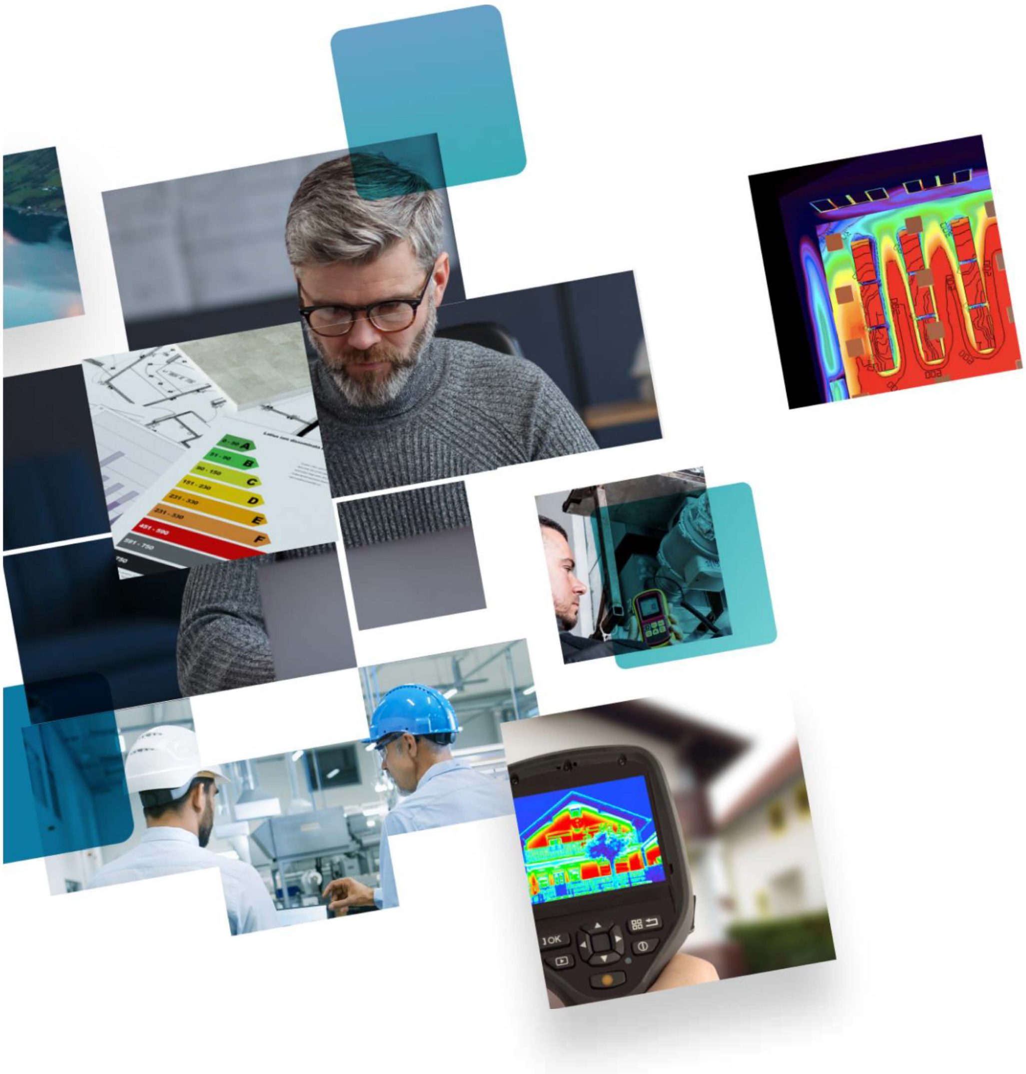

STUDY AND PRACTICE GUIDE

INSTRUMENTAL ENERGY AUDIT

Yurchenko Y., Koval O., Liakhovetska-Tokareva M., Nikiforova T., Kosenko L., Bondarenko A., Demidov O., Sokolova K.

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REI «PRYDNIPROVSKA STATE ACADEMY OF CIVIL ENGINEERING AND ARCHITECTURE»
NATIONAL ERASMUS+ OFFICE IN UKRAINE

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The guide is implemented in the framework of the UKRENERGY project – 101082898, co-funded by the European Union: «Innovative master's courses to support the improvement of the energy and carbon footprint of the Ukrainian building stock».

The book reviews the results of research and practical experience in the field of energy efficiency and innovative technologies through instrumental energy audits.

For researchers, postgraduates, teachers, masters, bachelors, students of technical faculties energy auditors, of business and government representatives , as well as for a wide range of readers.

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INTRODUCTION

The study and practice guide is developed within the framework of the project No.101082898, co-funded by the European Union, 'UKRENERGY – Innovative Master Courses supporting the improvement of the energy and carbon footprint of the Ukrainian building stock'.

