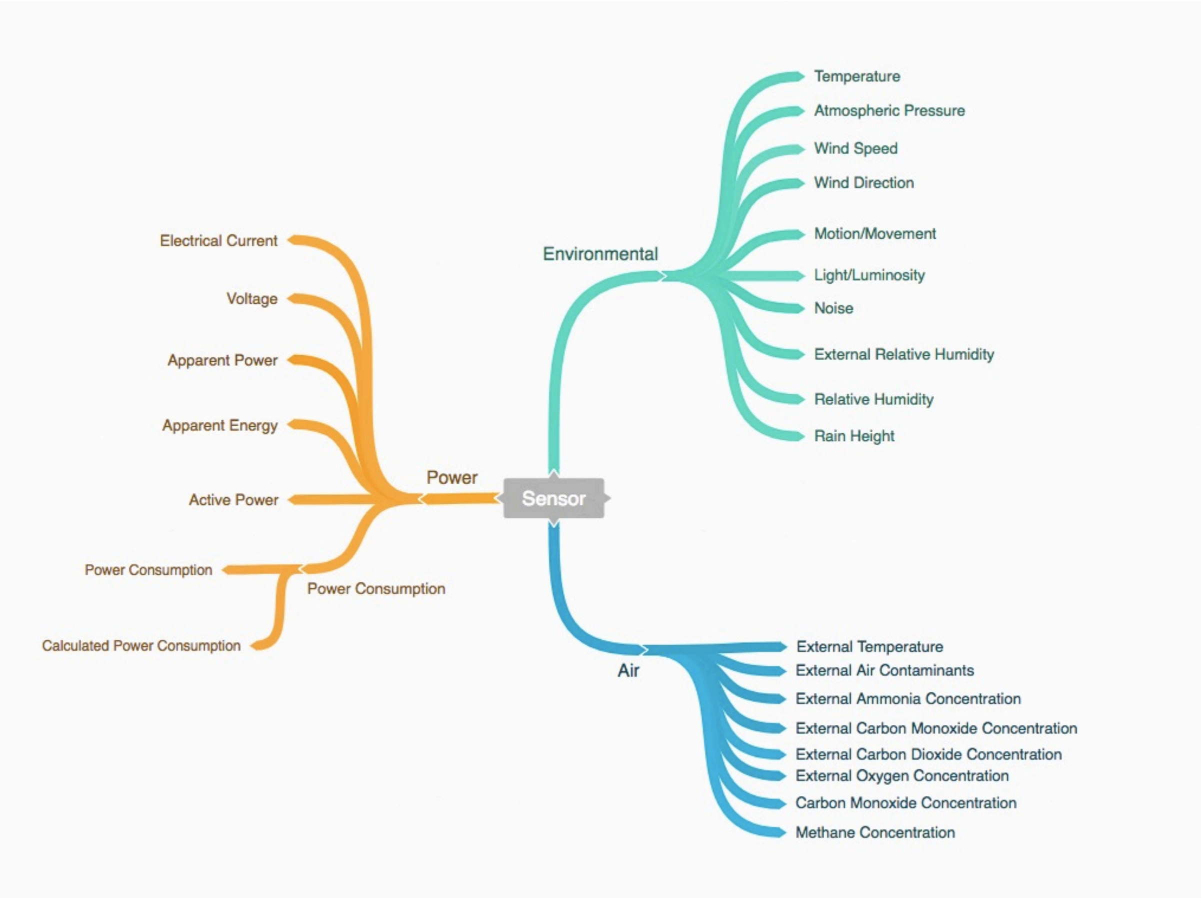

Figure 2 Cluster by types of data sensors collect

Apart from the direct advantages such IoT infrastructure has, with respect to energy consumption, regarding the rest of the activities supported:

- Such an infrastructure complies with the privacy policies and restrictions. This is a very important factor to consider for such an IoT deployment since we are dealing with students, and by utilizing such infrastructure we already eliminate several risks with respect to identifying individual behaviors and activities since we are dealing with classrooms, building sectors and floors.

- It provides a solid foundation to develop educational applications; data are retrieved in almost real-time, with good enough precision, which in turn can be further utilized in other parts of the ecosystem.
- Real-world data that can potentially augment end-user engagement, and even provide a certain "scientific" aura to the overall experience.
- Such data can be easily integrated into a school curriculum to provide real-world examples with data produced in real time, enriching the learning process and making it more personal and easier to relate to for students.
- Such data can be used by research communities for algorithm and systems' validation and optimization purposes.

Table 1 summarizes the different sensors deployed and the corresponding measurement units.

Table 1 Sensor Type, Measurement and units

TYPE	Measurement with units
Power	Calculated Power Consumption, mWh
	Power Consumption, mWh
	Electrical Current, mA/A
	Active Power, mW
	Apparent Energy, Vah
	Apparent Power, VA
	Voltage, V
	Power Factor, Raw Value
	Reactive Energy, VARh
	Reactive Power, VAR
Indoor environmental	Temperature, Centigrade
	Motion, Raw Value
	Relative Humidity, %
	Luminosity, Raw Value
	Noise, Raw Value
Outdoor weather	Atmospheric Pressure, kPa
	External Relative Humidity, %
	Light, lux
	Rain Height, mm
	Wind Direction, degrees
	Wind Speed, m/sec
	Movement, Raw Value
	External Temperature, Centigrade
	Radiation, uSv/h
	External Air Contaminants, Raw Value
Atmospheric condition	External Ammonia Concentration, Raw Value
	External Carbon Dioxide Concentration. Raw Value
	External Carbon Monoxide Concentration, Raw Value
	External Oxygen Concentration, Raw Value
	Carbon Monoxide Concentration, Raw Value
	Methane Concentration, Raw Value

The design approach allows the combination of data arriving from different buildings into single, unified views. As an example, Figure 3 provides a unified view of the overall power consumption of schools located in Greece. Such unified views can be used to create a baseline for the power consumption using the similarity in different schools. In such a simple representation of the available data it is easy to identify that the 8th Gymnasium Patras (ID 27827) use more energy than the others at the same time.

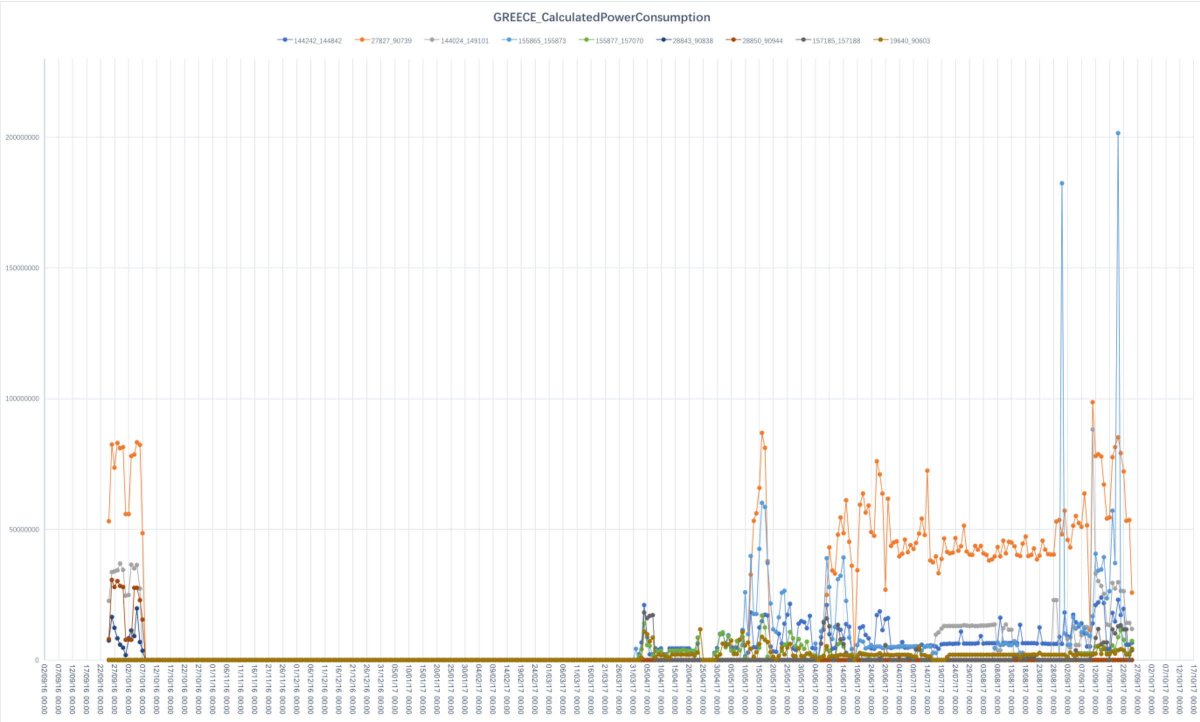

Figure 3 Power Consumption in Greece Schools

During the analysis of the data collected from the IoT deployment it is important to keep in mind that although the availability of the data is a very powerful tool, in most cases each school is a separate entity with different operating conditions and building infrastructure. In the case of the 8th Gymnasium Patras (ID 27827), after consulting the opening schedule for this school, it is easy to understand that this building is shared by two schools one in the morning another in the afternoon. In this case it is reasonable to expect that the overall power consumption is higher than the other schools.

It is therefore important to examine the different deployment sites and highlight the basic operating conditions that affect the indoor and outdoor environmental conditions.

2.3 Deployment Sites

In this section, information on the deployment sites are provided. The building properties are presented along with facts regarding the actual day-to-day operation of each school. Essentially, a short building profile is given in order to be in a position to better understand the data collected from the IoT deployment.

Overall the real-world IoT platform has deployed sensors in Greece (blue pins), Italy (green pins), Sweden (yellow pin) as shown in Figure 4, and the brief information about the overall deployment is shown in Table 2

Table 2 Sensor Deployment Information

Parameter	Numbers	Description
Educational Buildings	18	13 Greece, 4 Italy, 1 Sweden (15 active so far)
Sensing Points	725	5 sensors per device in average
Students	5500	students in all levels
Teachers	900	teachers in all levels
Sensing Rate	30 seconds	classroom sensors

These school buildings share certain similarities with each other and also have distinguish characters. In the following sections the schools participating in the IoT platform are presented in terms of the physical characteristics of the buildings, the layout of the rooms and the sensors deployed.

The building floorplans are used as an important reference while analysing and predicting the room environment condition from their location, orientation and usage. It is expected that south-orientation classroom achieve a higher indoor temperature compared with those with north-orientation due to longer time exposed to the direct sunlight.

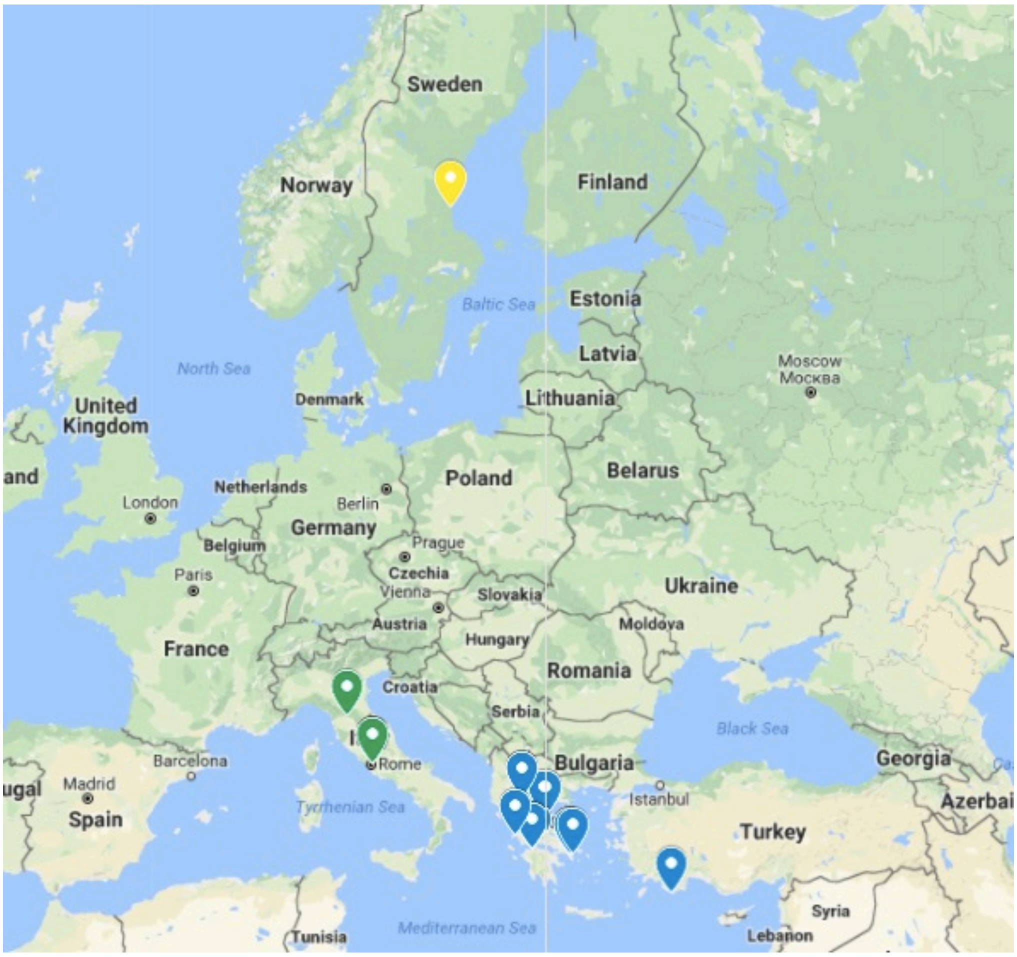

Figure 4 IoT deployment map

2.3.1 Greece

2.3.1.1 Junior High school of Pentavryssos, Kastoria

The school is located in a small village in Northern Greece. The school has 19 teachers and 44 students. During the winter, the area experiences very low temperatures. During the cold days heating is operated throughout the day while during autumn and spring it is operated for 2 hours every day. The lights on the yard turn on automatically every night.

The school is open from Monday to Tuesday, from 8:00 to 14:00. On average, primary schools are open with students more or less 203 days per year. The school remains closed during Christmas and Easter holidays (4 weeks totally). The cleaner comes every day at the afternoon. The school is used periodically from the parents' association the afternoon.

Table 3 Basic information of Junior High school of Pentavryssos, Kastoria

Site ID	Start time	Deployed Sensor Types		
19640	before 2015-10-30	Atmospheric Pressure External Relative Humidity External Temperature Luminosity Motion Noise Radiation Rain Height Relative Humidity Temperature Wind Direction Wind Speed	Calculated Power Consumption Electrical Current	External Air Contaminants External Ammonia Concentration External Carbon Dioxide Concentration External Carbon Monoxide Concentration External Oxygen Concentration

Table 4 IoT devices available in Junior High school of Pentavryssos, Kastoria

IoT Gateway (XBee communication with sensors)	Yes	1
Sensor units (Sensor Box)	Yes	8
Weather Station	Yes	1, Arduino
Atmospheric Conditions Unit	Yes	1
Radiation Meter Unit (Libelium)	Yes	1
Power meter	Yes	2 (3-phase (1) and 1-phase (1))

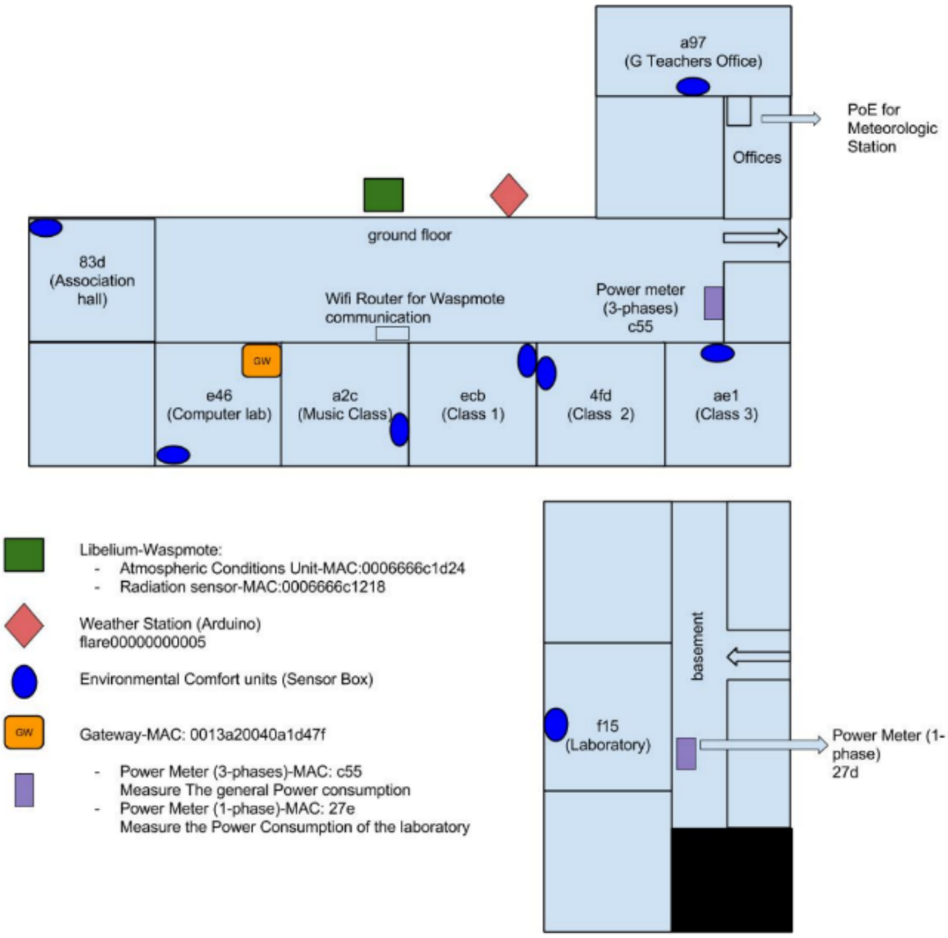

Figure 5 Flor Plan of Junior High school of Pentavryssos, Kastoria

Table 5 Orientation details of Junior High school of Pentavryssos, Kastoria

Room Name	Room Orientation	Room Temperature Sensor ID
Class 1 ecb	North-East	90580
Class 2 4fd	North-East	90601
Class 3 ae1	North-East	90572
Music Class a2c	North-East	90586
Association Hall 83d	South | South-East	90541
Laboratory f15	South-West	90540

2.3.1.2 Primary School of Lygia, Lefkada

The school is located in the island of Lefkada, in the North-West part of Greece. In this school, there are 6 classrooms, 117 students in total.

Working hours: 07:45- 16:00 regularly, the responsible person for the buffet goes every day at 07:10 a.m. and the cleaner comes every day at 15:00-18:00. . On average, primary schools are open with students more or less 203 days per year. The school remains closed during Christmas and Easter holidays (4 weeks totally).

Heating hours: the heating is manually turned on from 07:00-09:45 am in the cold days.

