



# Recommendations on monitoring the energy efficiency of buildings

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## 1. Introduction

As the Coordinating Beneficiary, the Silesian Voivodeship is implementing the LIFE integrated project 'Silesia: Blue Sky Restored'. Project activities are being carried out in collaboration with over 80 partners, including the Silesian University of Technology and local authorities in the Silesian Voivodeship, among others.

The project's main goal is to ensure the smooth and effective implementation of the Air Quality Programme for the Silesian Voivodeship. This involves developing and implementing remedial measures to improve air quality and reduce its adverse impact on the health and lives of the region's inhabitants.

As part of project activity C.3, the Silesian University of Technology is developing models of sustainable construction for public buildings in collaboration with the Silesian Voivodeship. These models will help to identify the most effective organisational, legal and investment solutions for improving energy efficiency, and will also represent a step towards a climate-neutral economy [1].

A preliminary step in the development of these models is to carry out energy efficiency monitoring, which involves installing sensors and monitoring energy consumption within the building.

As part of the LIFE project 'Silesia. Blue Sky Restored', energy efficiency monitoring will cover 27 cultural, educational and administrative buildings across the Silesian Voivodeship, whilst five buildings will undergo modernisation aimed at implementing sustainable building models.

The aim of this guide is to analyse the monitoring activities that should precede the implementation of thermal modernisation and renovation works. The energy efficiency monitoring described here enables the precise identification of the thermal characteristics of buildings, which, in the long term, translates into more accurate planning of investment and renovation measures leading to the achievement of thermal comfort indoors [2].

## 2. Identification of sensor requirements and measurement characteristics.

Table 2.1 provides a list of proposed sensors that are recommended for installation prior to planned thermal modernisation works on buildings [3].

Tab 2.1 Sensor type and measurement characteristics

| Sensor type                                                                         | Measurement characteristics                                                                                                                                                                                  |
|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| outdoor temperature sensor                                                          | minimum measurement range from -30 °C; data recorded in the system at one-minute intervals;                                                                                                                  |
| wind velocity sensor                                                                | minimum measurement range from 0 m/s to 30 m/s – unit of measurement: m/s; data recorded in the system at one-minute intervals;                                                                              |
| sunlight sensor                                                                     | minimum spectral range from 400 to 1400 nm, minimum radiation intensity measurement range 0–1500 W/m <sup>2</sup> – data recorded in W/m <sup>2</sup> ; data recorded in the system at one-minute intervals; |
| indoor temperature sensor                                                           | minimum measurement range from -10 °C to +50 °C – recorded in °C; data recorded in the system at one-minute intervals;                                                                                       |
| indoor CO <sub>2</sub> concentration sensor                                         | minimum measurement range from 0 to 5,000 ppm – recorded in ppm; data recorded in the system at one-minute intervals;                                                                                        |
| door opening counter and opening/closing time counter                               | minimum data set: door open/door closed/time; measurements taken at one-second intervals, data recorded every minute;                                                                                        |
| electricity meter (air conditioning units)                                          | unit of measurement: kWh; data recorded in the system at one-minute intervals (active and reactive power);                                                                                                   |
| electricity consumption meter (boilers, hot water heaters, etc.)                    | unit of measurement: kWh; data is recorded in the system at one-minute intervals;                                                                                                                            |
| electricity meters for other appliances (evaporators, ovens, fans, etc.) – 20 units | unit of measurement: kWh; data recorded in the system at one-minute intervals (active and reactive power);                                                                                                   |
| meter for total electricity consumption in the building                             | unit of measurement: kWh; data recorded in the system at one-minute intervals (active and reactive power);                                                                                                   |
| a meter for measuring the amount of electricity generated by PV panels              | unit of measurement: kWh; data recorded in the system at one-minute intervals (active and reactive power);                                                                                                   |
| gas consumption meter (mainly for gas cookers, heaters, etc.)                       | unit of measurement: m <sup>3</sup> ; data is recorded in the system at one-minute intervals;                                                                                                                |
| heat meter for central heating                                                      | measurement of water flow (m <sup>3</sup> /h) and the temperatures of the return and supply water in the central heating system; data logging in the system at one-minute intervals;                         |
| heat meter for domestic hot water                                                   | unit of recording: GJ; data is recorded in the system at one-minute intervals;                                                                                                                               |

|                                                        |                                                                                |
|--------------------------------------------------------|--------------------------------------------------------------------------------|
| meter for measuring the heat generated by solar panels | unit of recording: GJ; data is recorded in the system at one-minute intervals; |
|--------------------------------------------------------|--------------------------------------------------------------------------------|