The guide describes the basics of instrumental energy audit of buildings and structures. It gives basic principles of the audit, modern measurement equipment and methods of data processing. A particular attention is paid to the practical application of modern equipment for energy auditors. The guide includes practical recommendations that will help professionals in performing a quality audit in accordance with modern standards and regulatory requirements. The material will be eligible and useful for students, postgraduates, lecturers, as well as practicing energy auditors, designers and engineers. It will contribute to the development of competencies necessary for carrying out professional activities in the field of energy audit and energy efficiency of buildings.

The use of instrumental energy audits is a key step in the development of energy saving strategy, which is essential for the country's sustainable development and energy independence. Therefore, the knowledge gained from this guide will help professionals make informed technical decisions to ensure energy-efficient reconstruction of Ukraine.

CHAPTER 1. MICROCLIMATE PARAMETERS: TEMPERATURE, HUMIDITY, CO_2

1.1 Introduction

This chapter of the guide provides clear and consistent instructions for measuring indoor climate parameters (t°, %, ppm). The information and data can be useful for ensuring comfortable living and working conditions, as well as for improving the energy efficiency of buildings.

1.2 Terms and definitions

Indoor Microclimate Parameters are the conditions of indoor climate that affect the heat exchange of a person with the environment through convection, conduction, heat radiation and moisture evaporation; these conditions are determined by a combination of temperature, relative humidity and air velocity, temperature of the surfaces surrounding the person and intensity of thermal (infrared) radiation. [5]

Data logger is a device or software designed to automatically collect, store and analyze data on various parameters, such as temperature, humidity, CO_2 level, atmospheric pressure. Loggers are used to monitor and control microclimate parameters (to, %, ppm) in buildings, industrial facilities, research and other industries where it is necessary to record environmental or process parameters in real time.

Thermal Regime of Indoor Spaces is a set of parameters that characterize the thermal state of internal building environment. It includes temperature, humidity, air velocity, and other factors that affect the comfort and health of people in the building. The thermal regime is determined by both design calculations and actual measurements and is regulated by building codes to ensure proper living or working conditions.

Humidity Regime of Indoor Spaces is a set of indicators that characterize the air humidity in the indoor environment of a building.

Indoor Air Quality is a set of characteristics of the air environment that affect health, comfort and productivity of people indoors. It is measured by the level of CO_2

concentration (ppm - parts per million) of various pollutants, humidity, temperature and ventilation efficiency.

Ppm (parts per million) is a unit of measurement for the concentration of gases in the air, which indicates the number of particles of a particular substance per million air particles. For example, a CO_2 concentration of 1000 ppm means that there are 1000 particles of carbon dioxide per million air particles.

1.3 Theoretical foundation

CO_2 content is a key parameter to measure the level of air pollution caused by human activity. An increase in CO_2 concentration in a room is usually accompanied by odours intensity associated with human metabolism.

Thus, the level of CO_2 in the air of a room is directly related to the intensity of its use. The CO_2 concentration is also a basic indicator for the other regulation areas, such as design of ventilation and air conditioning systems, as well as for ventilation recommendations in naturally ventilated spaces such as schools and assembly halls.

In the actively used rooms, the CO_2 level depends on the following factors:

- number of people and area of the room;
- the activity of people in the room;
- the duration of people»s stay in the room;
- air exchange rate and volume of fresh air flow.

The rapid increase in CO_2 concentration in the air is often the result of a large number of people in relatively small space (e.g. conferences or classrooms) with insufficient air exchange. Figure 1.1 shows changes in CO_2 concentration in the air by the example of a school classroom, where the number of people in the room influences the level of CO_2.