Table 6 Basic Information of Primary School of Lygia, Lefkada

Site ID	Start time	Deployed Sensor Types		
144024	before 2015-10-30	Atmospheric Pressure External Relative Humidity External Temperature Luminosity Motion Noise Radiation Rain Height Relative Humidity Temperature Wind Direction Wind Speed	Calculated Power Consumption Electrical Current	External Air Contaminants External Ammonia Concentration External Carbon Dioxide Concentration External Carbon Monoxide Concentration External Oxygen Concentration

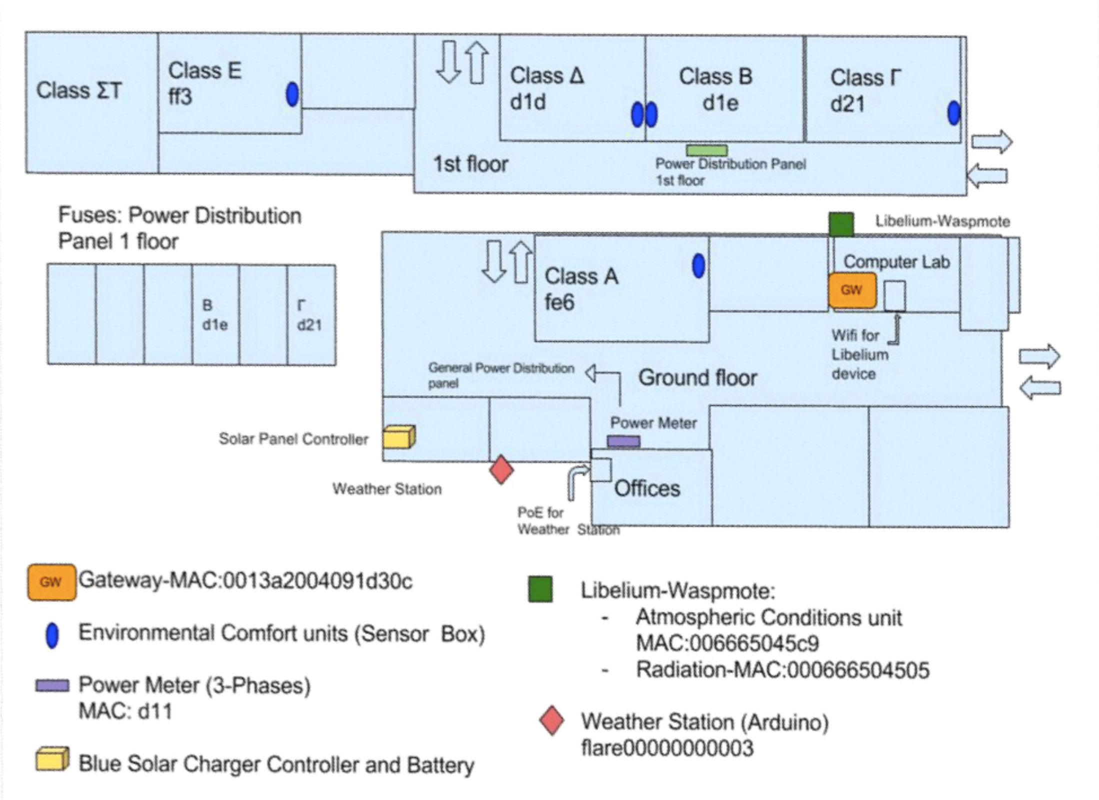

Figure 6 Floor Plan of Primary School of Lygia, Lefkada

Table 7 Orientation Details of Primary School of Lygia, Lefkada

Room Name	Room Orientation	Room Temperature Sensor ID
Class A fe6	South-East	149059
Class B d1e	South-East	149085
Class Γ d21	South-East	149067
Class Δ d1d	South-East	149075
Class E ff3	South-East	205610

2.3.1.3 2nd Technical High School, Larissa

The school is located in central Greece, in the city of Larissa. The school is a technical high school with 57 teachers and 212 students.

Working hours: 08:10 - 16:00 regularly, the cleaner comes every day at 07:30 a.m. On average, primary schools are open with students more or less 203 days per year. The school remains closed during Christmas and Easter holidays (4 weeks totally).

Heating hours: the heating is manually turned on for 3-4 hours in the cold days.

Table 8 Basic Information of 2nd Technical High School, Larissa

Site ID	Start time	Deployed Sensor Types		
28843	before 2015-10-30	Atmospheric Pressure External Relative Humidity External Temperature Luminosity Movement Noise Power Consumption Rain Height Relative Humidity Temperature Wind Direction Wind Speed	Calculated Power Consumption Electrical Current	External Air Contaminants External Ammonia Concentration External Carbon Dioxide Concentration External Carbon Monoxide Concentration External Oxygen Concentration Methane Concentration

Table 9 IoT devices available in 2nd Technical High School, Larissa

IoT Gateway (XBee communication with sensors)	Yes	1
Sensor units (Sensor Box)	Yes	6
Weather Station	Yes	1, Synfield
Atmospheric Conditions Unit	No	1, Libelium
Radiation Meter Unit (Libelium)	No	1, Libelium
Power meter	Yes	1, 1-phase

2.3.1.4 Primary School of Megisti, Kastelorizo

Kastelorizo is an island with only 492 inhabitants on the easternmost part of Greece. The primary school has 8 teachers and 18 students. Due to the location of the island the temperatures remain high even during winter times.

Working hours: 08:10 - 16:00 regularly, the cleaner comes every day at 16:30 a.m. On average, primary schools are open with students more or less 203 days per year. The school remains closed during Christmas and Easter holidays (4 weeks totally).

Thus heating is operated only for a few months during the year.

Table 10 Basic information of Primary School of Megisti, Kastelorizo

Site ID	Start time	Deployed Sensor Types		
144243	before 2015-10-30	Atmospheric Pressure External Relative Humidity External Temperature Luminosity Motion Noise Radiation Rain Height Relative Humidity Temperature Wind Direction Wind Speed	Calculated Power Consumption Electrical Current	External Air Contaminants External Ammonia Concentration External Carbon Dioxide Concentration External Carbon Monoxide Concentration External Oxygen Concentration

Table 11 IoT devices available in Primary School of Megisti, Kastelorizo

IoT Gateway (XBee communication with sensors)	Yes	1
Sensor units (Sensor Box)	Yes	4
Weather Station	Yes	1, Synfield
Atmospheric Conditions Unit	Yes	1
Radiation Meter Unit (Libelium)	Yes	1
Power meter	Yes	1

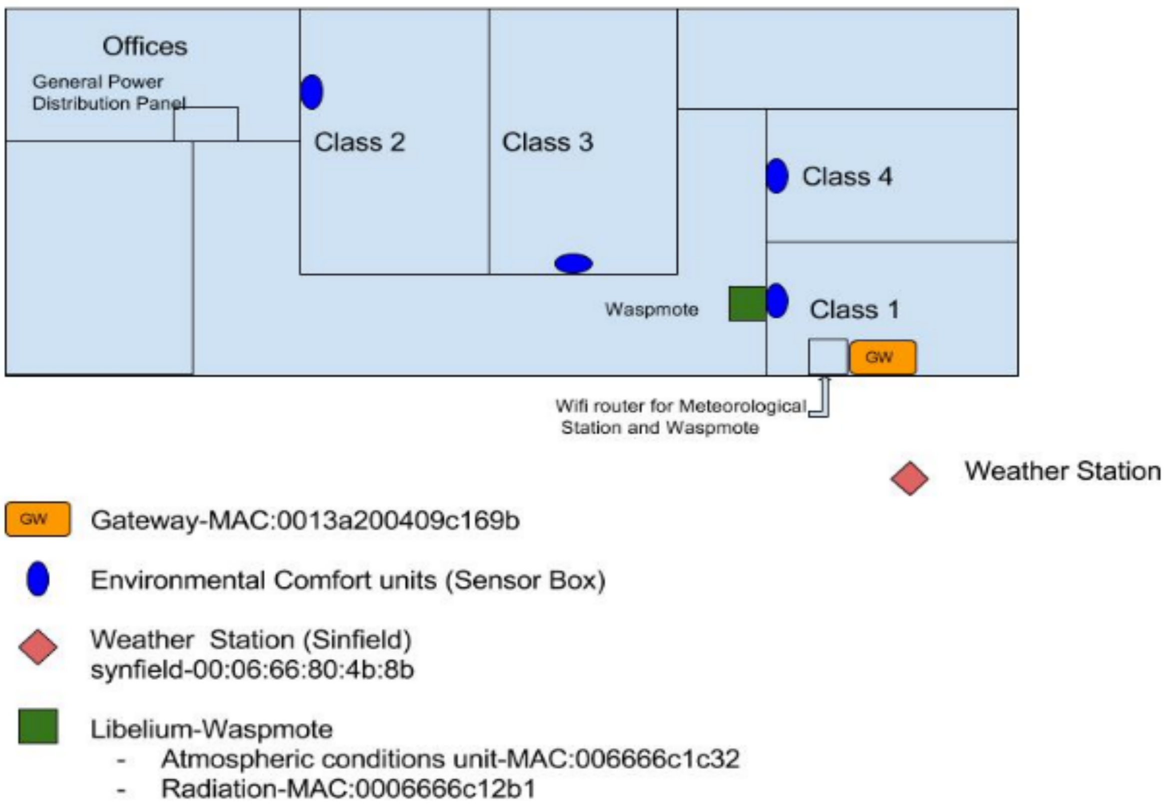

Figure 7 Floor Plan of Primary School of Megisti, Kastelorizo

Table 12 Orientation details of Primary School of Megisti, Kastelorizo

Room Name	Room Orientation	Room Temperature Sensor ID
Class1	North | North-West	145169
Class2	South-West	145171
Class3	South-West	145158
Class4	West	145230

2.3.1.5 2nd Elementary School of Patras

The school is located in the Western Greece, in the city of Patras. The school has 10 teachers and 67 students.

Working hours: 08:00 - 16:00 regularly, the cleaner comes every day at 16:30 a.m. On average, primary schools are open with students more or less 203 days per year. The school remains closed during Christmas and Easter holidays (4 weeks totally).

Parents can use the school building for their activities e.g. choir, art works, etc., for 2 hours after 16:15 2-3 days per week. It has been calculated that on average, every year the parents use the school for 45 days.

Heating hours: the heating is manually turned on for 2 hours in the cold days.

Table 13 Basic Information of 2nd Elementary School of Patras

Site ID	Start time	Deployed Sensor Types	
155877	2016-08-02	Luminosity Motion Noise Rain Height Relative Humidity Temperature Wind Direction Wind Speed	Calculated Power Consumption Electrical Current

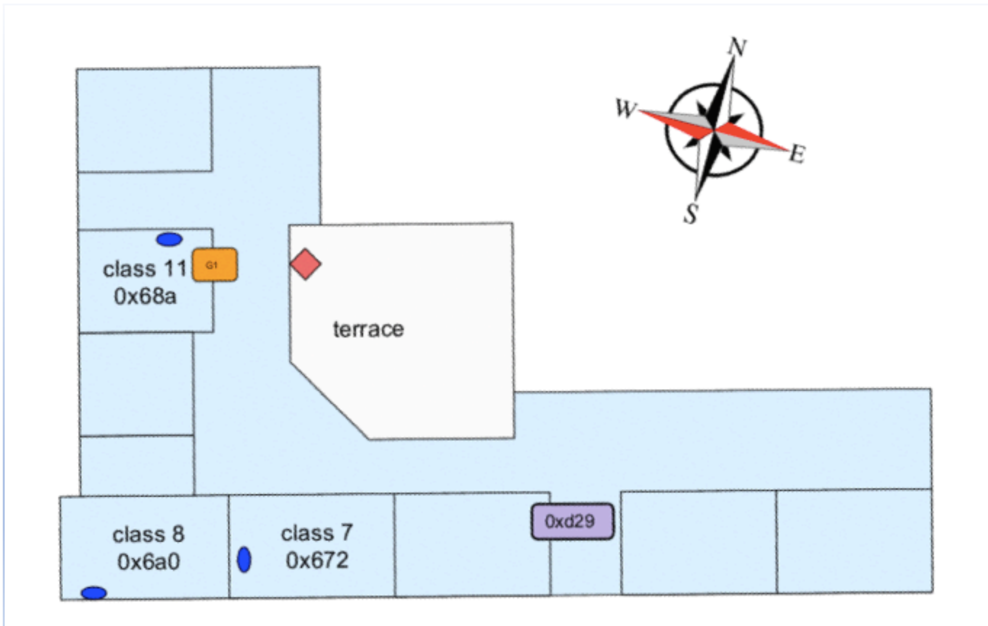

Figure 8 Floor Plan of 2nd Elementary School of Patras

Table 14 Orientation Details of 2nd Elementary School of Patras

Room Name	Room Orientation	Room Temperature Sensor ID
class 11 0x68a	West | South-West	155636
class 8 0x6a0	South | South-West	155635
class 7 0x672	East | South-East	155644

2.3.1.6 8th Gymnasium Patras

The school is located in the Western Greece, in the city of Patras. This school has 33 teachers and 199 students. There are 2 different schools in this building, one during morning hours and the other technical school during noon hours.

Working hours: 08:15 - 14:10 regularly, the responsible person for the buffet goes every day at 07:30 a.m. (it is estimated that consumes 40KW every day). On average, primary schools are open with students more or less 203 days per year.

Outdoor lighting: Manually some lights during the night are turned on.

Heating: Manually the cold days the heating is on for 1 hour. It is estimated that the school consumes 2000 lt per year, and the very cold days 80 lt the day.

Table 15 Basic Information of 8th Gymnasium Patras

Site ID	Start time	Deployed Sensor Types	
27827	before 2015-10-30	Luminosity Motion Noise Rain Height Relative Humidity Temperature Wind Direction Wind Speed	Calculated Power Consumption Electrical Current

Table 16 IoT devices available in 8th Gymnasium Patras

IoT Gateway (XBee communication with sensors)	Yes	1
Sensor units (Sensor Box)	Yes	6
Weather Station	Yes	1, Arduino
Atmospheric Conditions Unit	No	-
Power meter	Yes	1, 3-phase

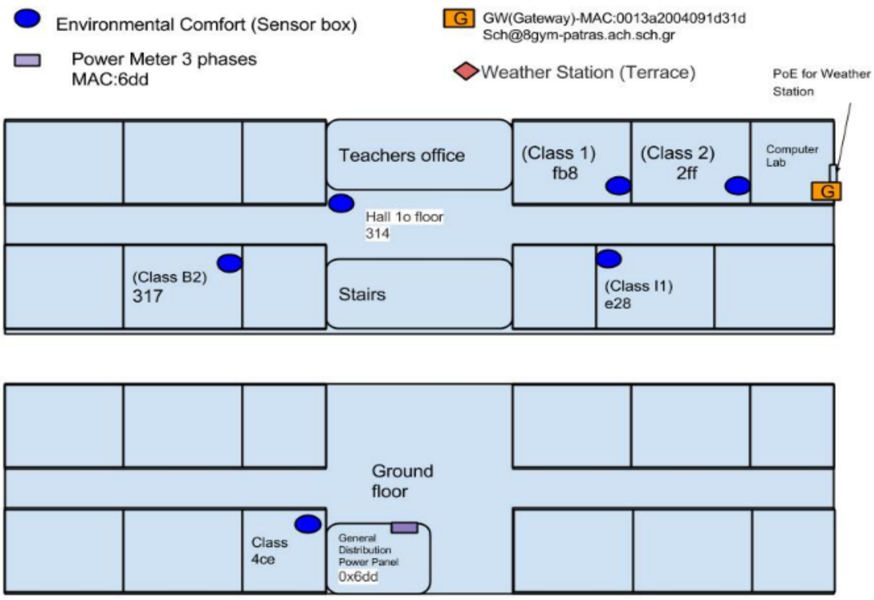

Figure 9 Floor Plan of 8th Gymnasium Patras

Table 17 Orientation Details of 8th Gymnasium Patras

Room Name	Room Orientation	Room Temperature Sensor ID
Class1 e28	North-West	157418
ClassB2 317	North-West	157477
Class 4ce	North-West	157867
Class2 2ff	South | South-East	202127
Class I1 fb8	South-West	157419

2.3.1.7 46th Primary School of Patras

The school is located in the Western Greece, in the city of Patras. This school has 25 teachers and 142 students.

Working hours: 08:00 - 16:00 regularly, the cleaner comes every day at 16:30 a.m. On average, primary schools are open with students more or less 203 days per year. The school remains closed during Christmas and Easter holidays (4 weeks totally).

Heating hours: the heating is manually turned on for 1-2 hours in the cold days.

Table 18 Basic Information of 46th Primary School of Patras

Site ID	Start time	Deployed Sensor Types	
155865	2016-08-02	Luminosity Motion Noise Relative Humidity Temperature	Calculated Power Consumption Electrical Current

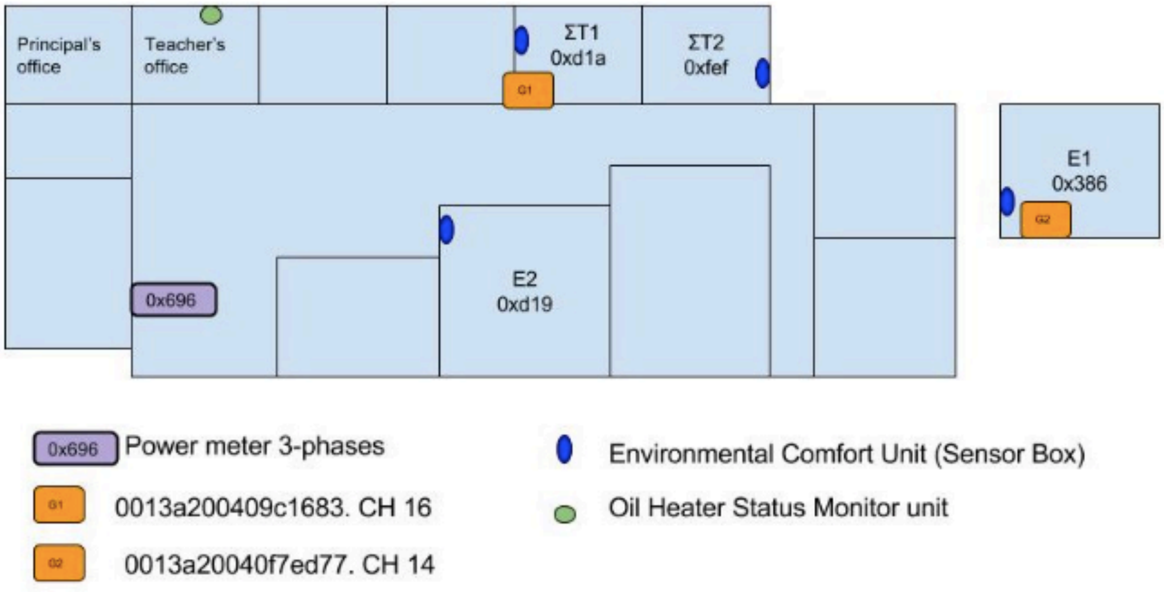

Figure 10 Floor Plan of 46th Primary School of Patras

Table 19 Orientation Details of 46th Primary School of Patras

Room Name	Room Orientation	Room Temperature Sensor ID
E1 0x3bd	South-West	205801
E2 0xd19	South-West	155096
ΣT1 0xd1a	North-East	155087
ΣT2 0xfef	North-East	155095

2.3.1.8 55th Primary School of Athens

The school is located in Central Greece, in the city of Athens. Primary schools have 6 different grades. The school has a staff of 21 teachers and 137 students.

Heating: Manually the cold days the heating is on for 3-4 hours.

Working hours: 08:10 - 16:00 regularly, the cleaner comes every day at 07:30 a.m.

Table 20 Basic Information of 55th Primary School of Athens

Site ID	Start time	Deployed Sensor Types	
28850	before 2015-10-30	Luminosity Methane Concentration Motion Movement Noise Power Consumption Rain Height Relative Humidity Temperature Wind Direction Wind Speed	Calculated Power Consumption Carbon Monoxide Concentration Electrical Current

Table 21 IoT devices available in 55th Primary School of Athens

IoT Gateway (XBee communication with sensors)	Yes	2
Sensor units (Sensor Box)	Yes	5
Weather Station	Yes	1, Synfield
Atmospheric Conditions Unit	No	
Power meter	Yes	1, 3-phase

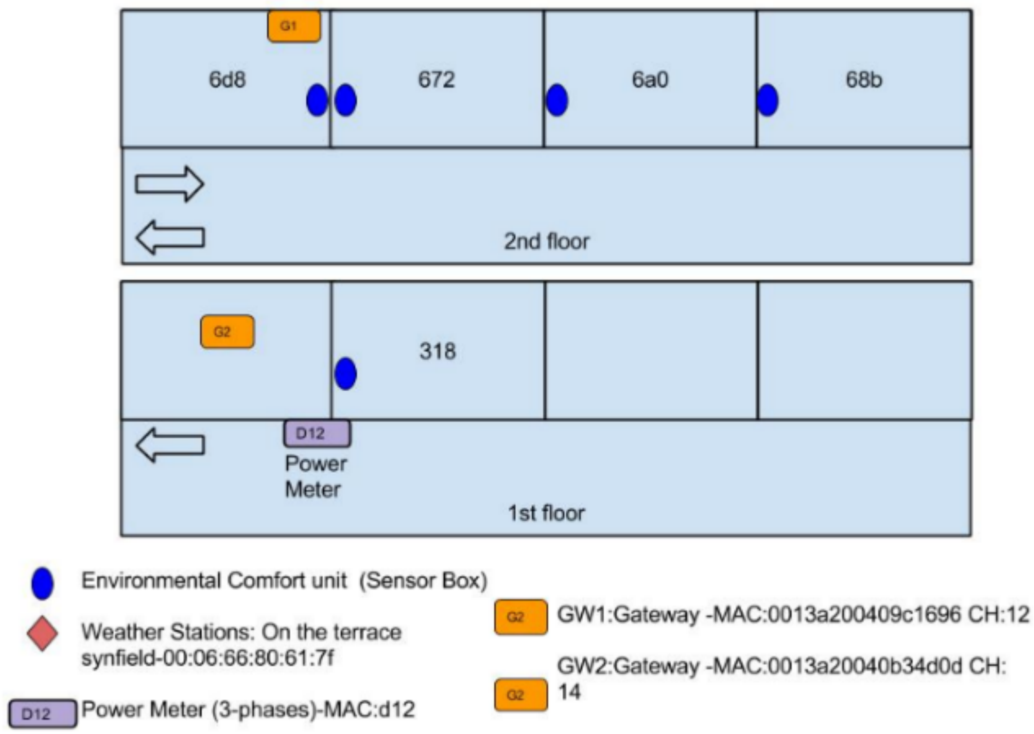

Figure 11 Floor Plan of 55th Primary School of Athens

2.3.1.9 EllinoGermaniki Agogi Private School

The school is located in Central Greece, in the city of Athens. Ellinogermaniki Agogi (EA) is one of the largest private schools in Greece and covers all stages of school education, from pre-school to upper secondary, covering the student age range from 6 to 17 years. In year 2015-2016 there are approximately 1,030 students in EA's primary school, and approximately 610 students in EA's secondary schools, with 25 students per classroom on average. The school is located in Athens.