### 3. Guidelines for the monitoring of buildings

The energy consumption required to heat buildings depends on various factors, including the design and condition of the building envelope, intensity and efficiency of use, weather conditions, and internal heat gains. Accurately determining these parameters, particularly in buildings that have been in use for many years, is only possible through measurement. In order to carry out a thermal assessment of buildings, it is necessary to measure all of the above factors [4].

#### 3.1. *Weather conditions*

In order to determine the magnitude of the energy flows exchanged between a building and its surroundings, it is necessary to measure atmospheric conditions such as solar radiation, air temperature, and wind speed. All of these parameters can be measured using a weather station.

#### 3.2. *Indoor comfort*

Indoor comfort is determined by temperature, humidity, and carbon dioxide concentration. It is essential to measure indoor temperatures in order to verify whether the required temperature is being maintained, or if there are instances of underheating or overheating. If overheating or underheating is detected, it is possible to calculate the energy consumption difference if the temperature were correct. Similarly, measuring carbon dioxide concentration allows the correct operation of the room ventilation system to be verified. An excessively high concentration of carbon dioxide indicates that the ventilation rate is too low. Humidity was omitted as determining it would require a mass balance of water. Given the water-retention capacity of walls, this would be subject to very high uncertainties. Furthermore, humidity does not significantly impact the amount of energy consumed for heating purposes. In representative rooms inside each building (e.g. classrooms and gyms in educational buildings, and offices and frequently used rooms in administrative or cultural buildings), the carbon dioxide concentration and temperature should therefore be monitored.

The number of rooms selected should depend on the building's volume and how the rooms are used.

### **3.3. Intensity of use**

The intensity of use is difficult to define unambiguously, let alone determine its impact on energy consumption. For instance, the length of time a door is open affects the volume of air entering the building and, consequently, the amount of energy required for ventilation. However, the nature of this relationship is virtually impossible to determine. Similarly, the number of people in a building affects the amount of carbon dioxide emitted through metabolic processes. However, each person emits a different amount of carbon dioxide depending on their body weight and the nature of their work. Nevertheless, the intensity of use should be measured in order to ascertain the potential for reducing ventilation levels during periods when the building is unoccupied (for instance, at night and at weekends in the case of administrative buildings). It is proposed that the time that doors are open be measured to determine the intensity of use.

### **3.4. Electricity consumption**

The amount of energy saved is largely influenced by electricity, thereby reducing the demand for heating. It is used in buildings for lighting and to power equipment such as computers, printers and photocopiers, as well as appliances used for communal purposes. The electricity used by these appliances is converted into heat and transferred to the rooms, thereby reducing the demand for heating. However, in some appliances, the amount of heat emitted does not equal the electricity consumed. For instance, air conditioners used for heating during the transitional season act as heat pumps, supplying significantly more heat than the electricity consumed to power them. Conversely, electric water heaters transfer the consumed electricity to the domestic hot water, which is then discharged from the building as waste water. Furthermore, if the building has its own electricity sources, such as photovoltaic panels, it is necessary to determine how much energy these panels produce. Therefore, it is essential to measure all electricity flows to and from the building, as well as those that are not entirely converted into heat.

### **3.5. Heating consumption**

A building's heating system may be supplied with heating energy from a district heating network, a gas boiler, an oil-fired boiler, a heat pump or a solid-fuel boiler. As the monitoring aims to assess the building's thermal performance rather than identify the heat source, it is necessary to measure the amount of heat supplied to the building. In the case of a boiler, it is more useful to measure the amount of heat produced than the amount of fuel consumed, since fuel consumption depends not only on the thermal condition of the building, but also on the efficiency of the boiler. It should also be noted that some of the supplied heat may be used for domestic hot water heating. Therefore, it is necessary to install a heat meter to measure the heat supplied to the heating system and for domestic hot water heating separately. Additionally, where solar collectors are present, some of the heat may be obtained from these devices. Although solar collectors are usually used to produce domestic hot water, which is not part of the building's thermal performance, it is important to measure the heat produced by the collectors for subsequent considerations regarding the possibility of using this heat for heating purposes.