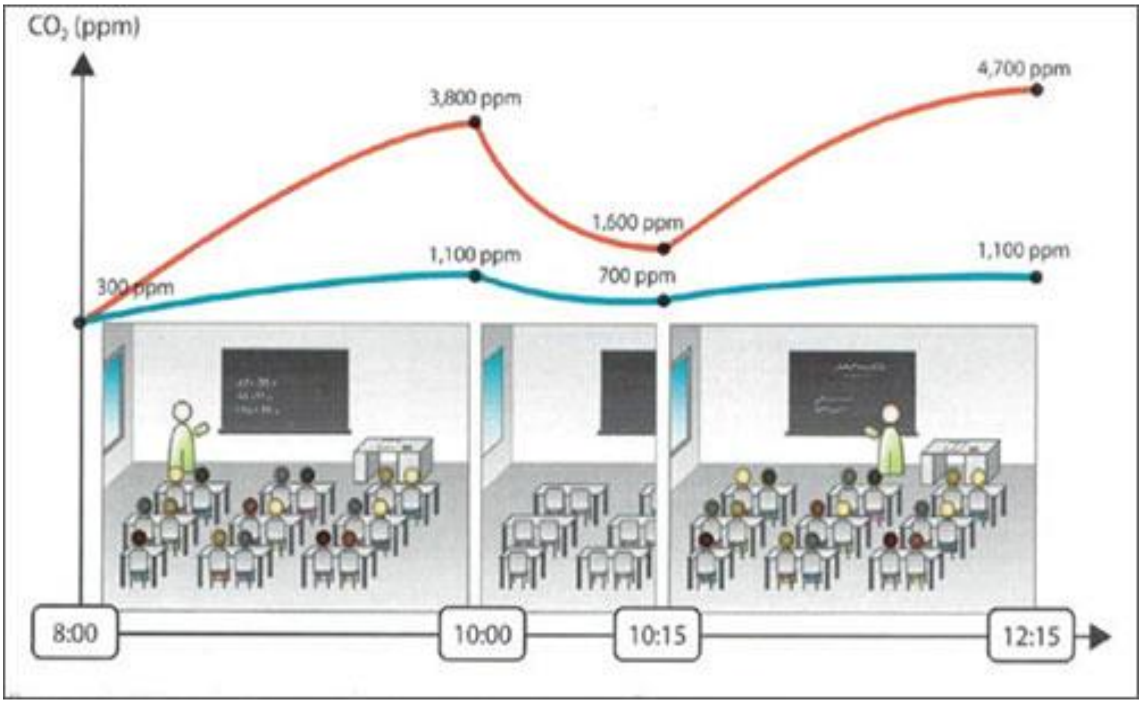


Fig 1.1. Increase in CO_2 in a classroom

Why is it happening? Classrooms are rarely ventilated, because any open window can cause colds in children and noise from the street. Even if a school building is equipped with ventilation, it is usually technically outdated and expensive to operate. But the windows in most schools are modern - plastic, airtight, draught-proof, and without forced ventilation, fresh air practically does not enter the premises.

The problem with ventilation is more relevant in apartments, office buildings and childcare facilities. In European schools, air quality is one of the main standards regulated by conttrolling authorities. In Ukraine, ventilation standards are still being finalised, and the problem of excessive CO_2 in schools and other educational institutions is being ignored. The problem of poor ventilation can be solved by using modern air handling units.

High CO_2 concentrations are often accompanied by other pollution factors such as volatile organic compounds or microorganisms. In sealed structures with very low air exchange, CO_2 concentrations can rise rapidly even with a small number of people (e.g. in apartments or offices).

In such conditions, CO_2 directly affects people»s comfort and well-being. According to the European Collaborative Action (ECA), if a CO_2 concentration is 1000 ppm, approximately 20% of people in a room feel uncomfortable, and with 2000 ppm, this figure rises to 36%.

Conference rooms are typically used intermittently for short periods of time, while classrooms are used for many hours at a time. With the constant presence of students and teachers, it is particularly important to control and monitor the CO_2 concentration in such spaces. Many recent studies in European countries confirm that high levels of CO_2 are a determining factor in indoor air quality. [7]

Indoor thermal conditions.

The right indoor temperature provides a comfortable level for occupants or employees to avoid overheating or hypothermia. Controlling thermal conditions promotes health, since the right temperature helps avoid health problems such as colds or allergies as a result of poor thermal conditions. Regular monitoring allows identifying and solving problems with insulation and heating or cooling systems in time, which helps maintain the building in good condition for a long period of time.

In the climatic zone, where Ukraine is located, winters can be quite severe, even despite global warming, and summers are very hot. The problem can be partially solved by installing modern plastic windows, insulating the walls, and ensuring air exchange with the help of special fans with heating or cooling functions. But all these measures will not be enough to create and maintain comfortable conditions if there is no heating and air conditioning.

Fig. 1.2. Thermal conditions of premises

Indoor air temperature is easy to measure, control and maintain at the required level. Despite the fact that many recommendations consider a temperature of +18-20 degrees Celsius to be optimal for living, not everyone is comfortable in such conditions. While some people wear shorts and T-shirts at 18 degrees, they can also open a window for ventilation. Others wear a tracksuit or a warm sweatshirt even at +22.

Humidity level

The right humidity level contribute to a comfortable environment for occupants or employees by preventing the air from becoming too dry or too humid, which can cause discomfort. Controlling humidity has a significant impact on health, as improper humidity levels can cause respiratory problems, allergies and promote the growth of mould and fungus. This is especially important for people with respiratory conditions or allergies. The right level of humidity also helps keep property in good condition. Excessive humidity can damage building materials, furniture, electronics, and even food, contributing to its rapid spoilage. Too dry air can lead to cracks in wooden furniture and floors.

Fig. 1.3. Humidity level in premises

Humidity monitoring contributes to a longer building lifespan, preventing from structural damage caused by high humidity, such as corrosion of metal structures or peeling of paint and wallpaper.

The causes of high indoor humidity can vary and depend on a variety of factors, including building construction, use and climate conditions.