EA's building utilizes a Building Management System (BMS) to monitor and control several processes.

Table 22 Basic information of EllinoGermaniki Agogi Private School

Site ID	Start time	Deployed Sensor Types	
157185	2017-02-01	Luminosity Motion Noise Relative Humidity Temperature	Calculated Power Consumption Carbon Dioxide Concentration Electrical Current Light

Figure 12 Floor plan of EllinoGermaniki Agogi Private School

Table 23 Orientation details of EllinoGermaniki Agogi Private School

Room Name	Room Orientation	Room Temperature Sensor ID
A 10 - ΣT1	South-East	156972
A 116 - ΣT4	North-East	156989
Computer Lab	South-East	157490
Physics Laboratory	South-West	157023
A 114 - ΣT5	North-East	156994
A 122 - ΣT3	South-West	156982
A 110 - ΣT7	North-East	157019
A 124 - ΣT2	South-West	156980
A112 - ΣT6	North-East	156997

2.3.1.10 1st Gymnasium Nea Philadelphia Attica

The school is located in Central Greece, in the city of Athens. The school has a staff of 29 teachers and 251 students.

Working hours: 08:15-14:10 regularly. The responsible person for the buffet goes every day earlier on the morning and the cleaner is later on the school between 12:30 to 16:30.

Heating hours: the heating is manually turned on for 1-2 hours in cold days.

Table 24 Basic Information of 1st Gymnasium Nea Philadelphia Attica

Site ID	Start time	Deployed Sensor Types		
144242	before 2015-10-30	Light Luminosity Motion Noise Radiation Rain Height Relative Humidity Temperature Wind Direction Wind Speed Atmospheric Pressure External Temperature	Calculated Power Consumption Electrical Current	External Air Contaminants External Ammonia Concentration External Carbon Dioxide Concentration External Carbon Monoxide Concentration External Oxygen Concentration

Table 25 IoT devices available in 1st Gymnasium Nea Philadelphia Attica

IoT Gateway (XBee communication with sensors)	Yes	1, Meazon 3G-enabled
Sensor units (Sensor Box)	Yes	5
Weather Station	Yes	1, Arduino
Atmospheric Conditions Unit	Yes	1, Libelium
Radiation Meter Unit (Libelium)	Yes	1, Libelium
Power meter	Yes	2, 3-phase

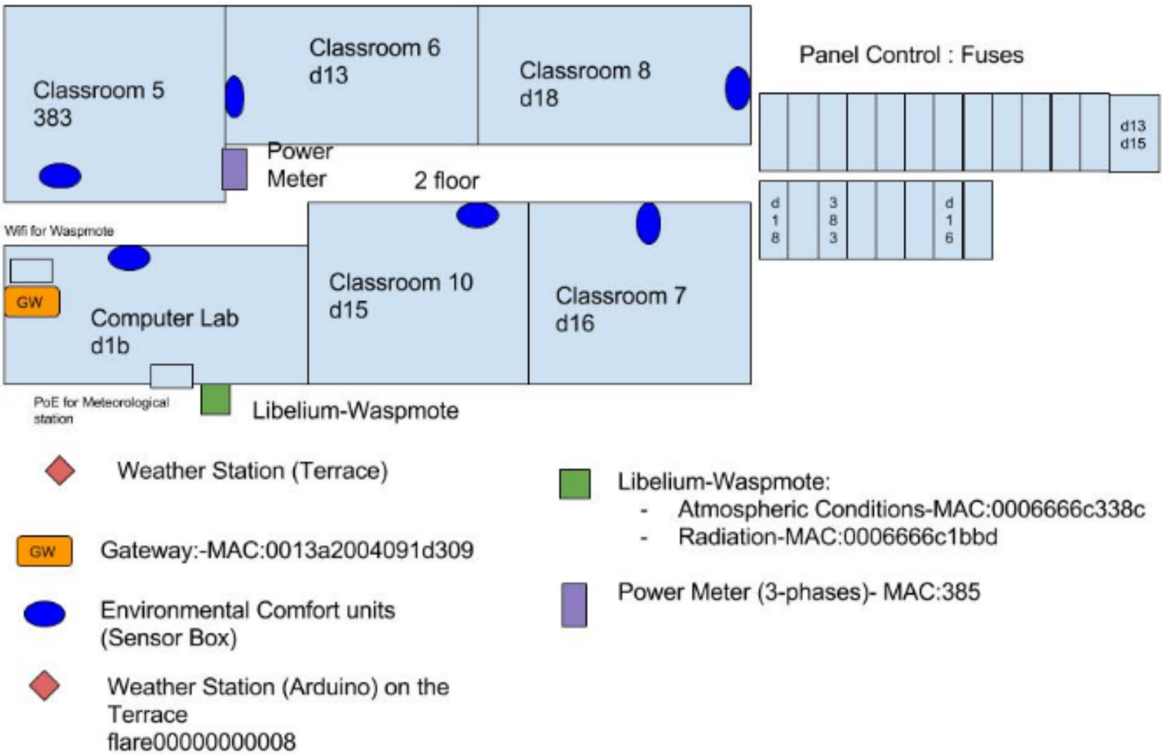

Figure 13 Floor Plan of 1st Gymnasium Nea Philadelphia Attica

Table 26 Orientation details of 1st Gymnasium Nea Philadelphia Attica

Room Name	Room Orientation	Room Temperature Sensor ID
Computer Lab d1b	South | South-East	155918
Classroom 5 383	West | North-West	155924
Classroom 10 d15	South | South-East	155928
Classroom 8 d18	West | North-West	155937
Classroom 7 d16	West | North-West	155933

2.3.1.11 6th Elementary School of Kesariani

The school is located in Central Greece, in the city of Athens. The school has a staff of 10 teachers and 135 students.

Working hours: 08:15-16:00 regularly. The responsible person for the buffet goes every day earlier on the morning and the cleaner is later on the school between 16:30 to 18:30.

Heating hours: the heating is manually turned on for 1-2 hours in cold days.

Table 27 Basic Information of 6th Elementary School of Kesariani

Site ID	Start time	Deployed Sensor Types	
155849	before 2015-10-30	Luminosity Motion Noise Rain Height Relative Humidity Temperature Wind Direction Wind Speed	Calculated Power Consumption Electrical Current

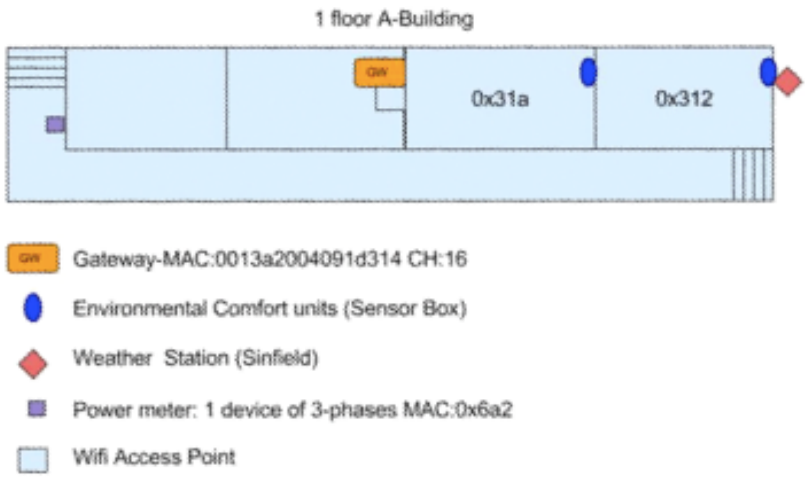

Figure 14 Floor Plan of 6th Elementary School of Kesariani

Table 28 Orientation Details of 6th Elementary School of Kesariani

Room Name	Room Orientation	Room Temperature Sensor ID
0x312	North-West	155162

2.3.1.12 5th Elementary School of Nea Smyrni

The school is located in Central Greece, in the city of Athens. The school has a staff of 12 teachers and 216 students.

Working hours: 08:15-14:10 regularly

Heating hours: the heating is turned on manually for 1-2 hours in cold days.

Table 29 Basic Information of 5th Elementary School of Nea Smyrni

Site ID	Start time	Deployed Sensor Types	
155851	2016-08-02	Luminosity Motion Noise Relative Humidity Temperature	Calculated Power Consumption Electrical Current

Table 30 IoT devices available in 5th Elementary School of Nea Smyrni

IoT Gateway (XBee communication with sensors)	Yes	1, Meazon 3G-enabled
Sensor units (Sensor Box)	Yes	5
Weather Station	Yes	1, Arduino
Atmospheric Conditions Unit	Yes	1, Libelium
Radiation Meter Unit (Libelium)	Yes	1, Libelium
Power meter	Yes	2, 3-phase

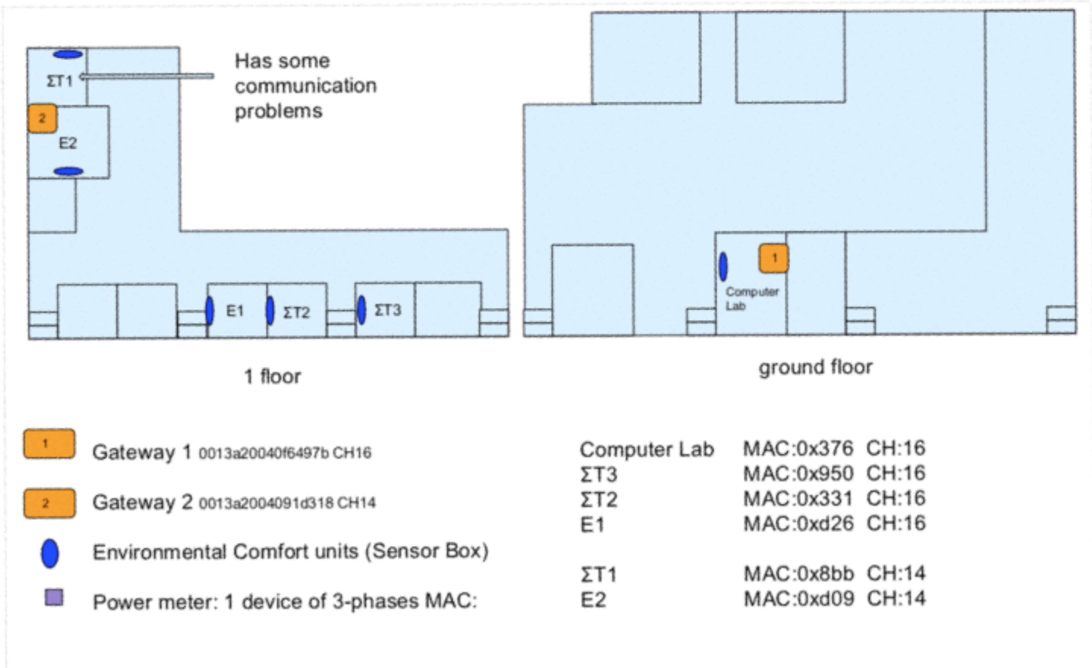

Figure 15 Floor Plan of 5th Elementary School of Nea Smyrni

Table 31 Orientation Details of 5th Elementary School of Nea Smyrni

Room Name	Room Orientation	Room Temperature Sensor ID
E1	South-East	155571
E2	South-West	156845
Computer Lab	North-West	157189
ΣT2	South-East	155553
ΣT3	South-East	155523

2.3.2 Sweden

2.3.2.1 Söderhamn, Staffangymnasiet

Staffangymnasiet is a local organization for Upper Secondary School in the city of Söderhamn. In Staffangymnasiet, there are around 800 students, 90 teachers, 4 janitors/building managers, 8 cleaning staffs, 2 nurses, 2 student study consultants, 1 social worker, 5 cafeteria staffs and 6 at principal's office, including principals.

There is a specific feature of the building, a central heating in the building based on water radiators. Heating hours: Monday between 04:00-15:00, 20°C in the building, Tuesday to Friday between 05:00-15:00, 20°C in the building, and all other hours: 17°C in the building.

The building utilizes a centralized building management system to monitor and control lighting, heating and ventilation in the building.

The operating hours of Staffangymnasiet are between 6am and 6pm, five days per week, Monday to Friday. Students use the building for 176 days per year, August to June, while teachers for 194 days per year, August to June. Administration staff work year round, 225 days/person and most of them are on vacation in July. The cleaning staff start their work at 6am and works until 3pm. Some of the administrative staff and janitors start at 7am and end the day at 6pm. Teachers and students start their classes at 7:45am and will have classes until 5pm. The cafeteria is open between 7am and 3pm every school day. The municipality's ICT group for primary and lower secondary school have their office and one education room in our school. The front door is open between 7am to 4:30pm, every school day. The school building closes at 9pm.

Table 32 Basic information of Söderhamn, Staffangymnasiet

Site ID	Start time	Deployed Sensor Types
159705	2017-09-21	Luminosity Motion Noise Relative Humidity Temperature

Figure 16 Floor Plan of Söderhamn, Staffangymnasiet

Table 33 Orientation Details of Söderhamn, Staffangymnasiet

Room Name	Room Orientation	Room Temperature Sensor ID
pi3	South-East	206446
pi2	North-East	206244
pi1	North-West	206211
pi7	South-East	206470
pi6	North-East	206459
pi5	South-West	206465
pi4	South-West	206455

2.3.3 Italy

2.3.3.1 Sapienza

The IoT deployment covers three buildings of the University of Rome "La Sapienza". The three buildings that participate in the IoT deployment are located in Rome.

Table 34 Basic Information of Sapienza

Site ID	Start time	Deployed Sensor Types
155077	2016-10-29	Active Power Apparent Energy Apparent Power Calculated Power Consumption Electrical Current Power Consumption Power Factor Reactive Power Voltage

2.3.3.1.1 Palazzo Servizi Generali

The building is used as front and back office for the student secretariat. All faculties' secretariats are in this building. It does not contain lectures hall. The building has seven floors including two basements. First two floors are used for front and back office. In the third and fourth floor only contains administrative/technical offices, one data centre, archive and four reading/PC rooms.

Open hours: Monday, Wednesday and Friday from 08:30 to 12:30, Tuesday and Thursday from 14:30 to 16:30. Secretariat back offices instead open at 08:00 and close at 18:00.

2.3.3.1.2 The Faculty of Economics

The building of the *Faculty of Economics* was built in 1969 and has an average student population of 10,000. The *Faculty of Economics* has a staff consisting of 185 teachers (63 full professors, 57 associate professors, 65 researchers) and 61 administrative technicians.

Open hours: The staffs enter the offices at 09:00 and exit at 18:00. The lectures could start at 8:30 and end at 22:30, because the university provides many evening lectures for working students. Entry and exit times are flexible, however most people are in the building both in the morning and in the afternoon. Therefore, usually there is activity from 08:00 to 22:30. Saturday and Sunday all floors are closed.

2.3.3.1.3 Orthopedics building

The Orthopedics building forms part of a series of structures designed from 1933 to 1935. The rooms in the Orthopedics building are mainly used for the teaching activities of the Faculty of Medicine and Surgery and some hospital ward.

Open hours: Commonly workers enter the offices at 09:00 and exit at 18:00. Entry and exit times are flexible. Usually, there is activity in the floor from 08:00 to 19:00. Saturday and Sunday all floors are closed.

2.3.3.2 Gramsci-Keynes School

The Gramsci Keynes School is an upper secondary school that offers three curricula: a scientific lyceum, a technical institute of building construction, and a tourism economic institute. The school building is located in the semi-peripheral area of Prato, a town of 187.000 inhabitants, close to Florence and is made of 4 blocks. The main central block contains the hall and at the first floor the offices of the administration and technical staff. Two blocks contain classrooms and laboratories, organized in three floors. A fourth block is an independent building connected to the main one through an aerial walkway. This block contains the canteen at the ground floor and the auditorium and a small gymnasium hall at the second floor, and also a gymnasium hall which is two floors high, with tribune seats and changing rooms. The main central block and one of the two classroom blocks have been completed in 1988, while the other two blocks have been completed in 1999. The gross floor area is 12.166,00 m2. The bearing structure is made of reinforced concrete. The external walls are made of slabs of concrete and expanded clay. The whole building surface is exposed and stands free on all sides. Glazing covers 40% of external surface.

The school is open from Monday to Friday from 7:00 to 19:00 (12 hours per day). Classrooms and laboratories are used for learning activities mainly during morning hours. Some learning activities can last till the late afternoon (using classroom and laboratories). The hall is open from 7:00 to 19:00. The administration and technical activity occur from 8:00 to 17:00/18:00. The gymnasium is open from 8:00 to 24:00 (some sports associations are given the permit to use the gymnasium in the afternoon and evening). The library and cafeteria are open from 8:00 to 17:00. The auditorium is used only for scheduled events.

The total number of students is 1500. The school has 132 teachers and 28 employees in the technical and administration staff. Students usually arrive at 8:00 and leave at 14:00. Once a week, students of commercial and tourism curricula stay at school till 16:00 (on Monday in 2015/16). The administration staff enters at 8:00-9:00 and leaves at 17:00-18:00. Teachers have lectures for 18 hours/week. Each teacher enters and leaves the school according to its personal schedule. The technical and custodian staff enter at 7:00-8:00. Between 7 and 8 am staff of the school do the cleaning (maximum 8 persons). In the afternoon an external company comes to do additional cleaning.

Regarding other groups of people using the facility, **s**port associations use the gymnasium hall in the afternoon and the evenings. Some persons attend professional education classes in the afternoon (on average twice a week). The school building closes at 19:00.

The heating is regulated according to the schedule defined by the Public Administration according to the climatic zone. Prato is in the D climatic zone. Heating is on from 1 November to 15 April. The heating can be on for maximum 12 hours/a day. The school may send specific requests to the Province of Prato for extraordinary turning on or off. In Annex III, an official letter from the Province of Prato is included, outlining the policies and the respective restrictions. During the night, the lighting in the hall is on and the outdoor lights (lighting with automatic twilight switch).

Table 35 Basic Information of Gramsci-Keynes School

Site ID	Start time	Deployed Sensor Types	
155076	2016-08-04	Light Luminosity Power Consumption Power Factor Rain Height Reactive Energy Reactive Power Relative Humidity Temperature Wind Direction Wind Speed	Active Power Apparent Energy Apparent Power Calculated Power Consumption Electrical Current

2.4 Platform Architecture & Services

The system is designed to enable easy and fast implementation of applications that utilize an Internet-of-Things infrastructure. The overall architecture follows the physical structure of the buildings, the network interconnecting the buildings and the services already provided for educational purposes at a national level. It offers high scalability both in terms of users, a number of connected devices and volume of data processed. The system accommodates real-time processing of information collected from mobile sensors and smart phones and offers fast analytic services.

The Cloud Services offer real time processing and analysis of unlimited IoT data streams with minimal delay and processing costs. Storage services use state of the art solutions like NoSQLand time series databases to ensure maximum scalability and minimal response times. Access to data retrieved from IoT installations connected to the system is granted using OAuth2.0 authentication to provide the easiest integration with external services.

The system delivers a set of services that are critical for all IoT installations:

Continuous computation engine. The real-time processing engine provides fast and reliable processing of an unbounded number of streams of data collected from IoT devices, smart phones, and web-services. The computation engine is very fast, being able to process a large amount of data collected from sensor nodes within just seconds. More details can be found in the evaluation section.

Online Analytics. Data collected from the streams of data and the output of the continuous processing are easily selected, extracted and processed to support business intelligence. The online analytics engine allows to organize large volumes of data and visualize them from different points of view.

End-to-end security. Communication across the components of the architecture and supported services are compliant with the current standards for Internet security. Communication throughout the service infrastructure is encrypted using data encryption standards like AES (Advanced Encryption Standard) and TLS/SSL (Transport Layer Security / Secure Sockets Layer) technologies.

Access management. Authorization of users and access to data can be easily managed in real-time down to specific user, device or time of day.

Storage & Replay. Data entering the system can be persisted in its original format and associated with the output of the continuous processing engine. Data streams can be forwarded at a later time to different components. Offline processing of data is facilitated for archiving services or for bench-marking different versions of components.