### **3.6. Gas consumption in appliances other than the boiler**

Gas consumed by appliances other than the boiler (e.g. in the kitchen) constitutes a source of heat, which reduces the consumption of heating energy by providing heat gain. However, this gain is difficult to measure accurately because a large proportion of the gas's chemical energy leaves the premises in the form of flue gases produced by combustion. These gases are extracted via a natural ventilation or extraction system. Nevertheless, it was decided to measure gas consumption in such appliances, as having an approximate figure for the heat gain is better than having no figure at all. Due to legal restrictions that limit the ability to interfere with the gas installation, plans are in place for meter readings to be taken using a camera that can identify and digitise the reading. This enables gas consumption to be measured without interfering with the gas installation.

### **3.7. Transmission of measurements data**

To ensure a continuous data stream, measurements should be taken and automatically recorded. The measuring devices must be able to connect to a wireless (Wi-Fi) or wired network so they can communicate with the server where the data will be recorded and stored. It may therefore be necessary to install an additional router or connect a Wi-Fi signal booster to the existing network in areas of the building where signal coverage is poor and measurements are being carried out. If there is no internet connection in the building, an LTE or 5G router may be required to transmit data to an external network.

### **3.8. Duration of the measurements**

To determine the building's thermal behaviour during both the heating and air conditioning seasons, it is recommended that energy consumption is monitored over a 12-month period (winter, spring, summer and autumn).

## **4. List of types and quantities of measuring sensors.**

Table 4.1 provides a breakdown of the recommended types and quantities of measurement sensors. This specifies the total number of electricity meters required for a given building, including those for consumption resulting from the use of air conditioning units, heaters, mechanical ventilation and total building consumption, as well as other measuring instruments.

Tab 4.1 List of the types and quantities of measuring sensors

| No. | Building type         | Area, m <sup>2</sup> | Type of current heating system | Number of measuring instruments                                                                                                                                                                                                                                    |
|-----|-----------------------|----------------------|--------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1   | Public administration | 284.45               | oil-fired boiler               | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensor: 4<br>CO <sub>2</sub> sensor: 4<br>Door opening counter: 2<br>Electricity meter: 5<br>Central heating heat meter: 1<br>Domestic hot water heat meter:1    |
| 2   | Public administration | 45000.00             | district heating               | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensor: 10<br>CO <sub>2</sub> sensor: 10<br>Door opening counter: 3<br>Electricity meter: 12<br>Central heating heat meter: 1<br>Domestic hot water heat meter:1 |
| 3   | Public administration | 2911.00              | gas boiler                     | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensors: 3<br>CO <sub>2</sub> sensor: 3<br>Door opening counter: 1<br>Electricity meter: 37<br>Central heating heat meter: 1<br>Domestic hot water heat meter:2  |
| 4   | Public administration | 650.90               | gas boiler                     | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensor: 3<br>CO <sub>2</sub> sensor: 3<br>Door opening counter: 2<br>Electricity meter: 15<br>Central heating heat meter: 1<br>Domestic hot water heat meter:1   |

| No. | Building type         | Area, m <sup>2</sup> | Type of current heating system | Number of measuring instruments                                                                                                                                                                                                                                 |
|-----|-----------------------|----------------------|--------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 5   | Public administration | 405.56               | gas boiler                     | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensor: 2<br>CO <sub>2</sub> sensor: 2<br>Door opening counter: 2<br>Electricity meter: 1<br>Central heating heat meter: 1<br>Domestic hot water heat meter:1 |
| 6   | Public administration | 93.18                | gas boiler                     | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensor: 1<br>CO <sub>2</sub> sensor: 1<br>Door opening counter: 2<br>Electricity meter: 4<br>Central heating heat meter: 1<br>Domestic hot water heat meter:1 |
| 7   | Community centre      | 1765.89              | gas boiler district heating    | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensor: 3<br>CO <sub>2</sub> sensor: 3<br>Door opening counter: 3<br>Electricity meter: 5<br>Central heating heat meter: 1                                    |
| 8   | Cultural centre       | 1000.00              | gas boiler                     | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensor: 1<br>CO <sub>2</sub> sensor: 1<br>Door opening counter: 1<br>Electricity meter: 2<br>Central heating heat meter: 2<br>Domestic hot water heat meter:2 |

