IOT SOLUTION APPROACH FOR ENERGY CONSUMPTION REDUCTION IN BUILDINGS: PART 2. MEASUREMENT SETUP AND PRACTICAL DATA ANALYSIS

Ansis Avotins[1], Andrejs Podgornovs[1], Armands Senfelds[1], Maris Vegeris[2]
[1]Riga Technical University, Latvia; [2]Lattelecom, Latvia
ansis.avotins@rtu.lv, maris.vegeris@lattelecom.lv

Abstract. IoT solutions enable to gather more detailed consumption data, and by adding other types of sensors to the system, it brings us to new functionality for process and business related monitoring and management. As a measurement object a whole building is selected, which is built in the last few years, already has the Building Management system, lighting, HVAC systems, and in consumption it is comparable also to industrial buildings. The building and measurement data for experimental purposes are arranged in three levels, where the zone level is focusing on rooms covered by one ventilation machine. For data analysis, real measurement parameters like electrical power consumption, room temperatures, humidity, CO_2 levels, heat energy, ventilation system pressures and also data from the meteorological weather station are obtained simultaneously for several months, using LoRaWAN network and sensors, thus giving ability to have wide data analysis options, to crosscheck complex systems. Detailed measurements and further data analysis show that even new building management systems have errors and there are possibilities to improve the energy efficiency, especially during the exploitation period, where many human errors could be traced and corrected using smart algorithms.

Keywords: energy efficiency, energy consumption, Internet of Things, LoRaWAN, sensors.

Introduction

Every year, the amount of energy consumption in the world increases, therefore also need for new energy saving technologies becomes very popular. Also political decisions in terms of climate protection are closely related with energy-efficiency measures in various countries, where Germany has placed one of the highest targets to be reached, already implementing its *"Energiewende"* program in various sectors, like in industry introducing novel DC-Grids [1] and industrial robots as re-used energy sources [2], as well as university campus grid infrastructure could be changed by implementing renewable energy systems, stationary storage, charging infrastructure [3]-[4]. The tendency shows that in future existing consumers will become prosumers, using a decentralised approach with the need to manage and measure electrical loads within each building.

Currently most of the buildings have a metering system provided by the power grid utility company, and if digital or smart meters are installed, it is possible to obtain daily total power consumption data. Nevertheless, it helps to manage the bills, but it does not really show the possibilities to find energy saving or optimization possibilities. In this case, the energy audit approach can be used, by means of obtaining detailed power consumption measurements. The resolution and type of measurement equipment must be selected appropriately to the measurement target load type. In case of sinusoidal AC (alternate current) character any common measurement equipment can be used, but in the case of DC measurements or even bidirectional power flow, more dedicated measurement equipment should be used [5] to get correct readings. The implementation of renewable energy sources, created a demand for various single phase AC grid-tied converters that use Clarke and Park transformations intended for three phase system phase locked loop (PLL) control, at the end decreasing measurement or control precision [6]. Precision can be improved, by implementing 10-bit ADC (or higher) to analogue voltage and current signals, at the end giving more precise average power consumption readings.

Distant data acquisition and telemetry systems are well known and lately have evolved to the Internet of Things data acquisition systems. Due to easy process of installation and software reconfiguration, wireless systems become very popular in various areas, like district heating monitoring and optimisation systems [7], high rise apartment buildings [8], passive buildings [9], building air conditioners [10] and many more.

Materials and methods

By using the IoT solutions, it is also possible to integrate new functionality to enable new process and business related monitoring and control modules that is very important for company resource and process management. In this research as a measurement object the whole Riga Technical University

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faculty building (Power and Electrical Engineering) is selected, which is built in the last few years, and already has the Building Management system, lighting, HVAC systems, and in consumption it is comparable also to industrial buildings. Selection of this building, description of the energy consumption mathematical model input data architecture as well as the block diagram of the proposed IoT solution data structure is given in the previous research, described in [11]. This research focuses mostly on electrical consumption data analysis. The described IoT approach is applicable also to farm type buildings.

The obtained building data and measurements for experimental purposes are arranged in three levels: whole building level, zone level (dedicated production area) and room (smaller production unit) level. Building level experiment is used to prove the need for detailed measurements in order to find potential energy savings. Zone level is focusing on the production process, for example, rooms covered by the same HVAC machine (see Fig.1. PN zones), as the electrical grid is allocated by building floors, but HVAC systems – by building facades (includes more than one floor). Room level is used to compare two identical rooms (in this case auditoriums N115 and N116), to do measurements in controlled experimental environment.