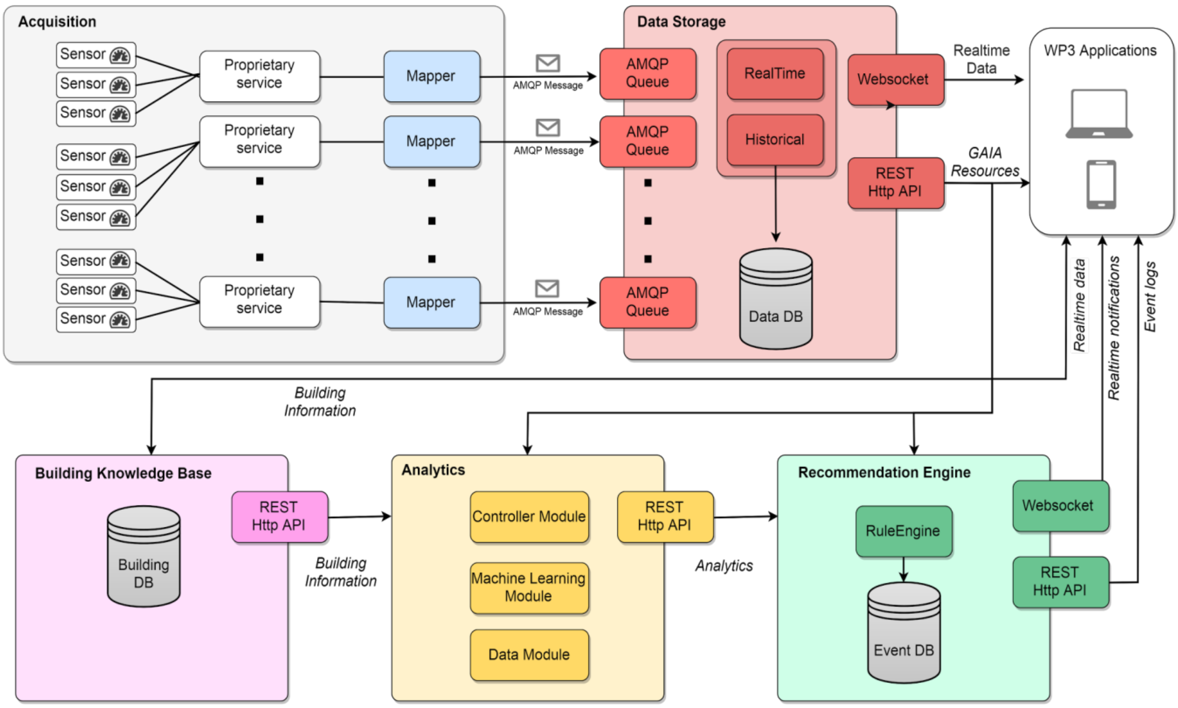

Figure 17 IoT Service Platform Logic Architecture

GAIA service platform provides a public API for a single-entry point to access different scale of requests from one single microservice to multiple ones. Data are collected through this API for all the sensors presented in the previous section.

Developing applications based on the system is very simple and can be done with any programming language. The services described above can be accessed via a well-defined set of APIs. The Data API is comprised of Real-time Data API and Historical Data API. Historical Data API allows retrieval of historical data registered into the platform by any device and also aggregated summaries (maximum values, minimum values, average values). Real-time Data API is a streaming API which gives low latency access to new Data registered to the platform. Directory API and AA (Authentication/Authorization) API describe how to create and manage devices, users and authorization roles.

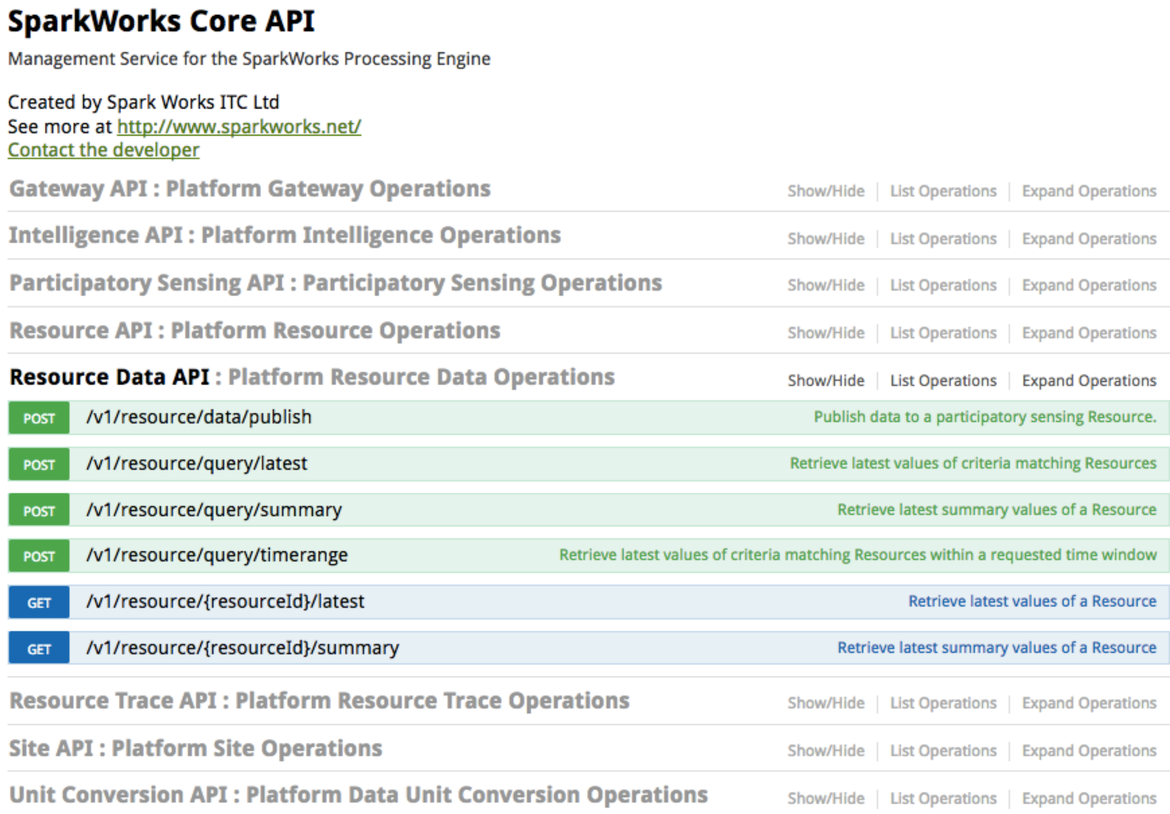

Figure 18 SparkWorks API

In order to provide analytics on the increasing growth of data an architecture is used which receives streaming data from multiple types of sensors and provides real time analytics over them. In general, the *Continuous Computation Engine* is composed by multiple sensors, a *Process Engine* which provides the analytics and the *Storage System* which is used for storing those results. The Process Engine receives events from multiple sensors and executes aggregate operations on these events. The output of the engine is stored at the Storage System.

Sensors and actuators produce (periodically or asynchronously) events that are sent to the Continuous Computation Engine via RabbitMQ. Those events are usually tuples of pairs: value and timestamp. All data received is collected and forwarded to a specific queue, where, they get processed in real time by the Storm cluster. The Storm cluster has a number of topologies for processing based on the data type. Each topology is responsible for a unique type of sensor such as general measurement sensors (temperature, humidity, wind speed etc.), actuators, power measurement sensors, etc. The produced analytics is output into summaries which are stored permanently either to a file system or to a database in the storage module.

The Process Engine is composed by topologies for every sensor type. Each topology has the ability to be easily modified in order to accommodate aggregation operations. The structure of a generic component (aggregator) which is used by the topologies is presented.

Aggregators process time intervals. First of all, they store all the events of the time interval and for each new incoming event, they process (using functions such as min/max/mean...) all the stored values of this interval. After this process, they update the existing interval value which is used by the next process level.

The Continuous Computation Engine receives this data and separates sensors to different types. The engine, which is implemented with Apache Storm, is consisted of topologies. As mentioned above each topology is responsible for a specific type of sensor. Each topology consists of a chain of aggregators which is called process blocks or process levels. The process blocks can aggregate data for specific time intervals.

Events which enter the Storm Cluster are processed consecutively. First, the Apache Storm topology performs aggregation operations on the streaming data, i.e., for a temperature sensor, Storm will calculate the average values of the 5-minute interval and it will store it to memory and disk for further process (when the topology receives more than one events for the same 5-minute interval, it calculates the average of those events). Every consecutive 5-minute interval aggregate is kept in memory (topology keeps 48 interval values k for 5min, hour, day, month intervals for each device) / stored in the disk. Next step is to update the hour intervals. Topology updates the 5 minute intervals inside the buffer of the hour processor and stores the average of those 5 minute intervals.

The process is similar to the daily processor but topology also stores the max/min of the day (based on the hour intervals). Same for monthly and yearly processors. For power consumer sensors, the scheme (topologies inside Storm) is the same with the difference that topology has to calculate and store the power consumption. Aggregators are used to performing aggregation operations on input streaming data. The topologies use aggregation for Power Consumption calculation (calculate the power consumption of the stream values), Sum calculation (summarize the streaming values), Average Calculation (calculate the average of the streaming values).

The IoT platform provides data with time interval from five minutes to one month. And for power consumptions they provide the real-time values shown in Figure 22, and aggregator process on summarize them [7].

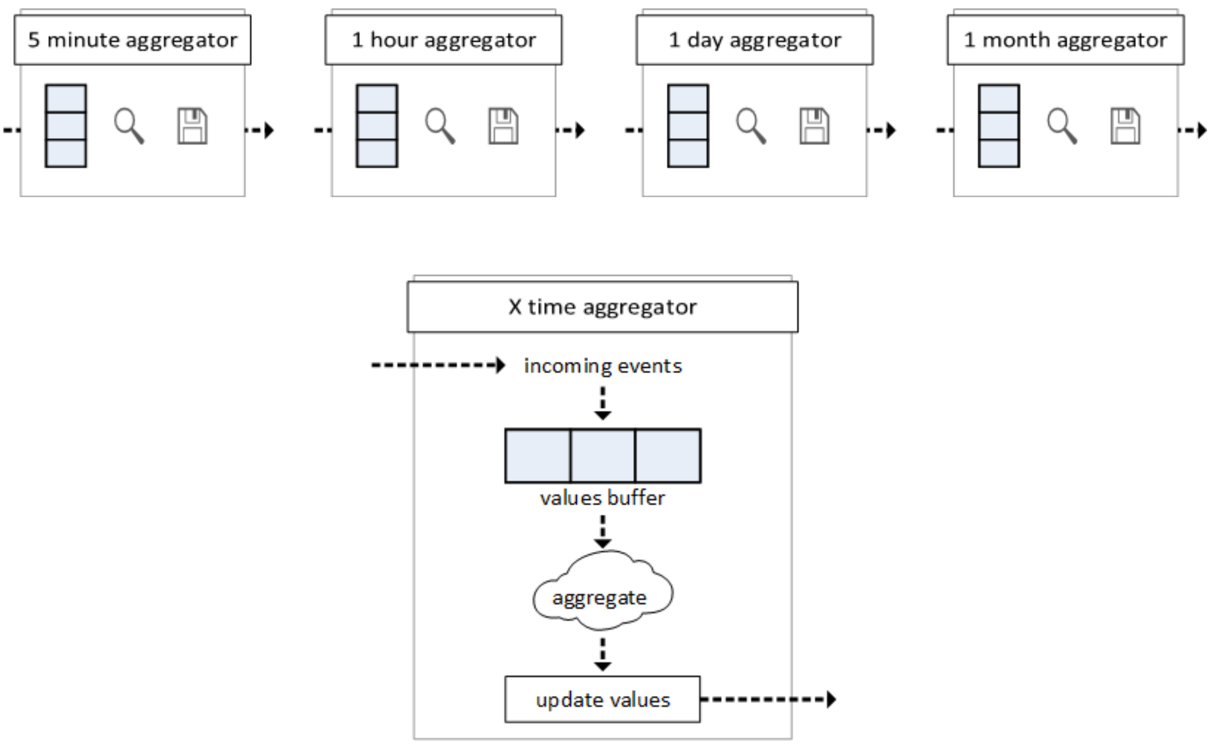

Figure 19 Aggregation Process

2.5 Data Acquisition

Access to the data collected from the IoT platform is provided by the SparkWorks IoT Framework platform, which is tailored to support a variety of users and connected to the heterogeneity of sensor devices and APIs from different platforms. Through those APIs, the platforms for the specific devices are acquiring or receiving data, transform data into the uniform way to feed into the IoT infrastructure.

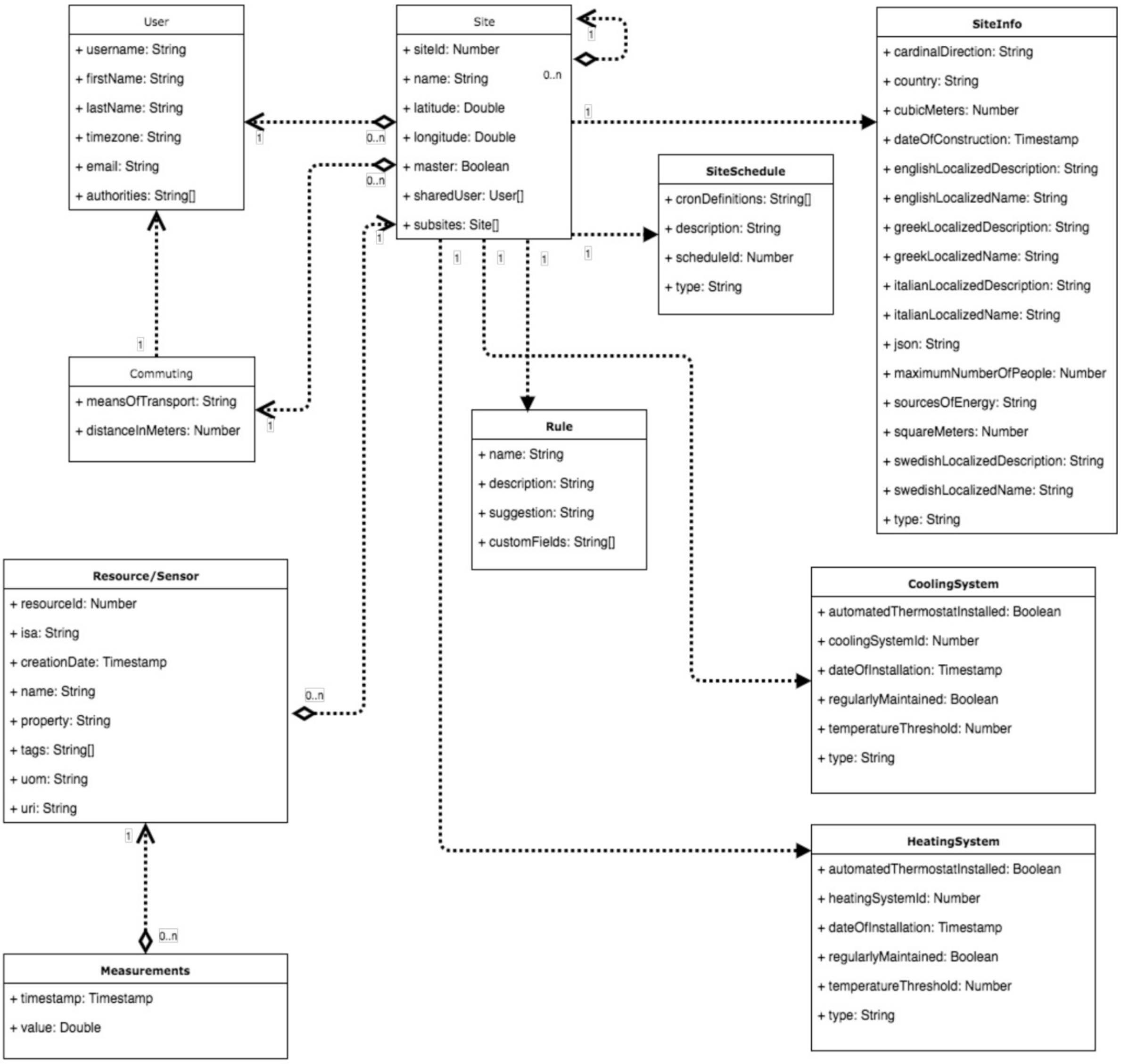

Figure 20 IoT Platform Data Schema

The conceptual model used to represent the main entities follows the Semantic Sensor Network ontology [SSN Ontology]. The SSN ontology can describe sensors in terms of capabilities, measurement processes, observations and deployments. A preliminary version of the base entities is provided in the conceptual model in Figure 20. The base entities described in the conceptual model are: the *Resource*, the *Site*, the *SiteInfo*, the *SiteSchedule* and the *Measurement*.

The *Site* entity represents a specific area, such as a building or a room, following the composite data model. The *Resource* entity represents an abstract data source. For instance, the most straightforward example of a *Resource* is a sensing device deployed on a *Site* while at the same time the entity holding participatory sensing information is represented as a *Resource* too. Finally, the *Measurement* entity represents a specific instant of Resource measurements.

The *Rule* entity represents a logical rule whose internal behavior is to evaluate a condition and trigger an action. It contains the required information to support its execution (e.g., the textual suggestion to be sent to the user and some custom fields such as thresholds to be applied to the measurements).

The *Site* Entity can have some entities associated that contains some descriptive information of the building/area, such as the schedule (opening and closing time, lectures, etc.) (*SiteSchedule*), information about the heating and cooling system, as well as general information about the site, such as description and square meters (*SiteInfo*).

The SparkWorks platform accommodates real-time processing of information collected from sensors and offers fast analytic services as shown in Figure 21 and Figure 22. The messages processed by the platform follow a specific schema. Each message is a comma separated triplet, indicating the unique sensor URI, the actual measurement value and a timestamp. Sensor names follow a URI scheme implicitly enclosing resource provider information. Each sensor should have a unique name and the name should contain as a prefix the identifier of its gateway, if present. Any device containing multiple instances of the same type of sensor should use an index suffix. Moreover, each sensor name should be prefixed by its client identifier as registered in the platform. Any data arriving in the platform that do not match a valid client will be ignored. Hence, a valid resource URI should look like:

clientId{/gatewayID}/deviceID/sensorName/{/index}

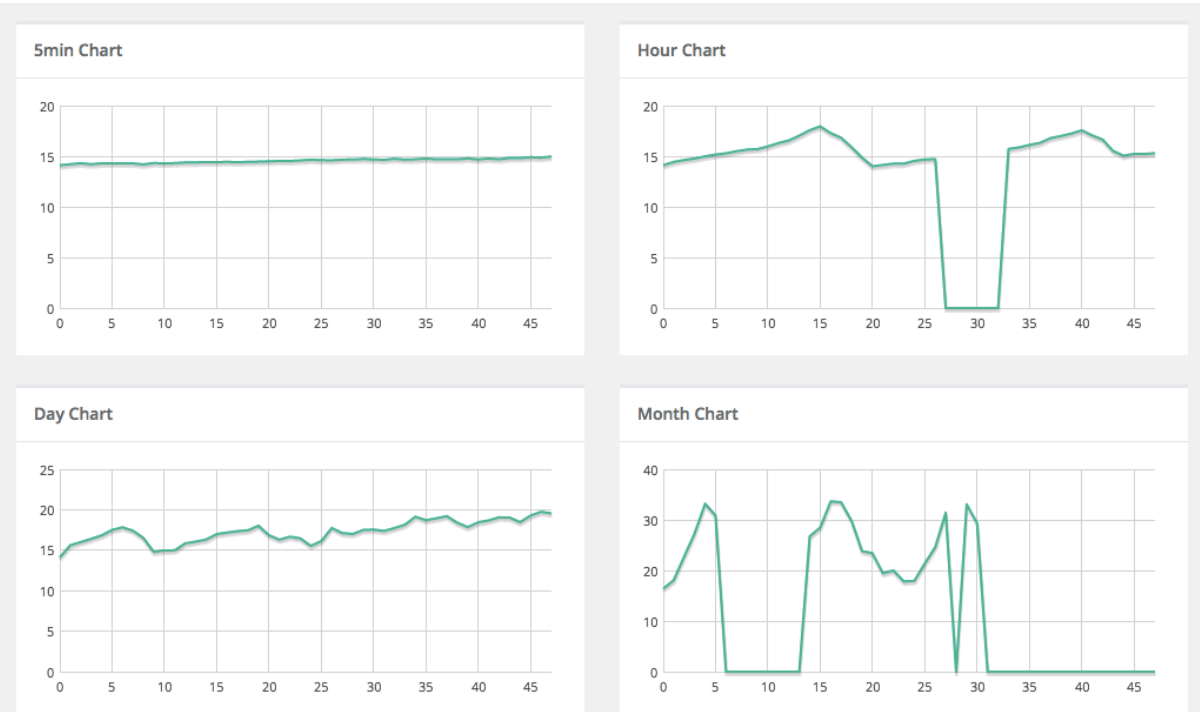

Figure 21 Indoor Temperature Real-time Monitoring

Figure 22 Power Consumption Real-time Monitoring

3 Data Availability

The IoT deployment of the GAIA platform is an ongoing process that continuously expands to include additional school buildings. Currently it includes a total of 18 educational building. The data collected from these deployments were analyzed to determine the variety of the sensors supported and their points of sensing (POS), the velocity of data arriving at the cloud infrastructure, as well as the variability of the data collected. During this initial high-level analysis, it became apparent that the data collected from the IoT devices was not always delivered properly to the cloud.