The main causes of high humidity are:

- **poor ventilation of the room**, moisture does not escape and accumulates inside. This is often seen in bathrooms, kitchens and laundries.

- leaking pipes, roofs or walls can lead to an increase in indoor humidity. Even minor leaks can contribute to moisture build-up over time.

- **condensation:** occurs when warm, humid air comes into contact with cold surfaces such as windows, walls or floors. This often occurs in winter or in rooms with poor thermal insulation.

- **climatic conditions:** in regions with high humidity or frequent precipitation, buildings are prone to high internal humidity. This is especially true in tropical and coastal areas.

- **engineering systems:** improperly configured or inefficient heating, ventilation and air conditioning systems can contribute to humidity.

- **use of household appliances:** washing machines, tumble dryers, dishwashers and other household appliances release a lot of moisture when they operate.

- some **building materials** used in construction can retain moisture and contribute to high humidity levels. For example, wood or plasterboard can absorb moisture from the air.

Microclimate conditions

There are four main types of microclimate conditions:

Optimal - a combination of microclimate parameters, influencing a person for a long time and systematically, ensure the preservation of the body»s normal thermal state without activating thermoregulation mechanisms; they create a feeling of thermal comfort and provide the prerequisites for a high level of performance. [5]

High optimal - optimal microclimatic conditions in rooms with very sensitive and weak people with special needs, such as disabled, sick, young children and the elderly. [5]

Permissible conditions are a combination of microclimate parameters, influencing a person for a long time and systematically, can cause changes in the body»s thermal state that quickly pass and normalise, but are accompanied by a strain on the thermoregulation mechanisms within the framework of physiological adaptation. At the same time, there is no violation of health, but the conditions create a feeling of thermal discomfort, lead to a decrease in performance, and deterioration of health. [5]

Limitedly permissible - permissible microclimatic conditions in the premises of buildings with limited use during the year (less than four consecutive months of the year). [5]

1.4 Regulatory and technical documents of Ukraine on microclimate parameters for various types of buildings.

DBN B.2.2-15-2019 «Residential buildings. Main provisions» [1].

These construction standards apply to the design of new and reconstructed houses, as well as major repairs and technical re-equipment of residential buildings with a nominal height of up to 73.5 m, such as single-family and multi-family, including specialised apartment buildings for the elderly and people with disabilities, and dormitories. The design of residential buildings with a nominal height of more than 73.5 m should be guided by the requirements of Sections 4 and 5 of these norms and DBN B.2.2-24.

DBN B.2.6-31:2021 «Thermal insulation and energy efficiency of buildings» [2]. Appendix B Thermal and humidity conditions of premises, materials in structures and outdoor air temperature for thermal engineering calculations. These standards establish requirements for energy efficiency indicators of buildings, thermal performance of building envelopes (thermal insulation envelope), energy efficiency indicators of engineering equipment of buildings during their design and construction, and criteria for the rational use of energy resources for heating and cooling of buildings to ensure the normative sanitary and hygienic parameters of the indoor microclimate, durability of building envelopes during the buildings operation.

DBN B.1.2-8:2021 «Basic requirements for buildings and structures. Safety of human life and health, protection of the environment» [3]. These standards apply to buildings and structures as a whole and their parts (structural and engineering systems) during design and construction, and establish provisions for compliance with the functional parameters of the facility during its operation.

The requirements of these standards are applied in the design and construction process along with other construction standards required for the following facilities: buildings, structures, their parts (structural and engineering systems) depending on their functional purpose.

They are also used to establish mandatory requirements for the construction facility, as well as to develop technical regulatory documents for structural and engineering systems.

International Standard ISO 7730 Third edition 2005-11-15 [5]

«Ergonomics of thermal conditions - Determination and explanation of thermal comfort using PMV (predicted mean value of thermal sensation) and PPD (predicted percentage of dissatisfaction) indicators and criteria for local thermal comfort». This standard covers the assessment of an acceptable thermal environment. It is one of a series of ISO documents which establishes the methods for measuring and evaluating the performance of acceptable and extreme thermal environments that affect people.

DBN B.2.5-67:2013 Heating, ventilation and air conditioning. These standards provide design requirements for heating and internal heat supply systems, general exchange and emergency ventilation, air heating, air conditioning and air cooling of buildings and structures in order to ensure the standardized sanitary and epidemiological parameters of the indoor microclimate, compliance with safety and environmental protection requirements, and the rational use of energy resources during operation.