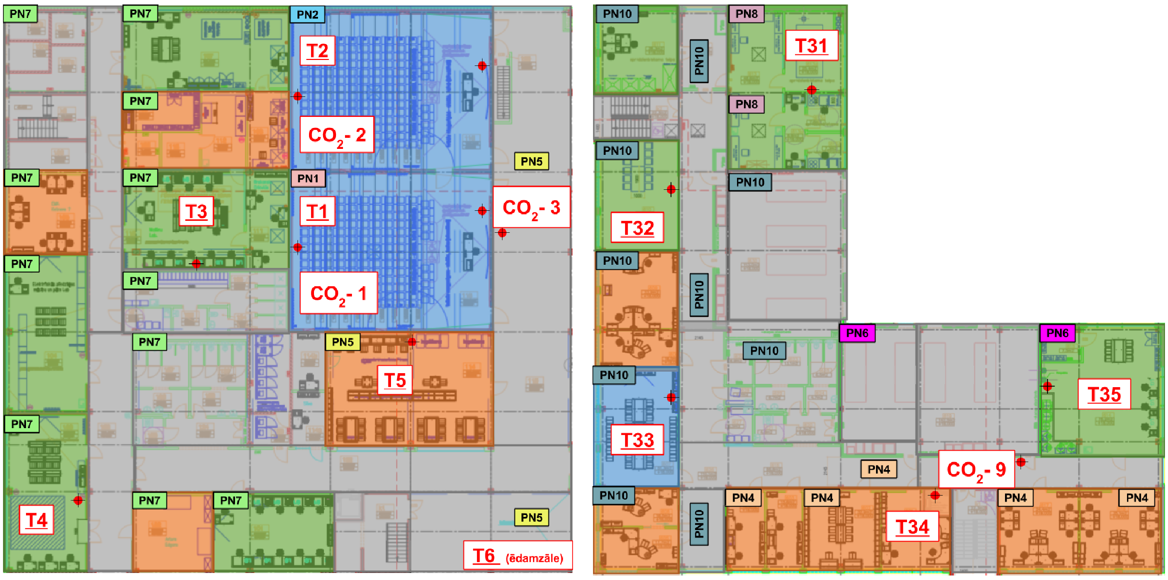

Fig. 1. **Faculty building PN zones and sensor placement:** first floor (left); sixth floor (right)

For data analysis, online measurement parameters like room temperatures, humidity, CO_2 levels, heat energy, and ventilation system pressures are obtained by special sensors, able to communicate in LoRaWAN network. Sensors are placed in all building floors, distributed by the room types, like laboratories (see Fig. 1 – green), offices (see Fig. 1 – orange), auditoriums (see Fig. 1 – blue) and technical rooms or corridors (see Fig.1 – grey). In total 35 pcs temperature (Senlab T), 8 pcs combined (CO_2, *t* ºC and humidity - GlobalSAT LS-111E) LoRaWAN sensors are placed in the faculty building, as well as 3 pcs heat (Dynasonics TFX Ultra), 2 pcs air flow sensors (Produal IML-M) placed at PN6 HVAC machine. Electrical power consumption data (obtained by 12 pcs Circutor CIR-E3) as well as data from the meteorological weather station are obtained from data loggers and then stored in the database system, thus at the moment more than 4 million data entries for several months are obtained, thus giving the ability to have wide data analysis options, to crosscheck complex systems.

Fast and detailed electrical power measurements and data acquisition are necessary in order to control the power consumption, therefore appropriate and regular power meter readings must be available. For on-line monitoring system, the data transmitting speed and amount are critical criteria for total system costs. When analysing existing measurement systems, each system has various aggregated data resolutions. In the monitoring system minimal requirement for the data acquisition system can be agreed upon power quality measurement methods. Summing up the power parameter measuring and power quality assessment requirements, it is recommended to provide the power monitoring system with a power meter appropriate to Class S with the measurement time resolution of one minute [11].