It is hard to ignore that a long period of missing data for all the schools in Greece in Figure 3. The data is not always reliable as we expected. Due to the low-cost devices, unstable connections to the platform or different schedules in schools, we have to examine the data values, extract the correct information and eliminate those potential outliers corresponding to the historical data.

3.1 A first approach for data availability

As a first step towards understanding the availability of measurements, we examine the data collected from the different sensors in order to assess the data availability. Remark that some sensors produce zero values which are correct. As an example, consider the motion sensors that produce zero values when no motion is detected. On the other hand, other sensors should never be zero, such as humidity sensors should always be above zero. In general, for one point of the sensor with some data has "legal" zero, the summary on the same timestamp should constantly beyond zero as long as it is active.

Algorithm:

1. Put all [value! = 0] = 1
2. Sum for all sensor data in one point of sensor
3. Normalized all [value > 0] = 1
4. Output: 1 = active, 0 = inactive for each point of sensor

By using the different way of retrieving the device data, the result will show slightly different from one way or another, but would not deviate too much.

3.2 Analysis based on the all the schools

Figure 23 is included that depicts the availability of measurements on a daily basis for each site and each sensor separately. In particular each different sensor corresponds to a specific horizontal line, organized based on the site of deployment. A single dark point signifies missing data for the specific on a specific day, while a white part signifies complete availability (i.e., according to the sensing rate of the specific sensor, see Table 36).

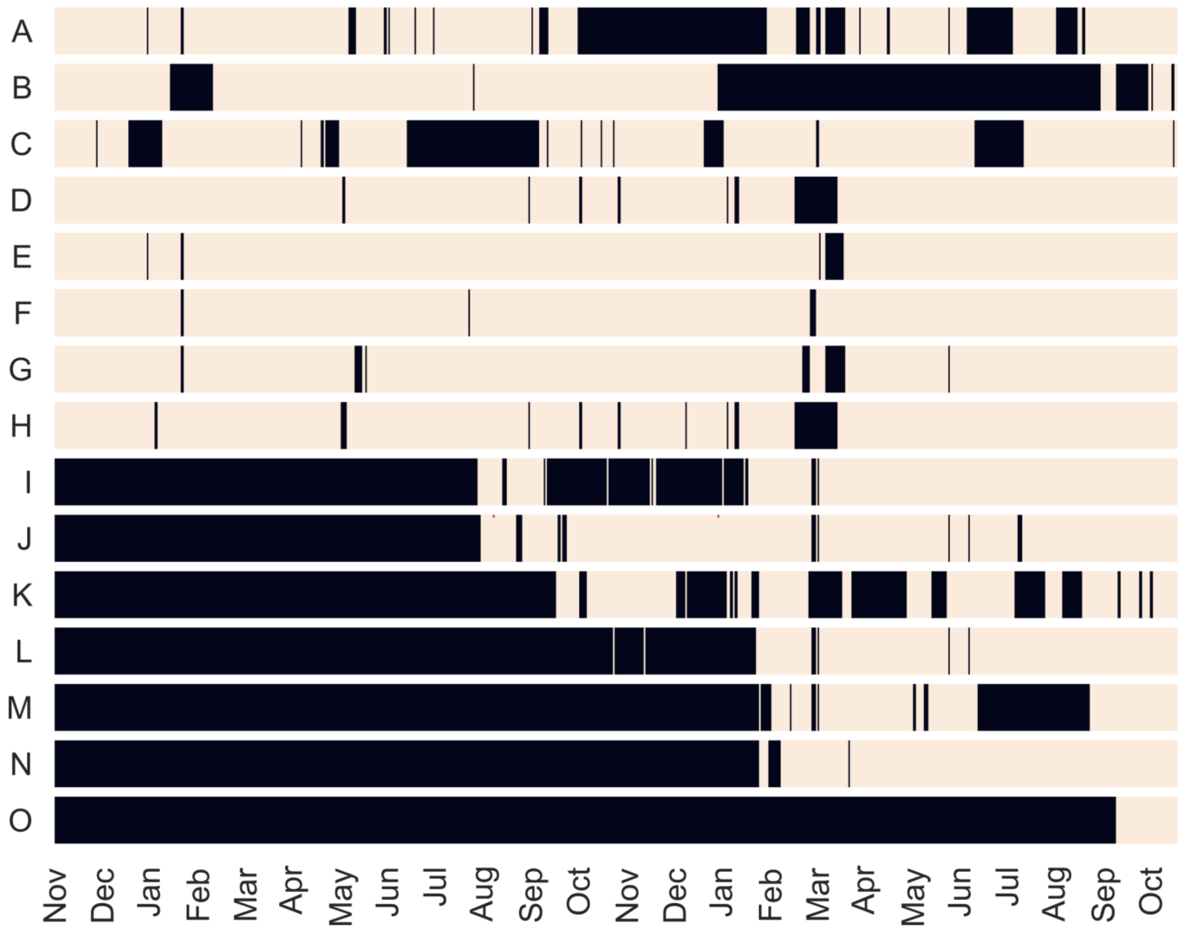

Figure 23 Sensor Data Availability from Jan-Oct 2017, 15 schools

Figure 23 clearly depicts that the stability of the IoT deployment. In almost all deployments there are values missing almost on a daily level.Essentially these measurements are missing either because they were never reported to the cloud infrastructure or due to a failure occurring while they were processed and stored by the cloud services. In the first case, network failures occur either due to a packet transmission error at the wireless network level (i.e., IEEE 802.15.4 or Wi-Fi) or due to a transmission error while an intermediate gateway transmitted the data to the cloud infrastructure over the Internet. For those points remaining long-term dark from the beginning, it is due to the platform deployment not been settled or deactivated during that period. A single dark point signifies missing data for the specific on a specific day, while a white part signifies complete availability, i.e., according to the sensing rate of the specific sensor, see Table 36.

Table 36 Availability for each school

Site ID	Alias in Figure 23	device number(POS)	resources number	Outage
144024	A	8	43	29.78%
28843	B	9	56	41.26%
144243	C	6	32	23.63%
28850	D	9	50	5.33%
144242	E	7	43	2.19%
19640	F	11	54	0.96%
27827	G	7	45	3.69%
155849	H	6	27	6.01%
155851	I	7	36	29.23%
155076	J	34	103	3.97%
155865	K	5	26	37.87%
155077	L	5	109	26.43%
155877	M	5	24	33.09%
157185	N	12	55	3.31%
159705	O	4	22	0.00%

Since the access to the measurements is done through the GAIA platform API, the reason for the missing information is completely unknown. However, as it will become evident in the following sections, specific data mining techniques can be used to overcome the problem of missing values. In Table 36 the 15 schools are in ascending time order when they were incorporated in the GAIA platform.

For each school building the number of points of sensing (POS) are listed along with the total number of sensors deployed. The table reports the outages recorded for each school, reflecting the periods during which no measurements were received from the school, as a percentage from the time point when the school was first incorporated in the GAIA platform, along with outliers the percentage of values that have been recognized from the total number of measurements received from this school.

To avoid issues related the confidentiality of private data, the names of the school buildings have been replaced with alias while presented in another paper. The analysis reveals that certain buildings experience very often data outages.

3.3 Analysis based on the device types

At a second step the same analysis of data is repeated based on the device type of the sensor.

The sensors deployed in the GAIA platform are organized in four main categories:

1) classroom environmental comfort sensors: sensors positioned within classrooms;

2) atmospheric sensors: sensors positioned outdoors;

3) weather stations: sensors positioned on rooftops of buildings;

4) power consumption meters: sensors attached to the main breakout box of the buildings that measure energy consumption.

For each device category, the percentage of outages and the percentage of outliers observed are reported in Table 37.

Table 37 Availability for each type

Name	Device(POS) number	Sensor	Outage
Environment	101	505	14.62%
Libelium for outdoor weather	7	56	19.56%
Synfield for outdoor weather	7	28	20.25%
Electrical Power Consumption	20	56	12.55%

In Figure 24 the representation of the availability of data is depicted on a daily basis for each sensor separately organized by sensor category. Based on this visualization observes that all sensors experience period loss of data. Apparently, the low-power networking technologies come with the result of a non-negligible and unpredictable data lost.

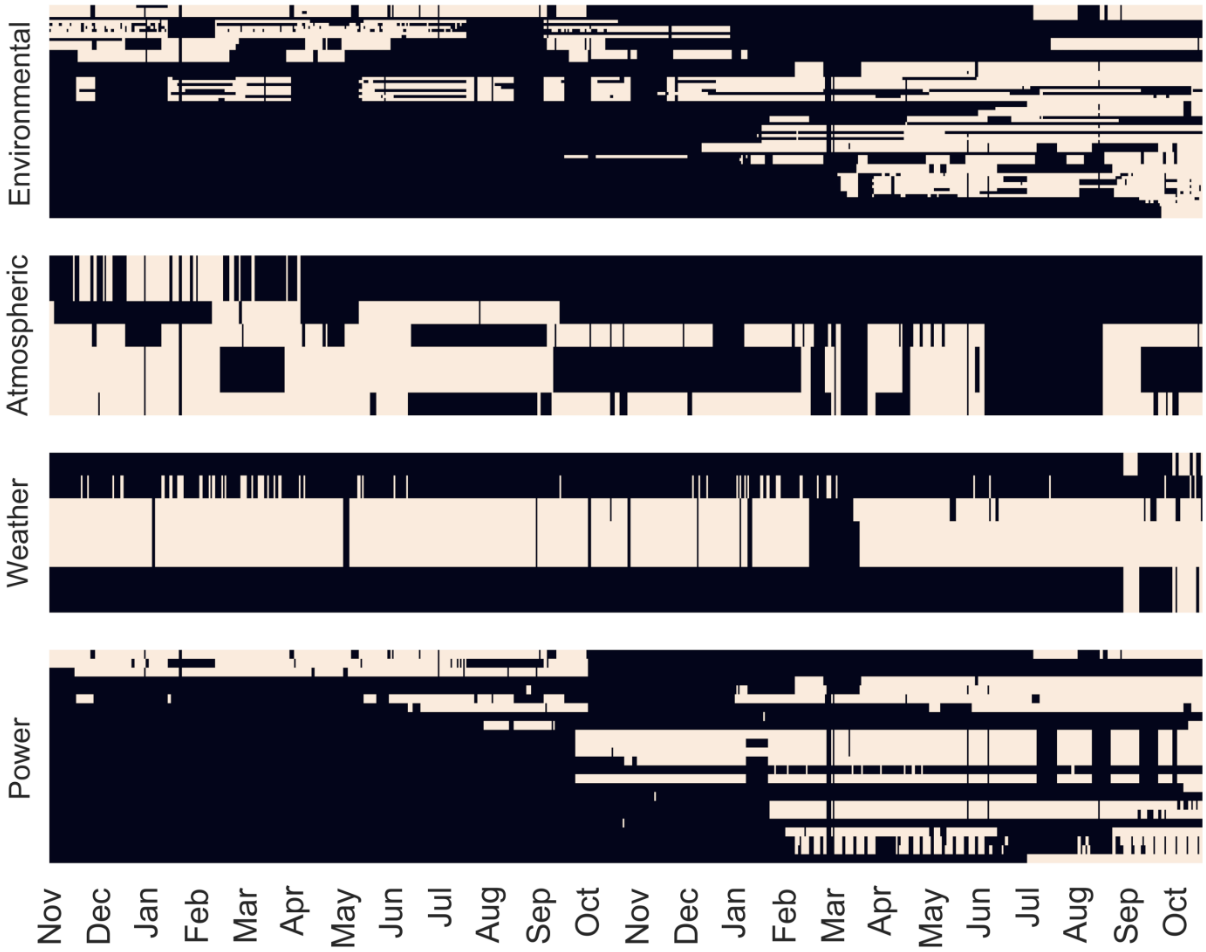

Figure 24 Sensor Data Availability from Jan-Oct 2017, 4 different types

3.4 Evaluating data quality

It is very common in the relevant literature to deploy relatively low-cost devices that produce low-quality measurements or are not properly calibrated. For this reason, we examined the values to identify possible outliers, that is observation points that are distant from the historic values. Such observations may be due to transient errors occurring on the sensing equipment and should be excluded from the dataset. The identification of outliers is based on the interquartile range (IQR) using the upper and lower quartiles Q3 (75th percentile) and Q1 (25th percentile).

- The lower boundary = Q1-3×IQR
- The upper boundary = Q3+3×IQR
- Where IQR=Q3-Q1

The values are examined per sensor/school basis using a time-window of size W.

If a value is outside the boundaries [Q1-3×IQR, Q3+3×IQR] it is flagged as an outlier.

Next, we replace the outlier's value with the history minimum or maximum or average value observed in the time window W depending on which strategy you choose.

After examining the values characterized as outliers two distinct cases were identified:

- Zero values which were clearly sensor error rather than natural events (e.g. humidity of 0% or 100%, temperature dropping from 20 degrees to 0 due to holiday power-off)
- Drastic changes in power consumption (i.e., spikes or fast drops) that could not be justified by the daily school activities.

Table 38 Outlier for each school

Site ID	Outlier
144024	2.67%
28843	2.84%
144243	2.82%
28850	1.45%
144242	1.63%
19640	3.36%
27827	1.33%
155849	1.31%
155851	1.68%
155076	3.19%
155865	1.70%
155077	1.22%
155877	2.67%
157185	5.09%
159705	13.22%

Table 39 Outlier for each type

Name	Outlier
Environment	7.76%
Libelium for outdoor weather	6.29%
Synfield for outdoor weather	0.95%
Electrical Power Consumption	4.17%

3.5 Improving data quality

To overcome the fact that the IoT deployment (1) experiences outages on a regular basis and (2) at a significantly lower rate, sensors report values characterized as outliers a moving window average technique is used. The moving window all to (1) smooths out short-term fluctuations for the case of outliers and (2) fills-in missing values using a simple local algorithm that introduces historic values to fill in the missing data for the specific time period. The moving window average also helps to highlight longer-term trends on the sensor values. Figure 25 depicts an example of the analysis conducted over a specific temperature sensor located in a classroom.

The next is implementing moving window average [12] technique to smooth the time series sensor data. The algorithm is the most straightforward calculation, the average over a chosen time period. The main advantage is that it offers a smoothed line, and provides a more stable level to reveal certain regular behavior to find out the pattern. The weakness is that it is slower to respond to rapid change. It is often favored by analysts operating on longer time frames which happens to be our case.

Besides working on the normal values collected from sensor data, the moving window will:

- Smooth out short-term fluctuations for the case of outliers
- Fill-in missing values using a simple local algorithm that introduces historic values to fill in the missing data for the specific time period.

The moving window average also helps to highlight longer-term trends on the sensor values. Figure 25 depicts an example of the analysis conducted over a specific noise sensor located in a classroom.

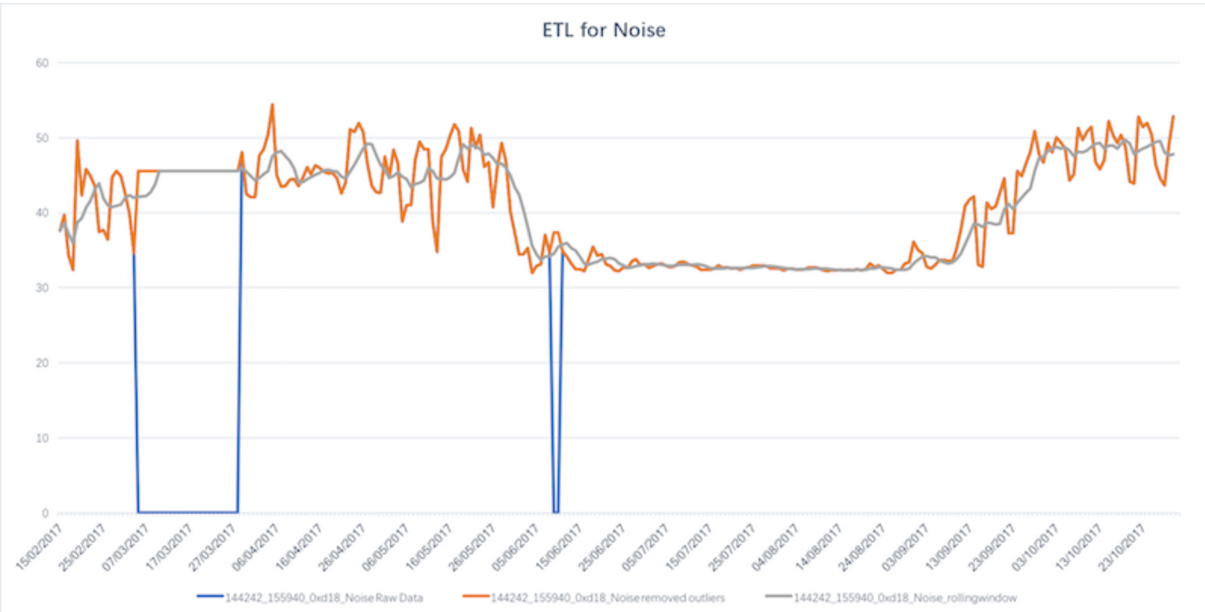

Figure 25 Data Processed After IQR and Moving Window Average

3.6 Extending data using third-party resources

Due to the holiday power-off, disconnection from internet and other reasons, the outdoor weather sensor devices do not provide data as reliable as we expected.

In order to validate the reliability including the accuracy of collected outdoor weather and might give more evidence to take further steps such as replacing the outdoor weather stations and reducing the instalment cost, we take a reference to several different APIs:

- For the time of sunrise sunset data: sunrise-sunset.org
- For daylight saving time offset data: googleapis.com
- For historical weather data: worldweatheronline.com
- For real-time weather data: openweathermap.org

Figure 26 and Figure 27 indicate the comparison of the outdoor temperature collected by the sensor (blue line) and retrieved from API (orange line).

In Figure 26 the API data indicates daily temperature with a regular pattern according to the time of sunrise and sunset which clearly dominates the outdoor temperature. However, the sensor data shows latency for the lowest temperature at 8'clock in the morning instead of late in the night. In Figure 27, due to unknown reasons, the sensor data has a number of missing values in the two-year observation. Meanwhile, the API data shows similar pattern comparing with the valid sensor data and also fill the gap for the period we cannot retrieve from outdoor sensor devices.

The API data indicated more reasonable (outdoor temperatures, changing curve as expected for 5days) and reliable (humidity, no outliers or power off for two years) characters than outdoor weather stations. It is reasonable for making a further movement such as replacing the outdoor weather station with the API data for better performance.