1.5 Testo 535, 160 device for measuring microclimate parameters

Fig. 1.4.Testo 535 device to measure microclimate parameters

The Testo 535 portable logger, shown in Figure 1.4, is designed to measure CO_2 concentration in the air in closed rooms. In addition to CO_2 concentration, the device displays the temperature and absolute pressure. The CO_2 logger is equipped with automatic absolute pressure compensation, thus the accuracy of the measurements is not affected by changes in weather and altitude. [6]

Technical characteristics

Type: CO_2 gas analyser in the air;

Measuring range: 0 ... 10,000 ppm;

Accuracy: ±100 ppm ± 5%;

Temperature and absolute pressure display;

Calculation of the average value by time and number of measurement points;

Sound alarm;

Bluetooth;

Smartphone data exchange;

Data processing and digital report app;

Data are displayed as a list, graph or table;

Portable printer for printing data;

Operating temperature: 0 ... +50 °C;

Protection class: IP 40 (probe IP 20);

Battery type: 3 pcs. AA;

Dimensions: 229 x 60 x 28 mm;

Weight: 229 g.

Testo 160 device to measure microclimate parameters

Fig.1.5. Testo 160 device to measure microclimate parameters

The Testo 160 logger shown in Figure 1.5 is used for a long-term monitoring of microclimate parameters. The device can store a large amount of data for a long period of time, which allows obtaining detailed information about changes in microclimate parameters. The data collected by the logger can be automatically transferred to the cloud storage, providing secure storage and easy access from anywhere. The device automatically notifies you when predefined thresholds are exceeded, allowing you to respond quickly to changing conditions.

Technical characteristics

Type - WiFi CO_2, temperature, humidity and pressure logger;

Measurement range:

- temperature 0...+50 °C
- humidity 0 ... 100% RH
- CO_2 0...5000 ppm

- Absolute pressure 600...1100 hPa

Accuracy:

- temperature ±0.5 °C
- humidity ±2 % RH (20...80 % RH)

±3 % RH (other range)

- CO_2 ±50 ppm ± 3% of the var.

±100 ppb ±3% of RH (no power supply connected)

- Absolute pressure ±3 hPa

Measurement frequency: 15 min ... 24 h (set manually), extended measurement frequency (1 min ... 24 h);

Built-in memory: 32,000 values;

Manual setting of boundary values;

Sending an e-mail when boundary values are exceeded;

Sending SMS when the boundary values are exceeded;

Sending an e-mail when the battery is low;

Sending an e-mail when the WiFi connection to the cloud storage is interrupted;

Transfer measured WiFi data to the cloud storage;

Access to the measured data from a tablet, smartphone or PC;

Free cloud storage;

Extended cloud storage with increased data storage space and advanced logger programming options;

Number of loggers that can be connected to one cloud storage: unlimited

Can be mounted on the wall;

Power supply unit for connecting the logger to the power supply, including sending e-mails in case of power cut.

Battery type: AA, 4 pcs;

Battery life: 12 months;

Operating temperature: 0...+50 °C;

Protection class: IP 20;

Dimensions: 117 x 82 x 32 mm;

Weight: 269 g;

Logger application

Loggers are used to monitor the comfort of indoor environments such as offices, warehouses, laboratories, and homes. For example, they can be used to monitor the temperature and humidity in a museum to ensure proper conditions for the preservation of exhibits. CO_2 loggers are effectively used to monitor indoor air quality in schools, offices and conference room to understand the need for ventilation in crowded areas.

A unique feature of the carbon dioxide gas analyser is the possibility to use a smartphone or tablet with the Testo Smart App installed as a second display. This feature is very useful when performing measurements:

- in very small rooms where a person cannot fully fit in and close the door (e.g. a bird incubator);
- in rooms where long-term measurements should be taken and the operator»s time spent in the room should be limited as much as possible from epidemiological perspective (e.g. hospital isolation rooms, poultry farms);
- in rooms where CO_2 concentration can be dangerous for the operator (e.g. mushroom farms, server rooms).

In the Testo Smart app you can view the measured values presented as a list, table or graph. You can save them, generate digital reports with the measurement results and send reports directly to the customer.

To process the data easily, the portable gas analyser automatically calculates the average CO_2 value over time and the number of measurement points. The CO_2 gas analyser can set boundary values - in case of exceeding values the alarm sounds to warn of a danger to the product or the operator»s health.

Measuring CO_2 concentrations can prevent from the spread of diseases in kindergartens and schools. [6]

1.6 Settings of the Testo 535, 160 logger to measure microclimate in a building.

Fig. 1.6. Example of using the Testo 535 logger

Here is the method of using the logger to measure indoor climate parameters:

- The CO_2 logger is installed in the room at a height of approximately 1-1.5 metres from the floor to ensure maximum accuracy.
- The data recording interval (e.g. every 5 minutes or 15 minutes) and the data storage parameters are set using the special software.
- The Logger automatically measures and records the CO_2 level, temperature and absolute room pressure level during the entire measurement period.

- At the end of the measurement period, the data from the Logger is saved and downloaded for analysis.

- Based on the measurement results, the peak values of CO_2 concentration, temperature, and humidity are determined and compared with the permissible standards.