However, for control of the BMS and taking into account the transient processes of the main power systems (based on the heating and ventilation system assessment), an adequate step of the resulting total data is taken one hour. This is sufficient to assess the ongoing process, make decisions and adjustments for the next period of data acquisition. Also, this period of time is synchronized with the data of counters of input energy resources, such as electricity and heat. For detailed statistical data analysis of the processes, the data from the placed electricity sensors were obtained with an interval of one minute, and compared to the readings of the central counter (see Fig.2.) and the data obtained by formula (1).

In the building level – for electricity consumption data acquisition JSC "Latvenergo" verified smart meter is used (Fig. 1, "Sk"), where data are retrieved remotely with an interval of one measurement per hour. Disadvantage of the building-level metering system is lack of more detailed and dynamic measurement data of the building, therefore the zone level metering system is applied as shown in Fig.2. This system metering evaluation period is from 01/01/2017 to 08/31/2017. The EEF building was separated into zones, which boundaries are actually determined by the floors of the building. During detailed measurement analysis, it was found that the "café" was paying only 25 % of the bill, as the current sensor of the digital counter had default factory settings for division 1:1, but should have 1:4.

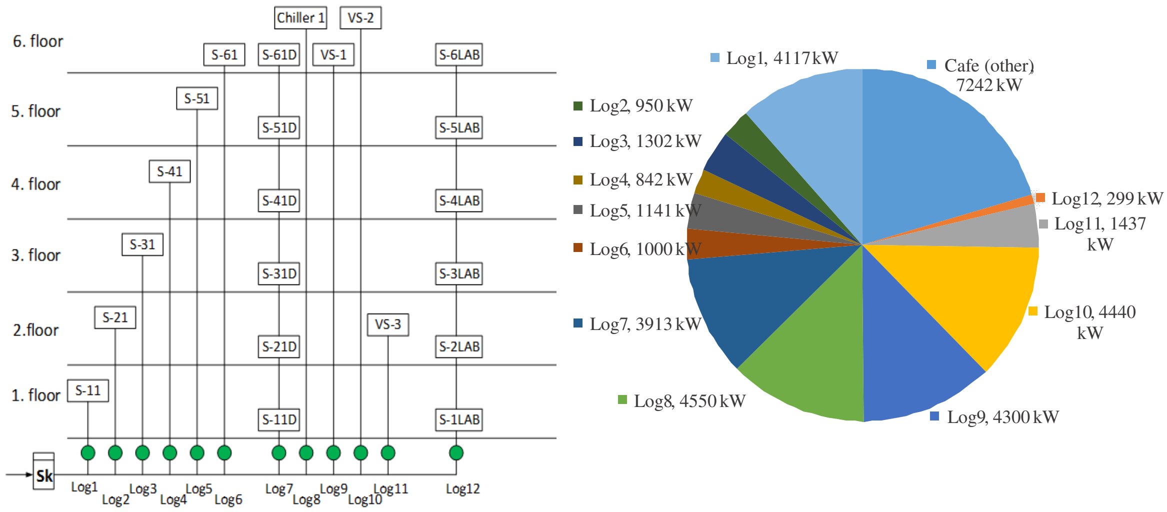

Fig. 2. **Schematic diagram of EEF building with distributed area meters (left) and consumed energy distribution diagram by zones (right)**

12 CIR-E3 meters (Log1-Log12) were installed in the EEF building, providing metering of consumed electrical energy: for each floor (six meters), for the entire computer network (one meter), for the chiller system (one meter), for the ventilation system (three meters), for laboratory special power supply (one meter). The task of the installed meters was to provide synchronized electricity metering and recording. Calculating active energy in the EEF building, the energy balance statement is:

$$E_{Sk} = E_{\text{Log}\,1} + E_{\text{Log}\,2} + E_{\text{Log}\,3} + E_{\text{Log}\,4} + E_{\text{Log}\,5} + E_{\text{Log}\,6} + E_{\text{Log}\,7} + E_{\text{Log}\,8} + E_{\text{Log}\,9} + E_{\text{Log}\,10} + E_{\text{Log}\,11} + E_{\text{Log}\,12} = \sum_{i=1}^{n} E_{\text{Log}\,i} \tag{1}$$

where E_{Sk} –active energy input of the building, Ws or kWh;
$E_{\text{Log}i}$ – active energy input of the zone meters, Ws or kWh.