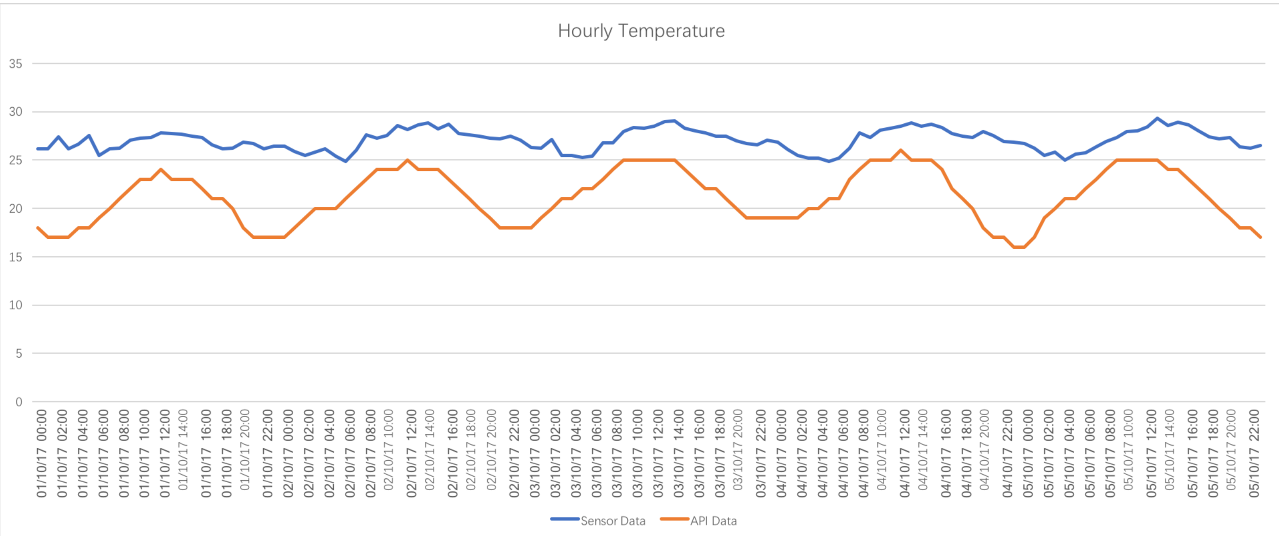

Figure 26 Weather Station Sensor Data vs API Data on 5-days Temperature

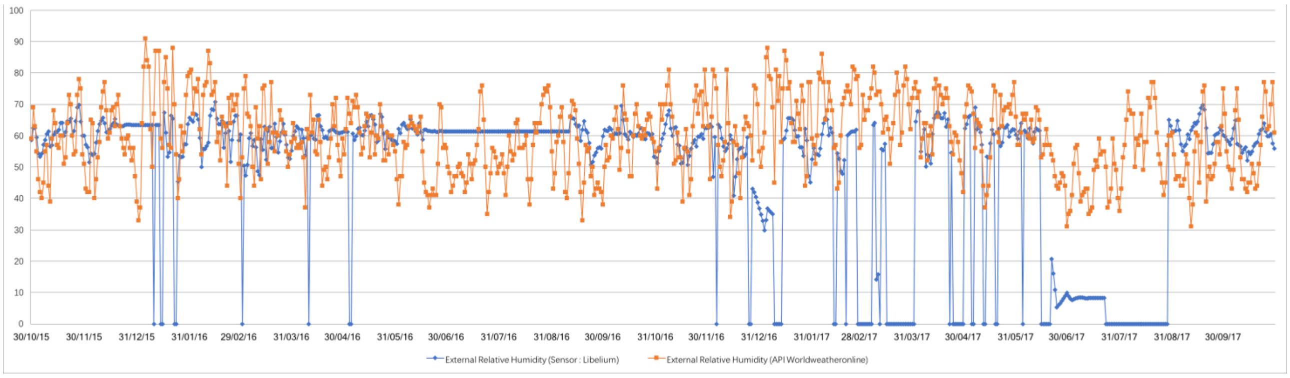

Figure 27 Weather Station Sensor Data vs API Data on 2-years Relative Humidity

4 Thermal Comfort

4.1 Thermal Comfort and ANSI/ASHRAE Standard 55

Everyone has constructive metabolism and constantly exchange the heat with the environment. When it reaches the balance, maintaining the stable thermal neutrality and human body start to feel comfortable, it is the thermal comfort [8]. But the condition of mindset is not easy to evaluate, and for the majority of the occupants is even more difficult.

We introduce another subjective evaluation called ANSI/ASHRAE Standard 55[9] (Thermal Environmental Conditions for Human Occupancy). It is a standard to evaluate the thermal indoor environments comfort. If the indoor condition meets the minimum requirements and reaches to a certain range we can claim it reaches the thermal comfort.

In this chapter. we will use this binary classifier: comfort/un-comfort to evaluate our schools with the tool CBE Thermal Comfort Tool for ASHRAE 55 from Berkeley [10]. By using this tool, we can have a deeper understanding of how the environment and human activity effect on the evaluation. This tool provides two different models: Predicted Mean Vote(PMV) and Adaptive Method.

The Predicted Mean Vote (PMV) model is one of the most thermal comfort models being used. And it requires air temperature, air speed, humidity of the air, means radiant temperature (a radiant transfer between human body and the environment), the metabolic rate of a human, and clothing level to protect the human body from heat or cold. However, we are short of accurate data to implement the evaluation of this model.

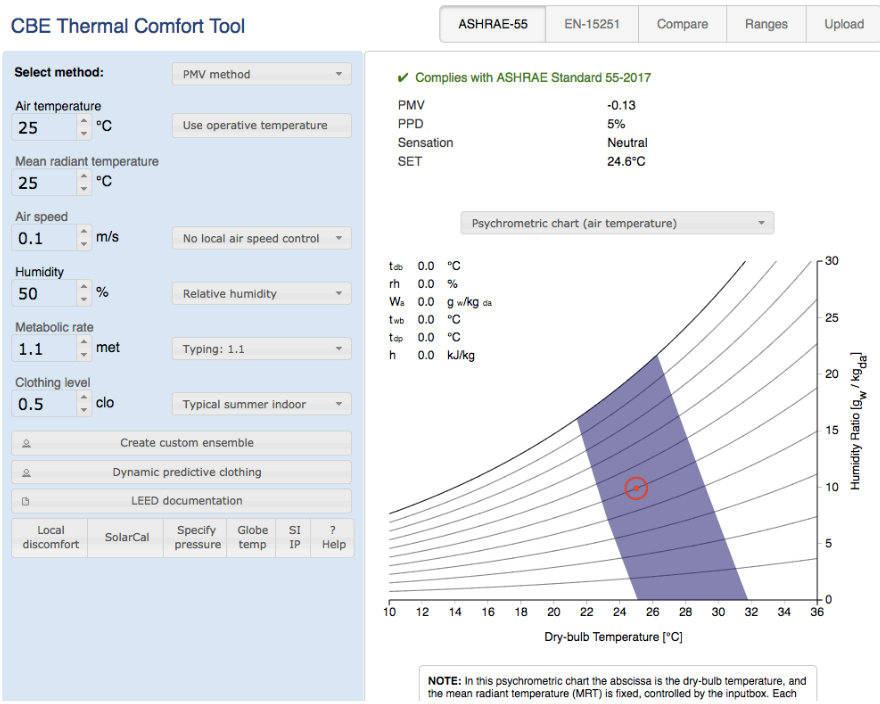

Figure 28 CBE tool on PMV method

In this work, we take the second option: adaptive method.

Figure 29 CBE Tool on Adaptive Method

The intuition for this model is that outdoor climate can affect on the occupant-controlled, natural-conditioned indoor environment, and the occupants naturally would adjust and adapt to the thermal fluctuation. Considering we are studying the educational building which is full of young students, besides the data set we have acquired, adaptive model is the ideal option in this case.

Here is one weekend September 2nd, 2017 from 0'clock to 24'clock in Primary School of Megisti Kastelorizo in Figure 30

The indoor temperature is between 28-33 degrees, in 5 minutes interval

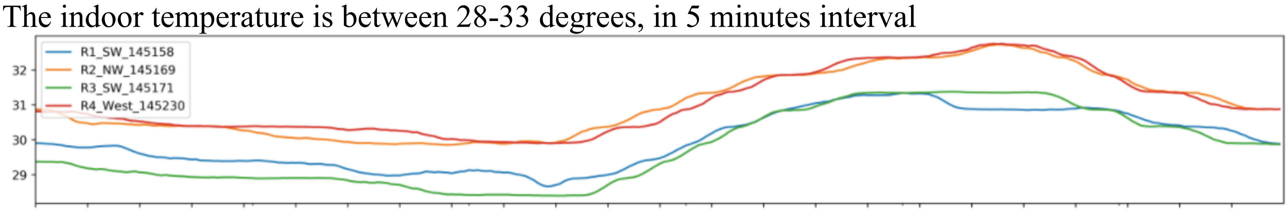

Figure 30 Indoor Temperature

In Figure 31 the outdoor temperature is between 20-31 degrees, in 1 hour interval

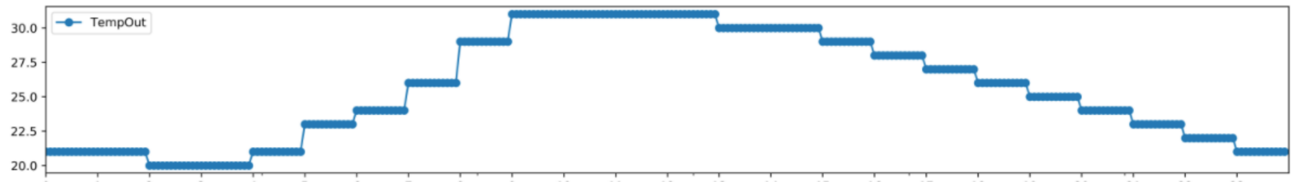

Figure 31 Outdoor Temperature

We put mean radiant temperature with indoor temperature, air temperature and prevailing mean outdoor temperature with outdoor temperature in the CBE tool. In Figure 32 the right chart, the red dot stays in the dark blue area which mean for both 80% and 90% acceptability the classroom 3 (temperature sensor ID = 145158) reached its thermal comfort at 10'clock in the morning.

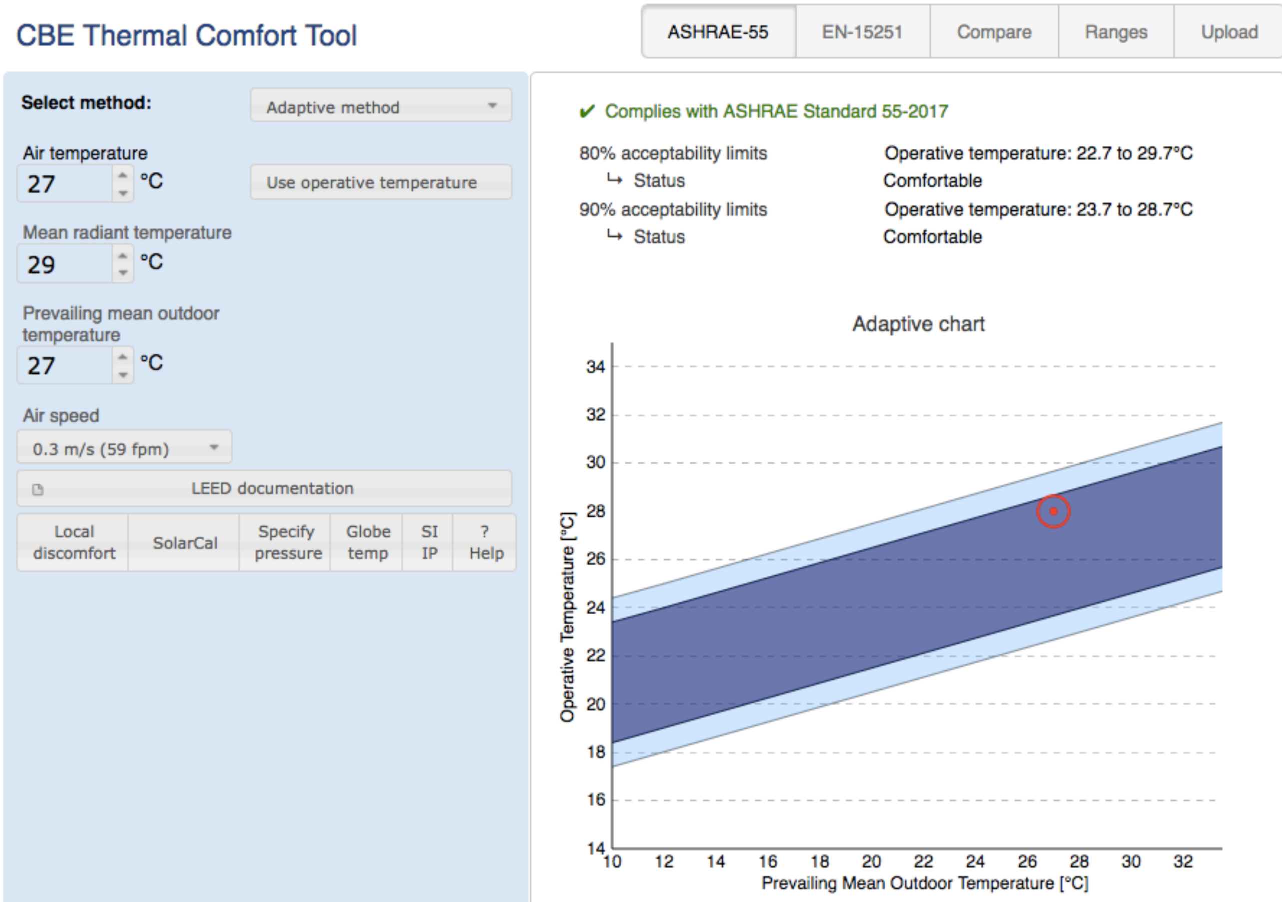

Figure 32 CBE Tool Demonstration

In this work, we tailored the back-end script cbe_comfort.py [11] and got the same result: comfort. Then we integrated this binary classifier for the time-serial indoor and outdoor temperature sensor data to continuously evaluate the thermal comfort.

4.2 Thermal Comfort for all the schools

GAIA platform covers a large range of climate areas including typical Mediterranean climate in Greece and Italy, hot, dry from April to September, and mild, rainy from October to March. Compared with Greece, Soderhamn in Sweden represents another climate type called humid continental, which means there would be a large seasonal temperature difference, with warm humid summers and severely cold winters there. In this section, we will explore this feature to evaluate the indoor thermal comfort in different scenarios and discuss about the overall comfort for all schools which have deployed the indoor environmental comfort devices.

We use CBE tool discussed in the previous section, combined with binary classifier algorithm to calculate output result as two different situations: comfort =1 and un-comfort =0.

We collected indoor temperature data from January 1st 2017 to September 30th 2017, retrieved from GAIA platform, and outdoor temperature data collected from third-party API.

In the Figure 33, each column represents in one single school with the average comfort of all its rooms. And each row represents one single day from Monday to Friday at 08:00 to 16:00(time interval: one hour) the average of the comfort situation for all the classrooms in each school.

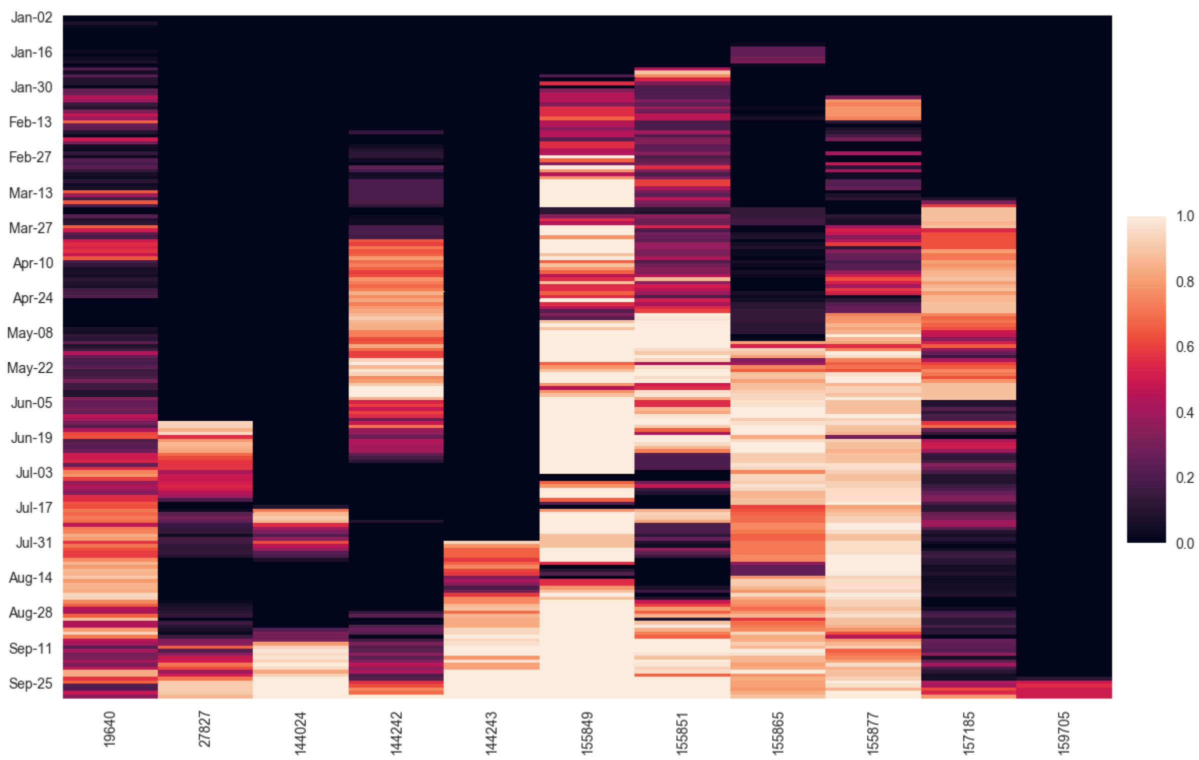

Figure 33 Comfort for all schools From Jan-Sep 2017

For Söderhamn (school ID 159705) from January to middle September, it was not involved in the project during that period. Due to the lack of data, CBE tools determined as long-term un-comfort for that case. The similar situation also appeared on school 27827 and 144243

Meanwhile, school 155849 stands out with very stable comfort condition for the room (there is only one device active), while the school 157185 are kept moving up and down but never achieve the comfortable status in the entire school, only some rooms occasionally from late August to the end of September.

During the active period: school 155877 indicates better comfort compared with other schools, while school 19640 is continuously flipping between comfort and un-comfort. The location for school 155877 is on the south of Greece while school 19640 is on the north. The geography location could be one of the reasons.

Apart from the reasons mentioned above, there are other reasons that affect thermal comforts, such as the construction materials and ages, the location and surrounding environment of the school and orientation and location of the classroom which affects the daytime exposed in the sunlight and also the position of the air conditioning system inside the classrooms. Part of those data is not included in the GAIA platform which makes it hard to determine which is the key effect on the comfort.

In the following section, we are going to use the data in the platform and third-party API to identify the potential key effects.

4.3 Thermal Comfort for single school

The following figures in this section indicate one single school, different rooms' comfort classifier result 1 or 0 corresponding to each hour during the working day and working time, instead of the average of the all the rooms' results. In the same school, at the same time, these results still have different behaviour considering the same outdoor temperature. We introduce the other features, such as the orientation of sensor device locations, the location or the usage for the classroom to seek the possible key effects.

We cross check the thermal comfort with floor plans and room orientation tables from Chapter 2.3.

4.3.1 EllinoGermaniki Agogi Private School

The school was not involved in GAIA project until February 2017. And it has the stable indoor temperature due to the heating/cooling system. Out of expectation, it is not the most comfortable school among the eleven schools. Sharing the same south-west orientation classroom ΣT3(6th room) and ΣT2(8th room) are less comfortable than those classrooms facing towards the north-east for most of the time. Among all the north-east rooms the classroom ΣT7 has better performance considering it is in the same location of the building and same orientation, especially the period between the late of June to middle of July. If we can obtain more information for the setting in ΣT7, we could improve the comfort in the rest of the rooms facing towards the same orientation. There is also an interesting observation in September, two rooms ΣT5 and ΣT2 which are located face to face to the corridor achieve a stable comfort condition at the same time. Maybe the air ventilation between these two rooms improve the comfort and we could use the same intervention for the room ΣT3 and ΣT4 as well. In this school increasing the air ventilation in the closed indoor environment might be the key to improve the whole comfort situation.