| No. | Building type            | Area, m <sup>2</sup> | Type of current heating system    | Number of measuring instruments                                                                                                                                                                                                                                                                                                    |
|-----|--------------------------|----------------------|-----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 9   | Cultural centre          | 459.37               | gas boiler                        | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensor: 2<br>CO <sub>2</sub> sensor: 2<br>Door opening counter: 1<br>Electricity meter: 6<br>Central heating heat meter: 2<br>Domestic hot water heat meter: 2                                                                   |
| 10  | Community centre         | 462.00               | district heating                  | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensor: 3<br>CO <sub>2</sub> sensor: 2<br>Door opening counter: 3<br>Electricity meter: 5<br>Central heating heat meter: 1                                                                                                       |
| 11  | Multifunctional building | 1265.00              | coal-fired boiler                 | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensor: 4<br>CO <sub>2</sub> sensor: 4<br>Door opening counter: 2<br>Electricity meter: 10<br>Central heating heat meter: 1                                                                                                      |
| 12  | Cultural centre          | 1095.00              | district heating,<br>solar panels | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensor: 3<br>CO <sub>2</sub> sensor: 3<br>Door opening counter: 2<br>Electricity meter: 2<br>Central heating heat meter: 1<br>Domestic hot water heat meter: 1<br>Electricity meter for PV panels: 1<br>Gas consumption meter: 1 |

| No. | Building type  | Area, m <sup>2</sup> | Type of current heating system | Number of measuring instruments                                                                                                                                                                                                                                                              |
|-----|----------------|----------------------|--------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 13  | School         | 3157.00              | district heating               | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensor: 5<br>CO <sub>2</sub> sensor: 5<br>Door opening counter: 3<br>Electricity meter: 24<br>Central heating heat meter: 1                                                                |
| 14  | Nursery school | 610.00               | gas boiler                     | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensor: 3<br>CO <sub>2</sub> sensor: 2<br>Door opening counter: 2<br>Electricity meter: 2<br>Central heating heat meter: 1<br>Domestic hot water heat meter: 1<br>Gas consumption meter: 1 |
| 15  | Nursery school | 330.01               | district heating               | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensor: 2<br>CO <sub>2</sub> sensor: 2<br>Door opening counter: 1<br>Electricity meter: 5<br>Central heating heat meter: 1<br>Domestic hot water heat meter: 1                             |
| 16  | School         | 2301.10              | district heating               | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensor: 6<br>CO <sub>2</sub> sensor: 6<br>Door opening counter: 1<br>Electricity meter: 2<br>Central heating heat meter: 1<br>Domestic hot water heat meter: 1                             |

| No. | Building type  | Area, m <sup>2</sup> | Type of current heating system | Number of measuring instruments                                                                                                                                                                                                                                                               |
|-----|----------------|----------------------|--------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 17  | Nursery school | 735.02               | district heating               | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensors: 4<br>CO <sub>2</sub> sensor: 4<br>Door opening counter: 2<br>Electricity meter: 7<br>Central heating heat meter: 1<br>Gas consumption meter: 6                                     |
| 18  | School         | 2305.7               | district heating               | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensors: 8<br>CO <sub>2</sub> sensor: 8<br>Door opening counter: 3<br>Electricity meter: 6<br>Central heating heat meter: 1<br>Domestic hot water heat meter: 1<br>Gas consumption meter: 4 |
| 19  | School         | 1967.00              | oil-fired boiler               | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensor: 7<br>CO <sub>2</sub> sensor: 7<br>Door opening counter: 3<br>Electricity meter: 19<br>Central heating heat meter: 1<br>Domestic hot water heat meter: 1<br>Gas consumption meter: 2 |
| 20  | School         | 2372.39              | district heating               | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensors: 4<br>CO <sub>2</sub> sensor: 4<br>Door opening counter: 4<br>Electricity meter: 17<br>Central heating heat meter: 1<br>Gas consumption meter: 1                                    |