Whole electrical energy consumption is 35539 kWh per month. Since the ventilation system work area is on several floors and various building facades, this area does not match the power supply system grids, where consumers are placed across different floors of the building. Therefore, to obtain heat energy gained from electrical equipment equal to their consumption (it affects the ventilation system recuperation), it was decided to move the CIR-E3 metering devices to cover all ventilation zone PN6. Data are synchronized and for graphical visualization, the 8th week of 2018 (from 02.12.2018 to 02.18.2018) is taken as an example (Fig. 3).

Received CIR-E3 measurement data (see Fig. 3) provide detailed information on the consumption of electricity and its distribution during the day. It is observed that the consumption of workdays in the floor area correlates with the consumption pattern in other weeks of the month, and Saturday's consumption is about half the working day's consumption.

The use of such detailed data also enables an efficient energy management system to be provided, as it gives an idea of which of the existing systems works at a specific time (or in what mode it works). The detailed data also show that on Sunday, when the building is closed and people are not present, the ventilation system energy consumption is the same as on a usual day. Furthermore, weekly energy consumption increases week by week, and it is due to filtering element condition, as it becomes greasy – more power is needed, thus using such detailed data we could determine, when exactly the filters need to be changed to get the best energy and cost efficiency.

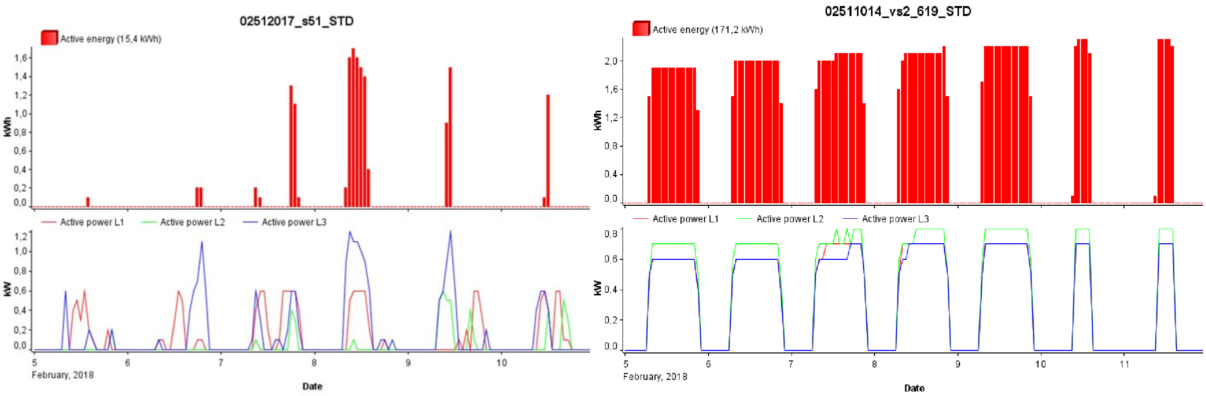

Fig. 3. **Electrical energy consumption data for 8th week of 2018:** 5th floor PN6 zone lighting (left), ventilation system PN6 (right)

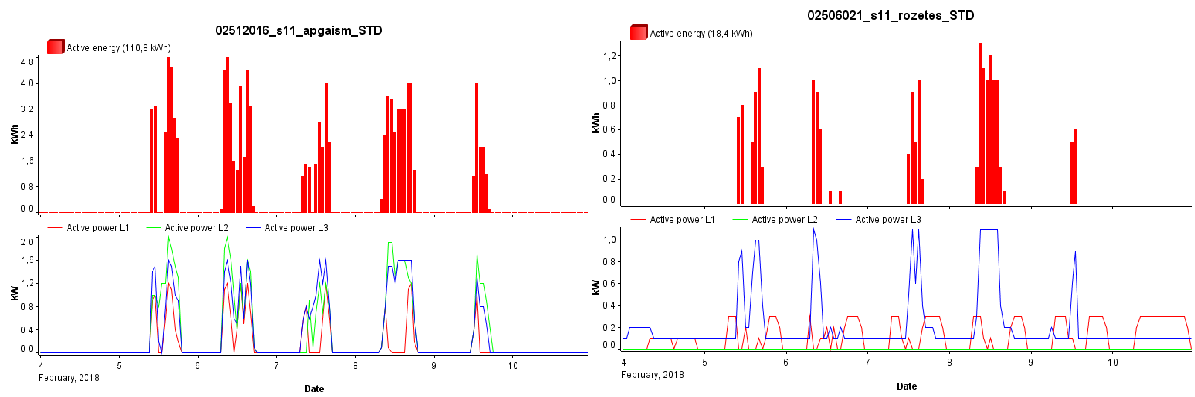

Fig. 4. **Room level auditorium electrical energy consumption data:** auditorium lighting (left), power supply sockets for presentation equipment (right)