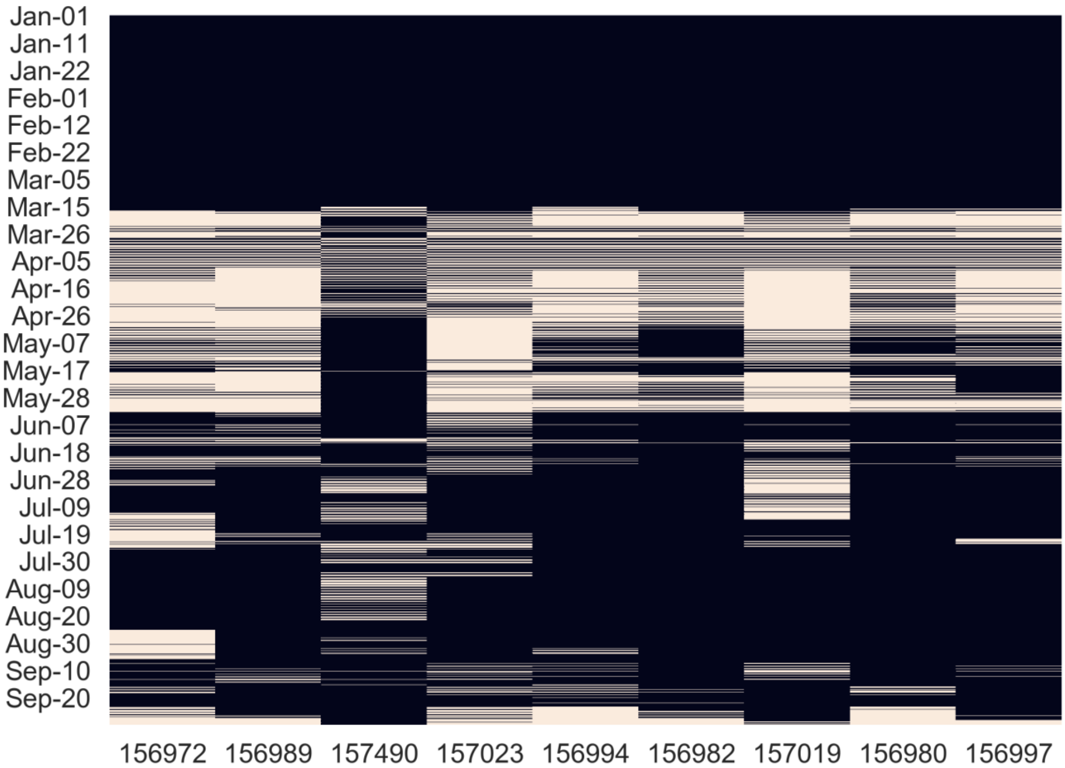

Figure 34 Thermal Comfort in EllinoGermaniki Agogi Private School

4.3.2 Pentavrysso Gymnasium, Kastoria

When we look at the worst performance example school 19640, it presents interesting variability no longer based on the orientation but on the location, usage. The first two classes class 1 (temperature sensor ID 90580) and class 2 (temperature sensor ID 90601) are sharing similarity not only their locations also their comfort. And the music class and laboratory are also sharing the similarity of comfort by their dedicated usage. In this school, the level of the floor, usage of the classroom, and sensor's position are the potential reason for the comfort.

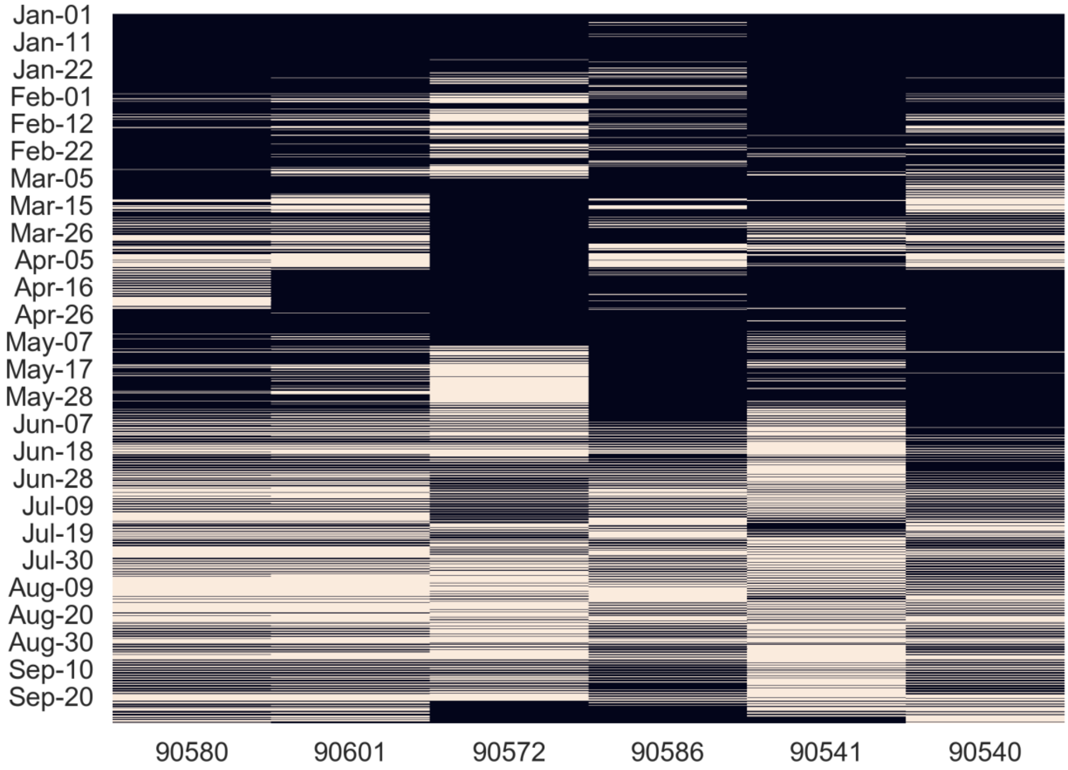

Figure 35 Thermal Comfort in Pentavrysso Gymnasium, Kastoria

4.3.3 Primary School of Megisti Kastelorizo

This school is located on the easternmost island of Greece. It suffered the uncomfortable condition for a long time until the August the situation got improved slightly. The Class1(2nd room) and Class4(4th room) which face towards the north-west have less comfortable time comparing with the rooms from south-west even in the summer season. We could assume this is because of the unique geography location for this school. Preserving the indoor temperature from the sea breeze might be able to improve this situation.

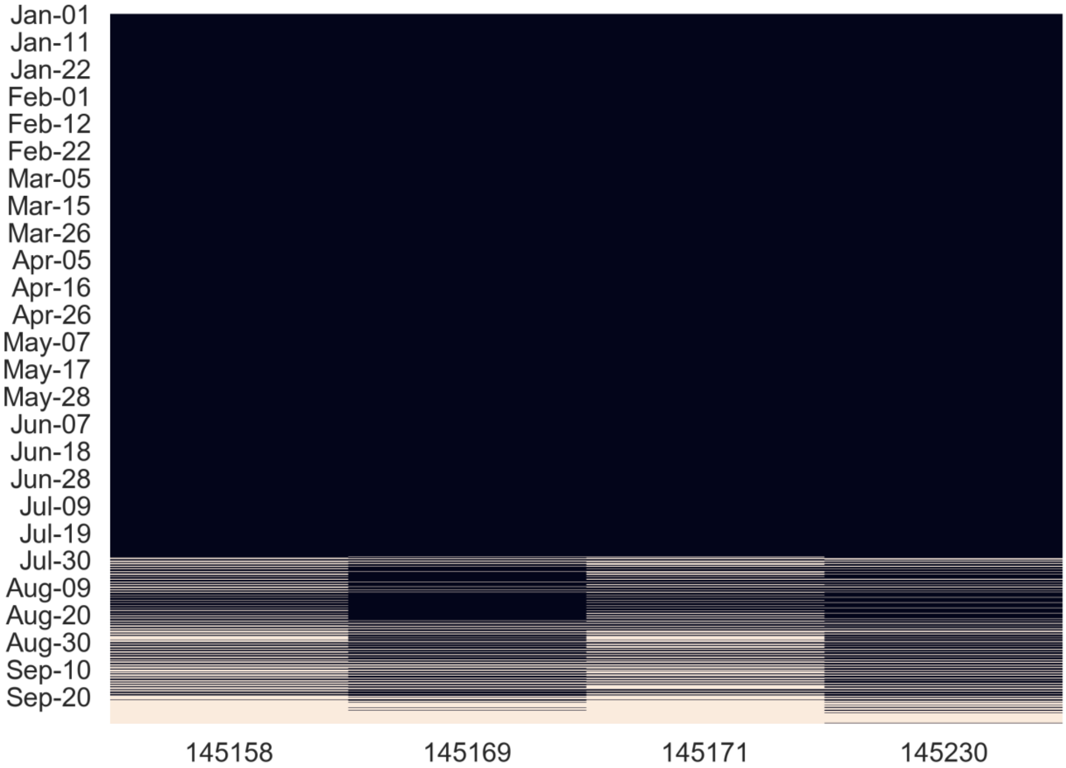

Figure 36 Thermal Comfort in Primary School of Megisti Kastelorizo

4.3.4 2nd Elementary School of Patras

The class 11 (temperature sensor ID 155636 facing to the north-west) on the floor plan appears better comfort in spring seasons but the class 7 (temperature sensor ID 155644, facing to the south-east) has a better condition in summer and early autumn season. And the class 8 (temperature sensor ID 155635 facing to the south) are switch between good and back for all the winter-spring time only have less fluctuate in the summer season. The room facing south in the cold weather and the room facing north in hot weather have a better comfortable condition which fits the seasoning circle of exposing time and angle from sunlight.

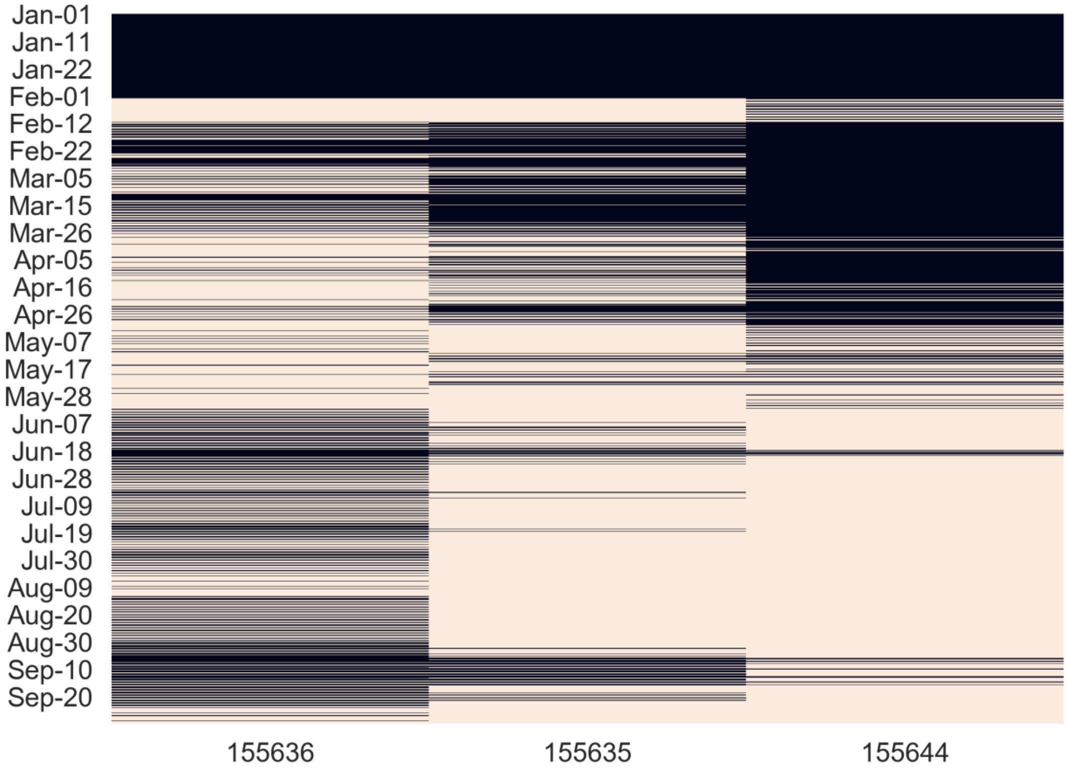

Figure 37 Thermal Comfort in 2nd Elementary School of Patras

4.3.5 8th Gymnasium Patras

The uncomfortable situation has only been changed after June. The Class 4ce (3rd room) on the ground floor is more comfortable than those classrooms on the first floor. The level of floors certainly effects the rooms comfortable. For the rooms on the same floor, we need more information to identify the main effects for the comfort. Because there is no obvious common feature between two similar thermal performance classrooms.

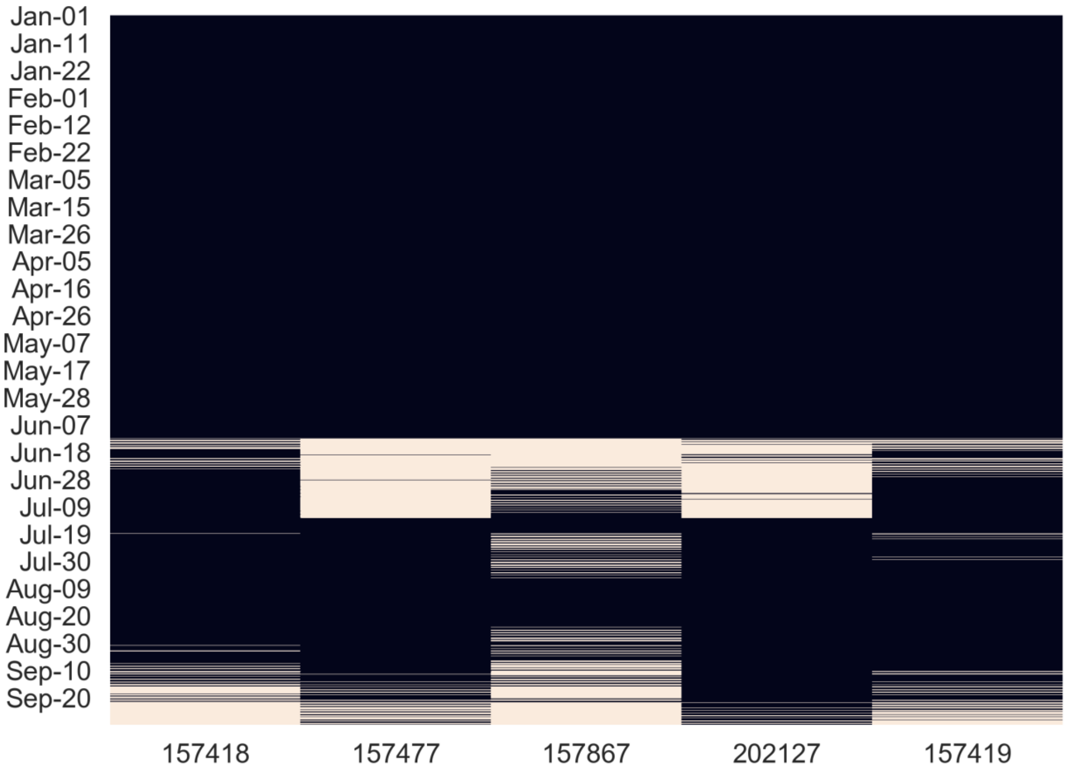

Figure 38 Thermal Comfort in 8th Gymnasium Patras

4.3.6 46th Primary School of Patras

The first room E1 is the only one room outside the main building, and might in cool and fresh sunshade for the summertime gives out a stable comfort condition. On the other hand, classroom E2(2nd room) facing to the south-west were suffering from the long summer afternoon results the un-comfort for the entire summer season. The rest two rooms are facing the northeast. Both showed a comfort situation in hot weathers but in the winter and spring season less exposed to the sunlight cause them in the uncomfortable condition. Since the sunshade could influence a lot on the comfort of the indoor room, we could use some intervention such as planting more deciduous trees around the buildings to improve the comfort in summer time.

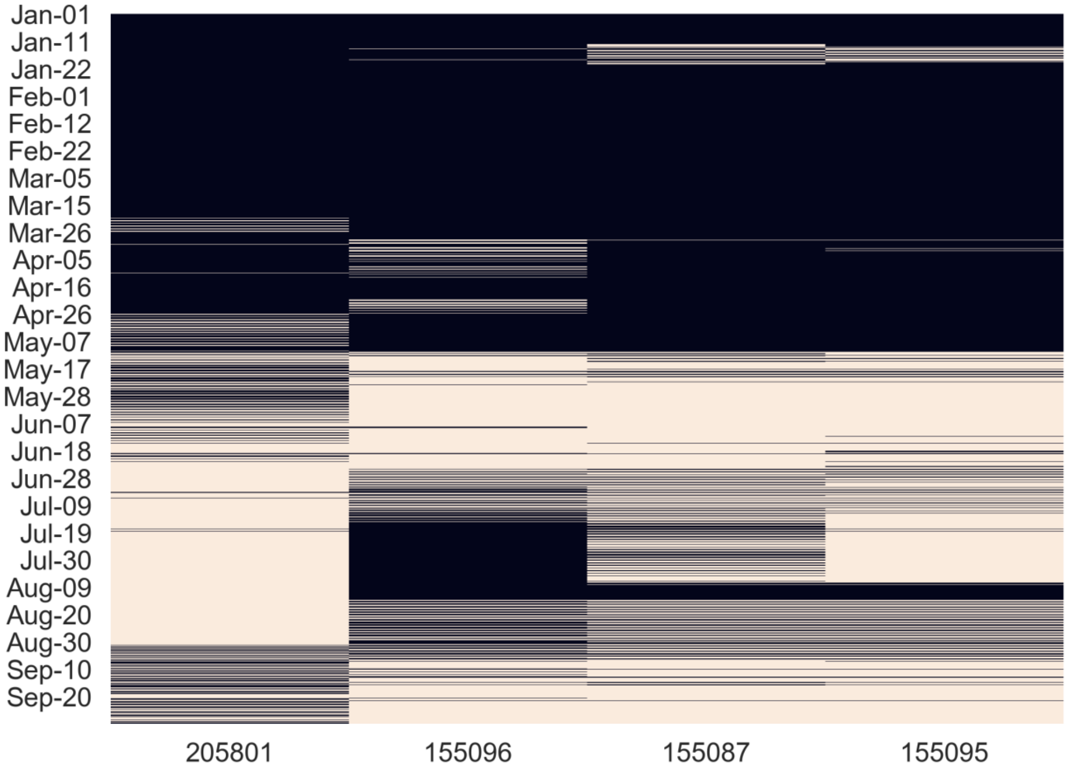

Figure 39 Thermal Comfort in 46th Primary School of Patras

4.3.7 Primary School of Lygia

For this school, most of the time the rooms were staying in the un-comfort condition, but since September the whole situation is changed and most of the time rooms are in the stable comfort condition. And the Class B (2nd room) and Class Δ (4th room) their sensor devices share the position, and the class Γ (3rd room) and Class E (5th room) the environment sensors are deployed in the similar location both of these pairs sharing their own unique similarity. In this school, the position of the indoor environment sensor device influences the accuracy of the room comfort calculation. We could eliminate the external impact like sunshade for different rooms causing this difference and acquire better evaluation.

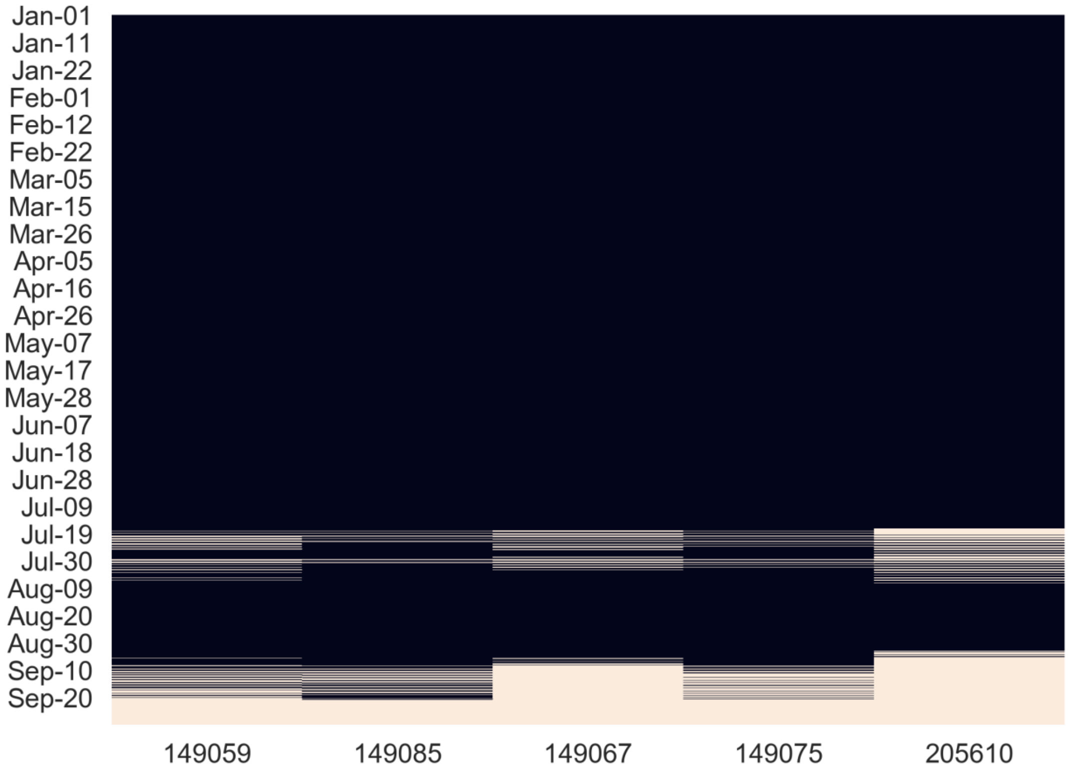

Figure 40 Thermal Comfort in Primary School of Lygia

4.3.8 1st Gymnasium Nea Philadelphia Attica

The computer lab (1st room) and classroom10(3rd room) are south-east and located next to each other. They are showing the similar comfort pattern, especially from April to August. While the classroom5(2nd room) and classroom 8(4th room) are north-west on the same floor, they are sharing the stable comfortable condition during the whole time from April to May. With the similar orientation, the classroom 7(5th room) is more comfortable than Classroom8 and rest of the classrooms in winter. We could contact the manager at this school for better understanding how to improve the rest of rooms about winter heating system performance with the reference of classroom 7's. The orientation with season sunlight changing could be the key effect on these rooms.