- If the results of the measurement of microclimate parameters exceed the permissible standards, measures are taken to improve ventilation in the room.

Optimal temperature and humidity conditions for different types of premises and buildings according to their purpose are given in Appendix B of DBN B.2.6-31:2021 «Thermal insulation and energy efficiency of buildings» [2]. As for CO_2 levels, currently there are no precise standards for these indicators in Ukraine. However, there are international standards that regulate ppm levels and air quality, as shown in Figure 1.7.

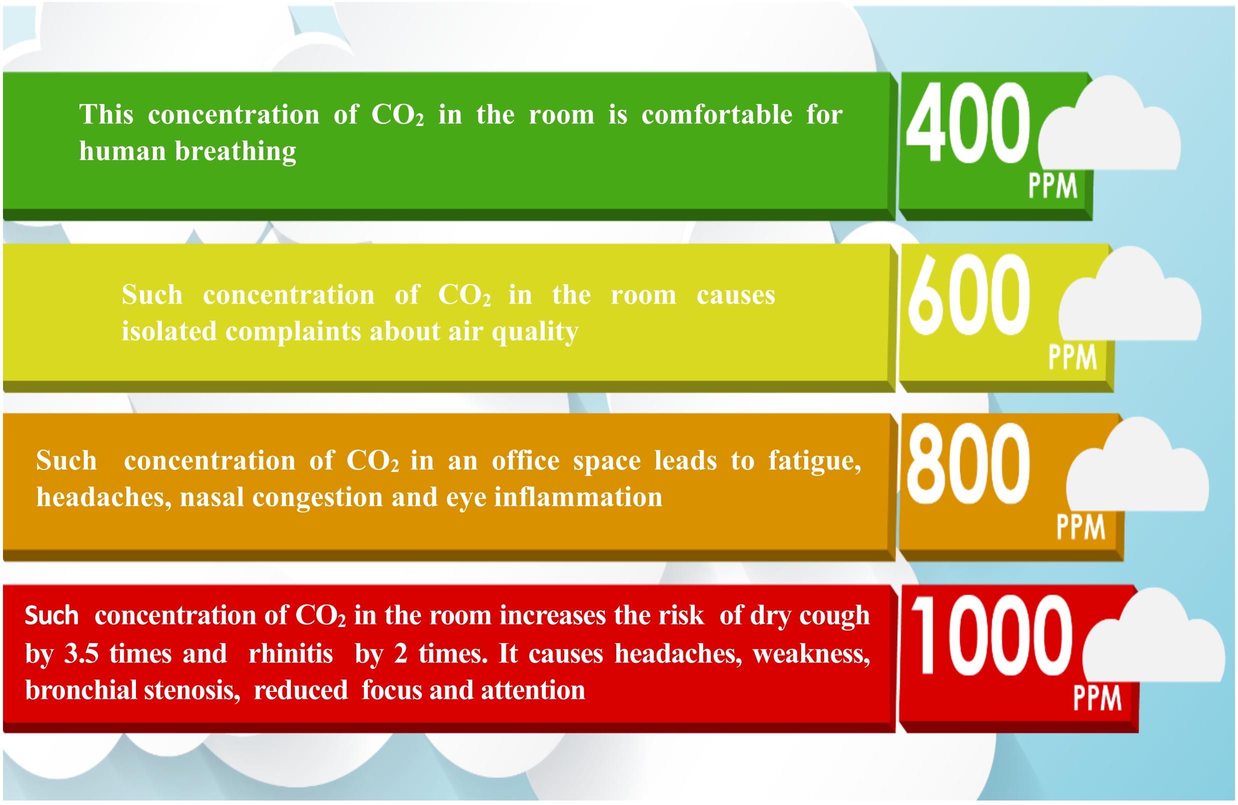


Fig. 1.7 CO_2 concentration level in the air

Measurement of indoor microclimate parameters is an integral part of comfortable and safe living and working conditions. Clear methodological guidelines provide accurate data on thermal conditions, relative humidity, and air quality.

Types of microclimate control rooms.

To measure microclimate parameters, the device should be located depending on the type and purpose of the room. It is necessary to keep in mind that proper placement of the loggers is important to obtain accurate and reliable data. Here are some basic premises and recommendations for placing loggers:

- Residential spaces (kitchen, bedroom, living room): in residential areas, the loggers should be placed about 1-1.5 metres above the floor, in the centre of the room, away from heat or cold sources such as radiators, air conditioners, and windows. In kitchen – far from stoves and ovens.

- Kindergartens (playrooms, recreation rooms): in kindergartens, the loggers should be placed at a height out of reach of children to prevent possible damage to the devices. It is optimal to place them in the centre of the room, away from windows and doors.

- Schools (classrooms, canteen, gym): in classrooms, it is best to install the loggers on the walls or ceiling, away from doors and windows. In the dining room, it is necessary to avoid placing them near kitchen appliances, and in gyms - away from areas of intense physical activity to avoid mechanical damage.