For room level case study two lectures auditoriums have been selected. Each auditorium has its own ventilation equipment, PN1 (02VS01) and PN2 (02VS01), respectively, serving the flow auditorium room No. 115 and No. 116. The auditorium electrical power supply ensures the operation of the ventilation system, lighting and wall contacts (230 V). The distribution of electrical energy consumption in the three main ways is: 28 % ventilation system, 62 % auditorium lighting, 10 % power supply sockets on the wall for presentation equipment (Fig.4). Fig. 5 depicts the experiment measurement results in the PN6 zone level, where 6 kW heater was used in laboratory No.422 (imitating heat dissipated by 60 persons), to obtain effect on the HVAC recuperating system.

Fig. 6 red line depicts weekly (08.03.2018-14.03.2018) power consumption of the HVAC machine for the PN1 zone, which ventilates room N115, and blue line room N116 accordingly (PN2 zone). Both auditoriums are identical, have the same settings and separate, but identical HVAC systems, and have the same settings for temperature and humidity parameters. Fig. 7 shows the temperature, humidity and CO_2 readings for both auditoriums on 08.03.2018., thus it can be said that environmental (comfort) parameters are almost the same in both cases.

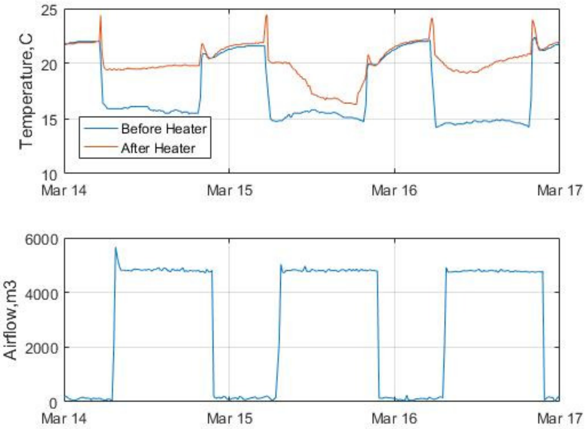

Fig. 5. **Experiment results in PN6 zone level using 6 kW heater**

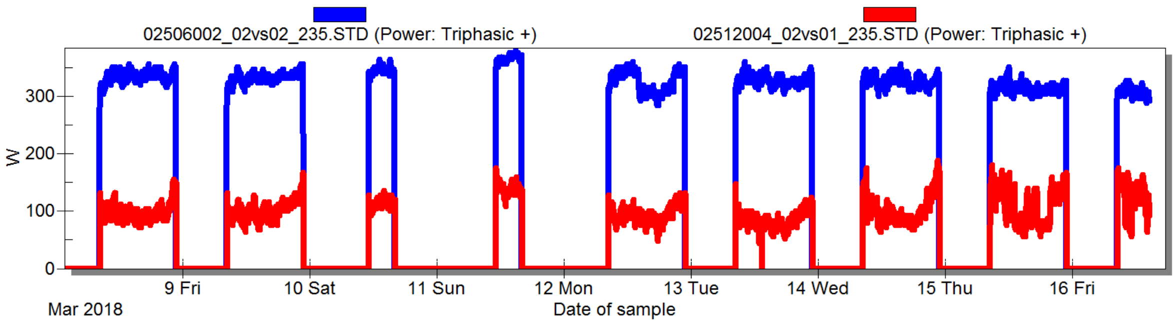

Fig. 6. **Power consumption measurements** (red – PN1; blue – PN2)