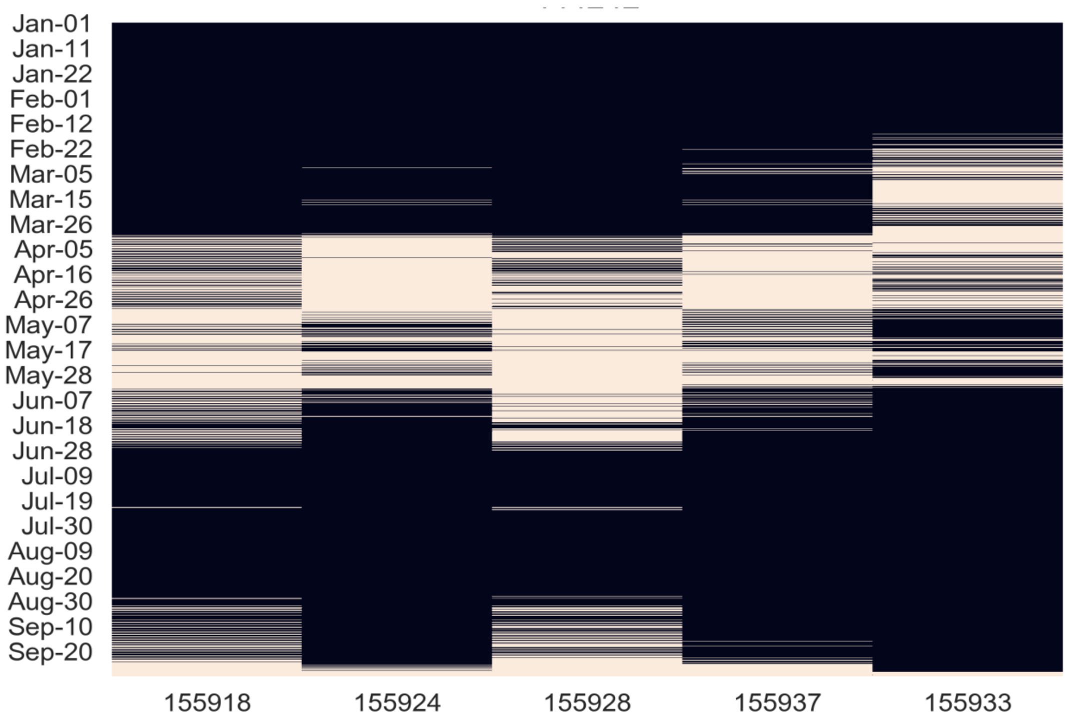

Figure 41 Thermal Comfort in 1st Gymnasium Nea Philadelphia Attica

4.3.9 6th Elementary School of Kesariani

There is only one class 0x312 (temperature sensor ID 155162 facing to the north-west) being counted into the comfort performance, and also the reason why this school could stand out among so many schools in the first section. It shows clear pattern that: from March to September most of the time this room mains in the comfort condition. Its most uncomfortable period is in summer and winter season. Since we don't have the exactly heating/cooling system operation schedule, we could just assume it is caused by the outdoor weather condition and the room location. But still, we need more evidence to prove it.

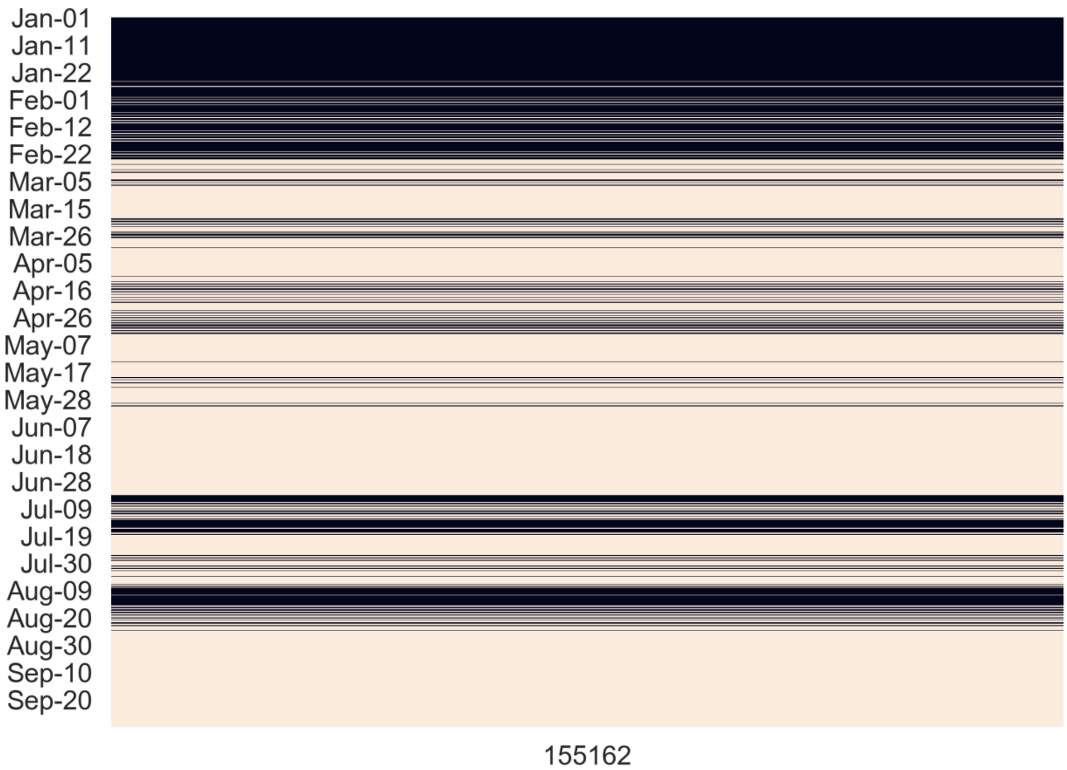

Figure 42 Thermal Comfort in 6th Elementary School of Kesariani

4.3.10 5th Elementary School of Nea Smyrni

The classroom E2 (2nd room) stands out as the most comfortable room for most of the year probably because this room separated from the rest located in the side of the building where might be exposed under better time of sunlight. The classroom E1(1st room) and ΣT2 (4th room) are next to each other, and also show up the exactly the same pattern even in May these two rooms are still not as comfortable as the rest. However, the classroom ΣT3 (5th room) is located on the same floor with the 1st and 4th but still could achieve better performance. This could give us a lead to adjust the room E1 and ΣT2 to simulate the ΣT3. The 3rd room is the computer lab, obviously the cooling system effect the comfort during the summertime brings more comfortable environment. We could reach the manager at the school and identify how to create a better sunlight exposing time for the south-east rooms such as remove the curtains of the rooms or introduce some cooling system to decreasing the indoor room temperatures in summer time.

For the winter, it is obviously most of the time the rooms require the heating system operating longer time instead of just one or two hours per day.

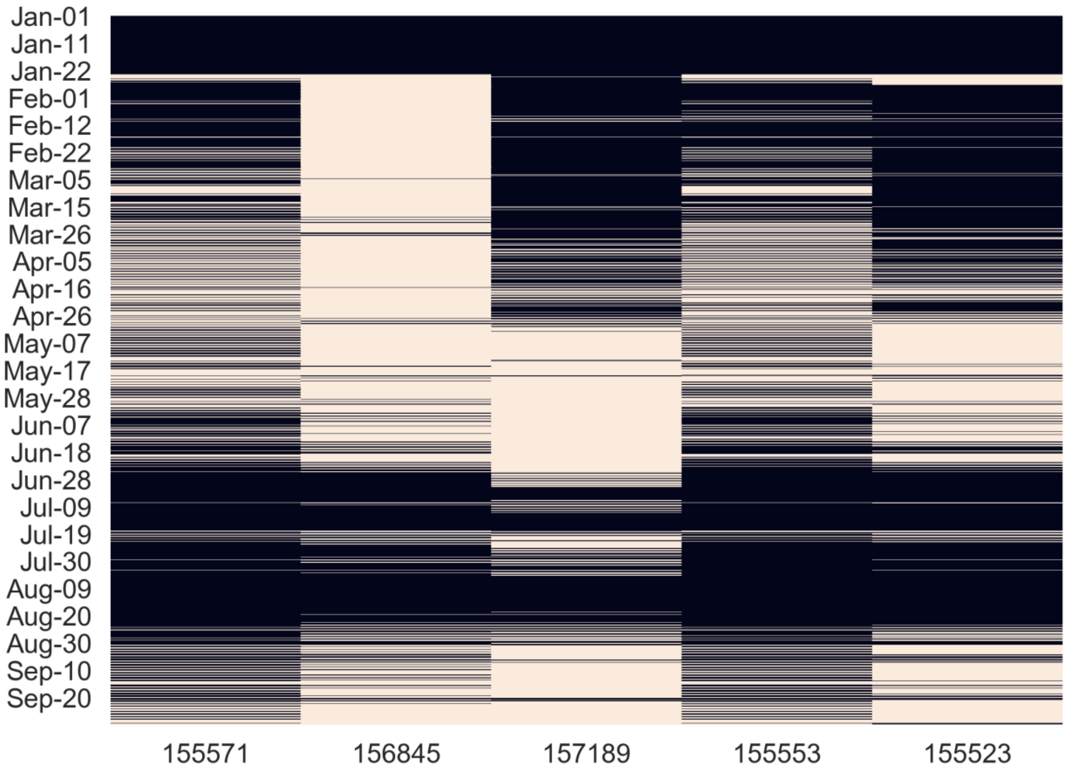

Figure 43 Thermal Comfort in 5th Elementary School of Nea Smyrni

4.3.11 Söderhamn, Staffangymnasiet

This school joined in the project in the late September 2017. With the measurement from the indoor environment sensors, the rooms facing to the west are in better condition than east. Considering the unique climate in Sweden, longer time exposed under the sun is the better way to absorb the heat from sunlight. If it is possible to prevent the heat loss or increase the heat gain from the natural heat source in winter season, we could expect less cost on the heating system.

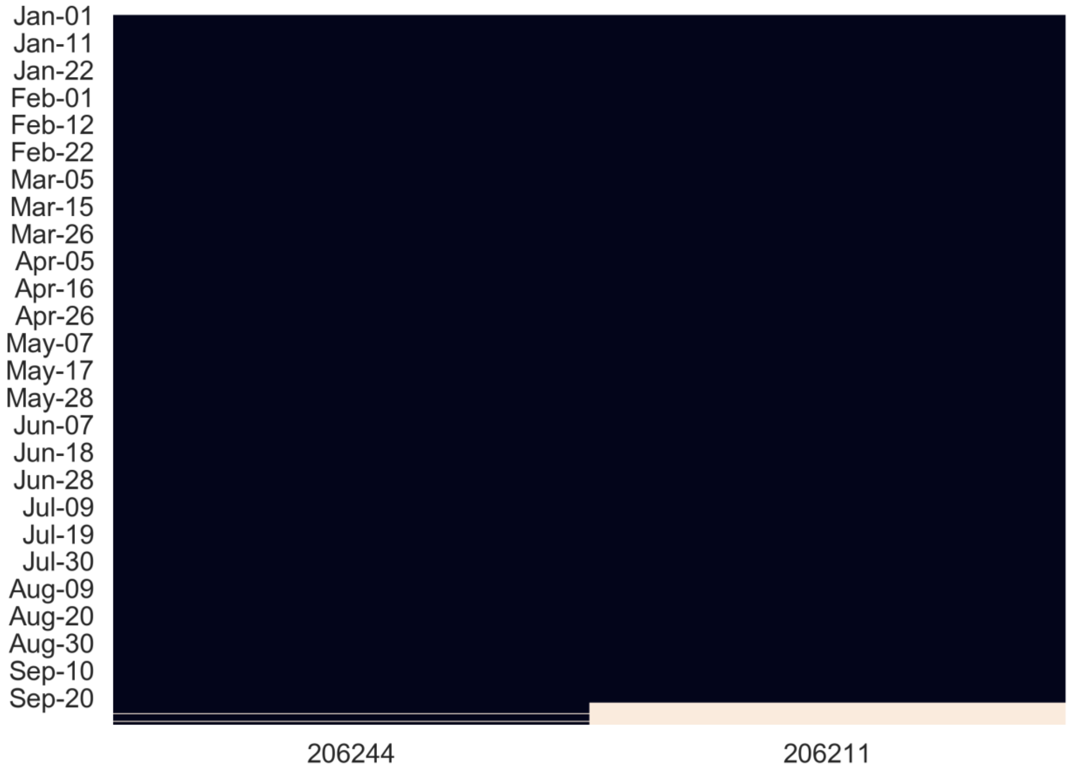

Figure 44 Thermal Comfort in Söderhamn, Staffangymnasiet

4.4 Thermal Comfort with human interference

In this section we look into the performance of the buildings during the weekends when there is no human interference. We observe the performance of the classrooms in order to identify similarities and anomalies between rooms with similar orientation, buildings located at similar geographical locations, etc. We have to accept the truth such as orientation and location of the rooms cannot be changed, but we could work on those effects such as installing blinds, or close/open the doors and/or windows
to improve the performance of the indoor comfort.

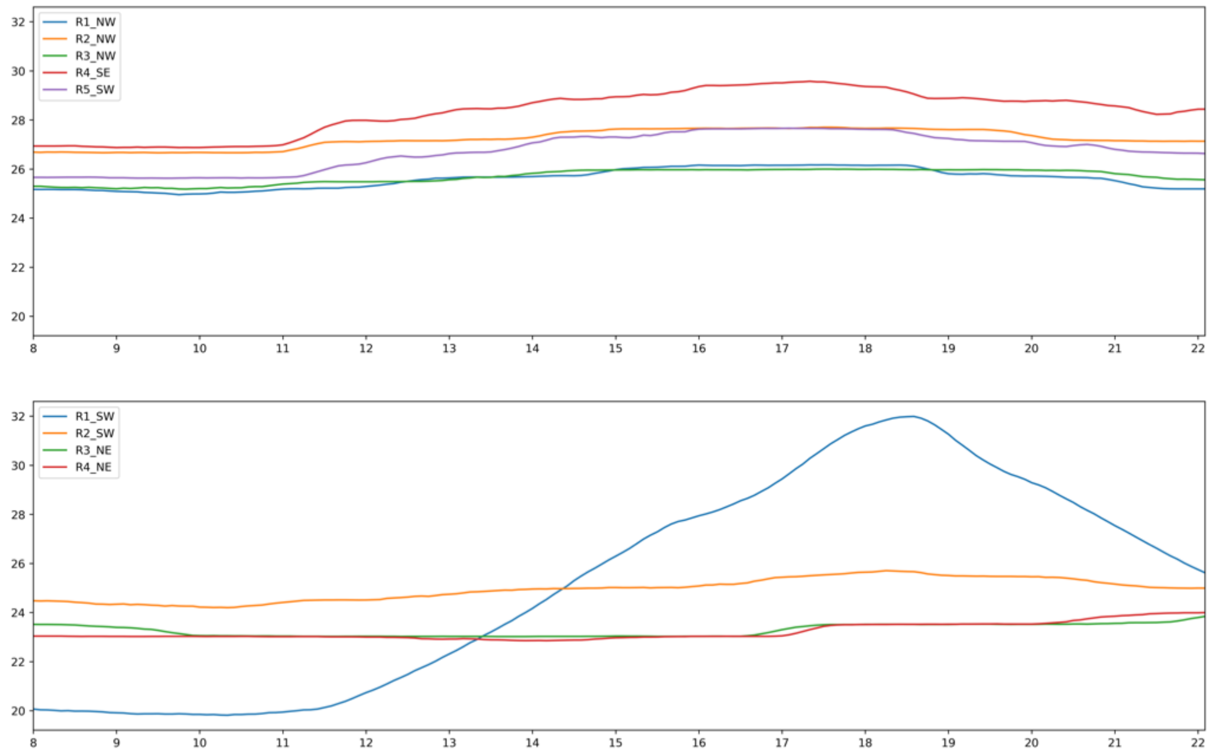

Figure 45 Classroom temperature during Sep 30th (Saturday) 8:00 -22:00

In Figure 43, we compared two different schools' indoor temperature which is located in the same cities during the weekend (no human activates during that period). The school in the top of the figure, two rooms facing towards the south-east/west, the indoor temperature in those two rooms increased two degrees. But the second room also facing south-west in the bottom of the figure remained in the stable temperature. With the confirmations from the managers in two schools, the differences are on the installation of the blinds on the windows. When there is a blind in the room, it will have a better preformation to prevent the effects from exposing in the sunlight.

The school in the bottom which has another room facing south-west have a worst and unbearable indoor temperature. For 8 hours, the temperate raised from 20 to 32 degrees. One reason for the poor performance is because the room is located outside the main building. Another reason is the prefabricated ISO box where insulation is very poor. We can predict this kind of installation effect and improve with different techniques to achieve better performance.

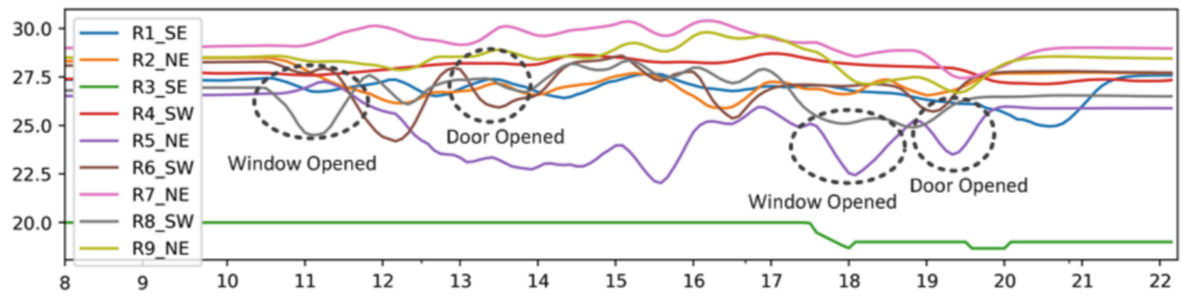

Figure 46 Activity in classrooms and effect on temperature

Now we check the human activates in Figure 46 compared with the previous discussion. We can see there is an immediately decreasing on the indoor temperature while the windows or the doors are opened. And if the indoor comfort dropping out of the comfort range, the users could take similar actions for circulating fresh air inside the rooms and achieve the comfort goal.

In this chapter, we reveal several interferences to achieve the indoor comfort.

- Proper installations of blinds in the south orientation rooms which suffer the sunlight longer time than the north ones.
- Increase the sunshade by planting deciduous trees for those long-time exposed rooms only in summer season.
- Install thermal insulation for reducing the indoor and outdoor heat transfer, specially for classrooms facing towards the north constantly in the uncomfortable condition.
- Keep enough fresh air circulating inside the building and classrooms, especially for those schools deployed the heating and cooling system in hermetic environment.
- Choose devices better insulation for more accurate measurement, and involve third-party weather APIs for long-term reliable data acquisition

5 Conclusions

Everyone is consuming energy in their daily activities, while at home, while at work, when using a car. Controlling the energy consumption during these daily activities can be achieved through a series of simple actions: remember to close the light before leaving the apartment, put a curtain on the windows to minimize the heat gain in summer, or take metro or bus to work. However, when looking at school buildings, the lights remain turned on when the room is empty, and the computers in the laboratory are barely being powered off during the weekends. People always complain for the poor environment of the schools, but they also say there is nothing to do to make it better. In fact, when involving all the users' intervention, it is possible to make a great effect on the energy consumption to save energy to make a positive impact on the environment, and the best part is the budget could be used for the more important purpose: sustainable education.

In this work, we analyse the data collected from sensors which are deployed in European school buildings. It covers a two-year period, including over 700 IoT endpoints, total data size beyond 14 Gigabytes. We used the data collected to provide evidence-based insights to the management of the schools on how to improve the comfort of the classrooms while reducing power consumption We implemented a binary classifier to indicate the comfort of each classroom and comparing the set of the buildings. We identified the impact of indoor environmental conditions on the comfort of the classrooms and highlighted classrooms operating outside the corresponding comfort zones. We identified similarities among the best performance buildings and classrooms, and revealed how to adjust the conditions within poorly performance classrooms in order to improve the efficiency of the energy consumption.

Possible future steps are to focus on the indoor air quality, visual comfort, acoustic comfort to provide a better environment status in school buildings.

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