- Offices (workplaces with people): in offices, the loggers are placed at or near workplaces, at a height of about 1.5 metres from the floor. It is important to avoid placing them near computers and other electronic devices that may affect the microclimate.

- Hospitals (wards, surgical and other units): in hospitals, the loggers should be placed on walls or ceilings, away from medical devices and areas with high humidity. In surgical and other units, it is especially important to maintain stable microclimate conditions, so the loggers should be placed not to disturb medical staff and ensure accurate measurements.

In addition, there are few more general recommendations to consider:

- Loggers should be placed to measure air parameters without any obstacles, i.e. away from furniture.
- Avoid places with direct sunlight, which can distort temperature data.
- Ensure regular access to the devices for maintenance and data reading.

Measurement period

The measurement period of microclimate parameters can vary depending on the goals set and can be either targeted (less than 24 hours) or detailed (over a month, day or year). It is essential to select the appropriate type of logger and measurement period to obtain accurate and reliable data.

For short-term measurements (from 1 to 2 hours), the Testo 535 logger is the best choice. This device is designed for quick measurements and provides immediate information on the state of the microclimate. It is ideal for situations where you need to obtain instant data on indoor air parameters, for example, to quickly assess conditions at a particular time. The Testo 535 can be operated and configured via a smartphone and transmits data via Bluetooth to a phone, providing ease of use and quick access to the collected information.

If the measurement is to last for more than a day, the Testo 160 logger is the best choice. This device is designed for long-term measurements and can store and transfer data to the cloud, which ensures continuous monitoring of microclimate parameters over a long period of time. Using such a logger allows you to collect detailed information about changes in indoor conditions over the course of a day, month or even a year, which is important for analysing seasonal fluctuations and other long-term measurement tasks.

Additionally, it is necessary to consider:

- the Testo 160 logger has a larger memory and data storage capacity, making it ideal for detailed research and analysis;

- connecting to the cloud storage allows you to ensure the security of the stored data and easy access to it from anywhere, which makes convenient to use and analyse information.

All in all, choosing the right type of logger and measurement period helps obtain accurate and reliable data needed to maintain optimal microclimate conditions in different types of spaces.

Information collection and analysis

The process of collecting information on indoor climate parameters involves the collection of detailed data to assess and analyse the operating conditions of a building. It is important to consider various factors that can affect the microclimate and provide an accurate and comprehensive analysis. Here are the main points to consider when collecting and analysing information.

1. Changing the mode of premises maintenance:
   - the number of people in the space over different periods of time;
   - use of the premises (e.g. for work, leisure, study).
   - changes in the schedule (e.g. weekends, weekdays, night hours).
2. Air conditioning:
   - when the air conditioner is switched on and off;
   - operating mode: (cooling, heating, ventilation).
   - location of the air conditioner in the room and its impact on the temperature: (analysing the temperature throughout the day helps assess the efficiency of the air conditioner. It is important to determine whether the air conditioner provides stable room temperature and how often temperature fluctuations occur).

- Impact on humidity: air conditioners can reduce the humidity level of the air. Analysing the data allows you to assess whether additional humidifiers are needed to maintain optimal humidity levels.

3. Heating:

- time the heating system is switched on and off;

- temperature settings of the heating system;

- type of heating system (central heating, individual heaters).

- location of heaters and their impact on the heat distribution in the room (assessment of the temperature distribution in the room helps identify areas with excessive or insufficient heating, thus it is possible to optimise the positioning of heaters to ensure even heat distribution).

4. Ventilation and air exchange:

- ventilation systems and their operation;

- air exchange rate (it is important to assess whether the building is providing an adequate level of air exchange. Inadequate ventilation can lead to the accumulation of CO_2 and other harmful substances, which negatively affects the health of the occupants);

- availability of natural ventilation (opening of windows, doors): open windows provide natural ventilation, which can have a significant impact on the level of CO_2 and other pollutants. It is important to assess whether open windows provide sufficient air exchange without significant heat loss;

- impact of air exchange on temperature and humidity: Analysing data on ventilation systems helps determine their impact on indoor temperature and humidity, as well as how to use natural ventilation effectively to maintain comfortable conditions.

5. Air humidity:

- the use of humidifiers or dehumidifiers;

- the influence of external conditions on the humidity level in the room.

6. Lighting:

- the use of natural and artificial light;

- intensity of lighting during the day;

- effect of lighting on indoor temperature.

7. Other factors:

- external weather conditions (temperature, humidity, wind speed): weather conditions can have a significant impact on indoor climate parameters. It is important to consider these factors when analysing data and developing measures to optimise indoor conditions;

- electronic devices that can generate heat (computers, kitchen appliances). Data analysis helps determine how these devices affect temperature and humidity;

- internal obstacles that can affect the distribution of temperature and humidity (furniture, partitions).