| No. | Building type                         | Area, m <sup>2</sup> | Type of current heating system | Number of measuring instruments                                                                                                                                                                                                                                                                         |
|-----|---------------------------------------|----------------------|--------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 21  | Nursery school                        | 373.00               | gas boiler                     | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensors: 4<br>CO <sub>2</sub> sensors: 4<br>Door opening counter: 2<br>Electricity meter: 1<br>Central heating heat meter: 1<br>Domestic hot water heat meter: 1<br>Gas consumption meter: 2          |
| 22  | Public administration cultural centre | 984.73               | coal-fired boiler              | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensors: 4<br>CO <sub>2</sub> sensor: 4<br>Door opening counter: 5<br>Electricity meter: 5<br>Central heating heat meter: 1<br>Domestic hot water heat meter: 1                                       |
| 23  | Public administration cultural centre | 11530.00             | gas boiler,<br>solar panels    | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensors: 4<br>CO <sub>2</sub> sensor: 4<br>Door opening counter: 4<br>Electricity meter: 1<br>Central heating heat meter: 2<br>Domestic hot water heat meter: 1<br>Electricity meter for PV panels: 1 |
| 24  | Public administration cultural centre | 1812.00              | district heating               | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensors: 3<br>CO <sub>2</sub> sensor: 3<br>Door opening counter: 2<br>Electricity meter: 4<br>Central heating heat meter: 1<br>Hot water heat meter: 1                                                |

| No. | Building type                        | Area, m <sup>2</sup> | Type of current heating system | Number of measuring instruments                                                                                                                                                                                                                                 |
|-----|--------------------------------------|----------------------|--------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 25  | Public administrationcultural centre | 904.63               | oil-fired boiler               | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensor: 4<br>CO <sub>2</sub> sensor: 4<br>Door opening counter: 4<br>Electricity meter: 6<br>Central heating heat meter: 1                                    |
| 26  | Public administrationeducation       | 809.34               | district heating               | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensor: 3<br>CO <sub>2</sub> sensor: 3<br>Door opening counter: 1<br>Electricity meter: 6<br>Central heating heat meter: 3<br>Domestic hot water heat meter:1 |
| 27  | Public administrationcultural centre | 293.00               | coal-fired boiler              | Wind speed sensor: 1<br>Sunlight sensor: 1<br>Outdoor temperature sensor: 1<br>Indoor temperature sensor: 3<br>CO <sub>2</sub> sensor: 3<br>Door opening counter: 2<br>Electricity meter: 4<br>Central heating heat meter: 1                                    |

## 5. Modernizacja budynków

Monitoring data allows the thermal characteristics of buildings to be identified far more accurately than computational methods can achieve. For monitored buildings, a multi-scenario analysis can be performed to evaluate various new heating system solutions tailored to their characteristics, while minimising environmental impact in terms of emissions of harmful substances [5]. These solutions are assumed to be consistent with the European Union's climate neutrality target for 2050. In particular::

- For buildings that are currently heated by local coal, oil or gas-fired boilers, it is proposed that these heating sources be replaced with ones that meet the zero CO<sub>2</sub> emission requirements. Depending on the building's location, this could be a heat pump or a district heating network.
- It is recommended that the installation or improvement of thermal insulation in buildings be analysed.

- It is recommended that the installation of mechanical ventilation with heat recovery via heat recovery units be analysed.
- It is also recommended to analyse the implementation or expansion of on-site heat sources, such as solar collectors and photovoltaic panels.
- It is also recommended to analyse the possibilities of installing heat storage tanks, which allow the volume of instantaneous energy consumption for heating purposes to be partially decoupled from weather conditions. For example, this would enable heat to be generated during the day when photovoltaic panels are producing electricity, but demand for heating is relatively low, and used at times when demand for heating is high, i.e. at night.

It is assumed that the benefits of modernising selected buildings will be analysed from the perspective of both the buildings themselves and the national energy system. In the case of heat storage tanks, for example, a building can draw electricity from the grid to power heat pumps when there is a surplus, while simultaneously storing heat in the tanks. The tanks can then be discharged during periods of energy shortage. Thus, a heat storage tank has a positive impact on the national energy system by reducing the need for significantly more expensive electricity storage.

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