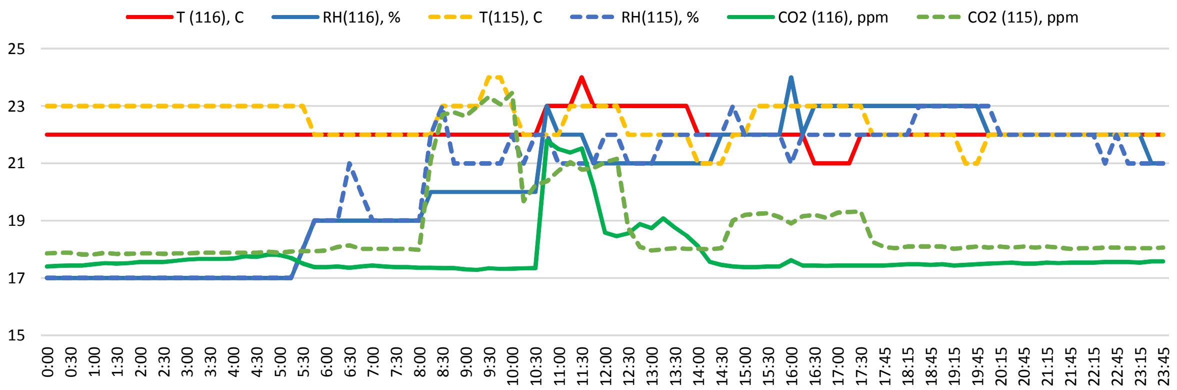

Fig. 7. **PN1 and PN2 zone measurement results of LoRaWAN sensors**

Results and discussion

As detailed electrical power consumption measurements (see Fig. 6) show great difference for both (PN1 and PN2) HVAC machines, it raises a question about the reason. If looking at one day cycle (see Fig.8), we can see that the original HVAC regulation system does not have input data from the CO_2 sensor. Also the daily energy consumption in room 115 (PN1) is 4.8 kWh and room 116 (PN2) is 1.44 kWh, thus the difference is 70 %.

At the end a human error was found, as someone forgot to change the HVAC systems minimal supply air pressure for PN1 back to 50 Pa (from 100 Pa). Without detailed measurements it would not be possible to detect such consumption difference.

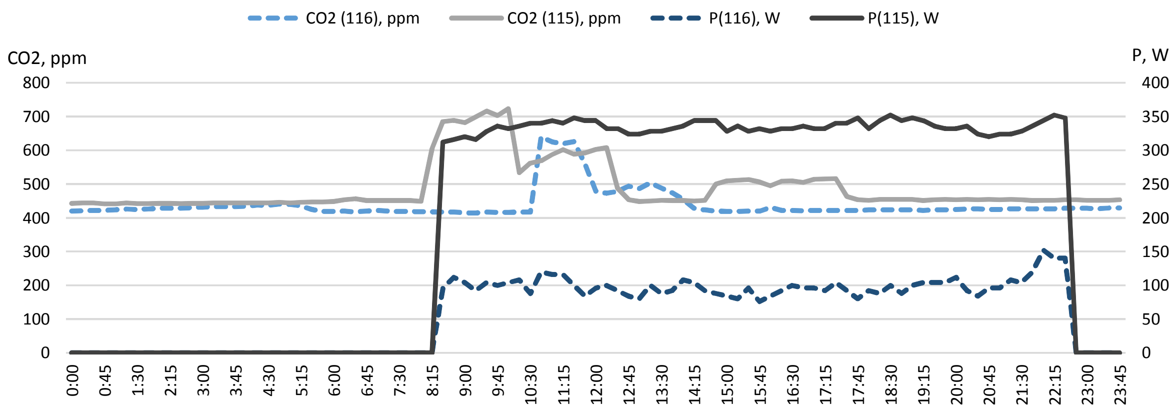

Fig. 8. **Comparison of measurement results in PN1 and PN2 zones for one day**

Conclusions

1. This article reveals the first measurement data and analysis results and prove the need for a mathematical model and prediction algorithm development for improved and energy efficient building regulation processes.
2. Zone level experiment shows that heat gains, created by people, affect the building's HVAC system, thus person count detection in real-time could be used for more energy efficient ventilation system regulation or keeping the best comfort level.
3. LoRAWAN network is well suited for the non-dynamic sensor data transfer, but not for detailed electrical power consumption, thus a new approach for data aggregation is needed, by means of embedded algorithms already within the power measurement equipment.
4. Various human based errors can be corrected using detailed power consumption measurements and comparing them with real-time environment data.

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