Conclusions and recommendations

The information obtained on the microclimate parameters makes possible to conclude that it is esswential to optimise and improve conditions to ensure stable temperature and humidity in the room. The recommendations may include the intallation or adjustment of heating and cooling systems, which will provide efficient use of energy resources, comfortable living and working conditions.

1.7 Example 1 - air quality survey report

AIR QUALITY SURVEY REPORT

Office and warehouse building

Customer:

Facility (object) address:

Contractor:

Contents

1.7.1 General information on the objects of the survey

Fig. 1.8 General view of the object

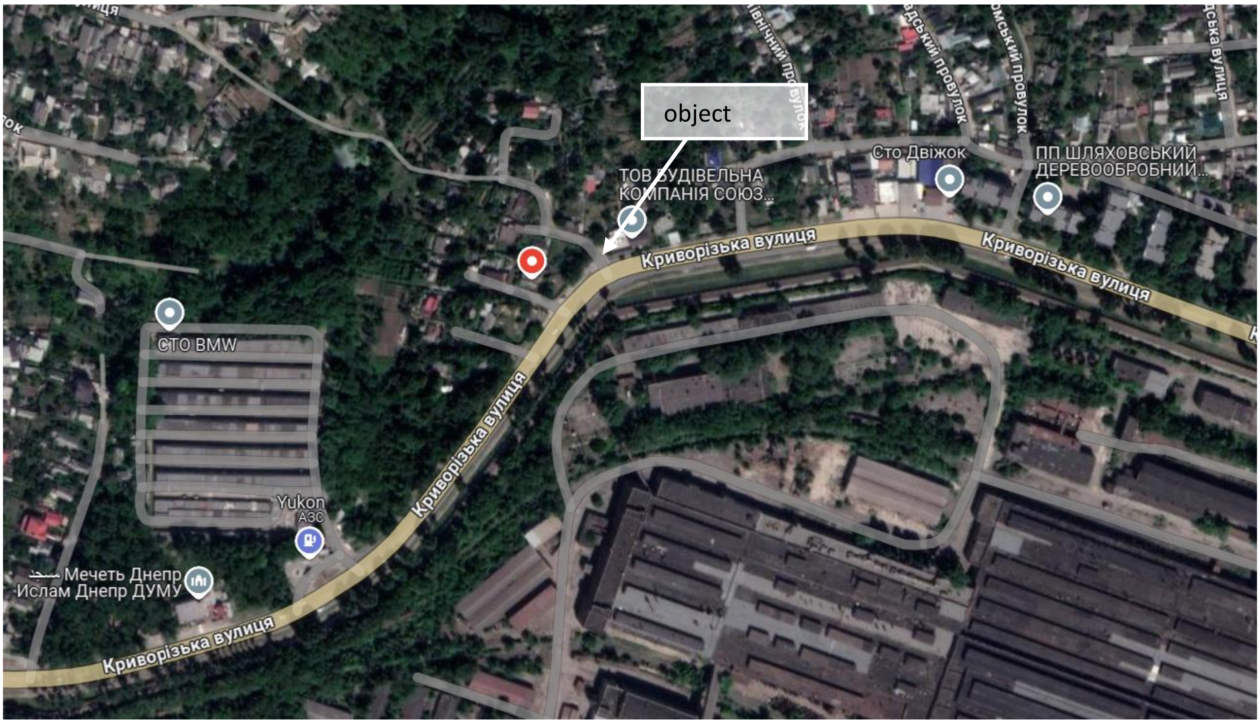


Fig.1.9 Situational plan of the area

1.7.2. Object parameters:

Table 1.1

Customer	Office and warehouse building
Address	Dnipro
Date	05.12.2023
Device model:	Testo535
Series number	-
Contractor	Full name

Description of the building structure	The office and warehouse building: - two-storey building; - total area of 206m2; - the height of the ground floor is 3m, the height of the first floor is 2.8m. The structural scheme of the building is frameless, with load-bearing external and internal walls and floor slabs. The foundations are strip, reinforced concrete. The attic floor is made of 220 mm thick reinforced concrete slabs. The building was constructed using 380 mm silicate bricks. The interior of the building is covered with 20 mm gypsum plaster. The exterior of the building is insulated with mineral wool insulation with a density of ρ0=150kg/m^3 and a thickness of 190mm.		
Outdoor air temperature, C°	1,6	**Indoor air temperature, C°**	19,4
Temperature difference between indoor and outdoor air, C°	17,8	**Weather conditions Other important factors affecting results**	dry no clouds no wind

Full name of the institution		Office and warehouse building			
Person responsible for the survey (name, tel, e-mail)		Full name, contact details			
№	Type of building	Location (address)	Purpose	Year of construction	Number of floors
1					

1.7.3 Measurenment results

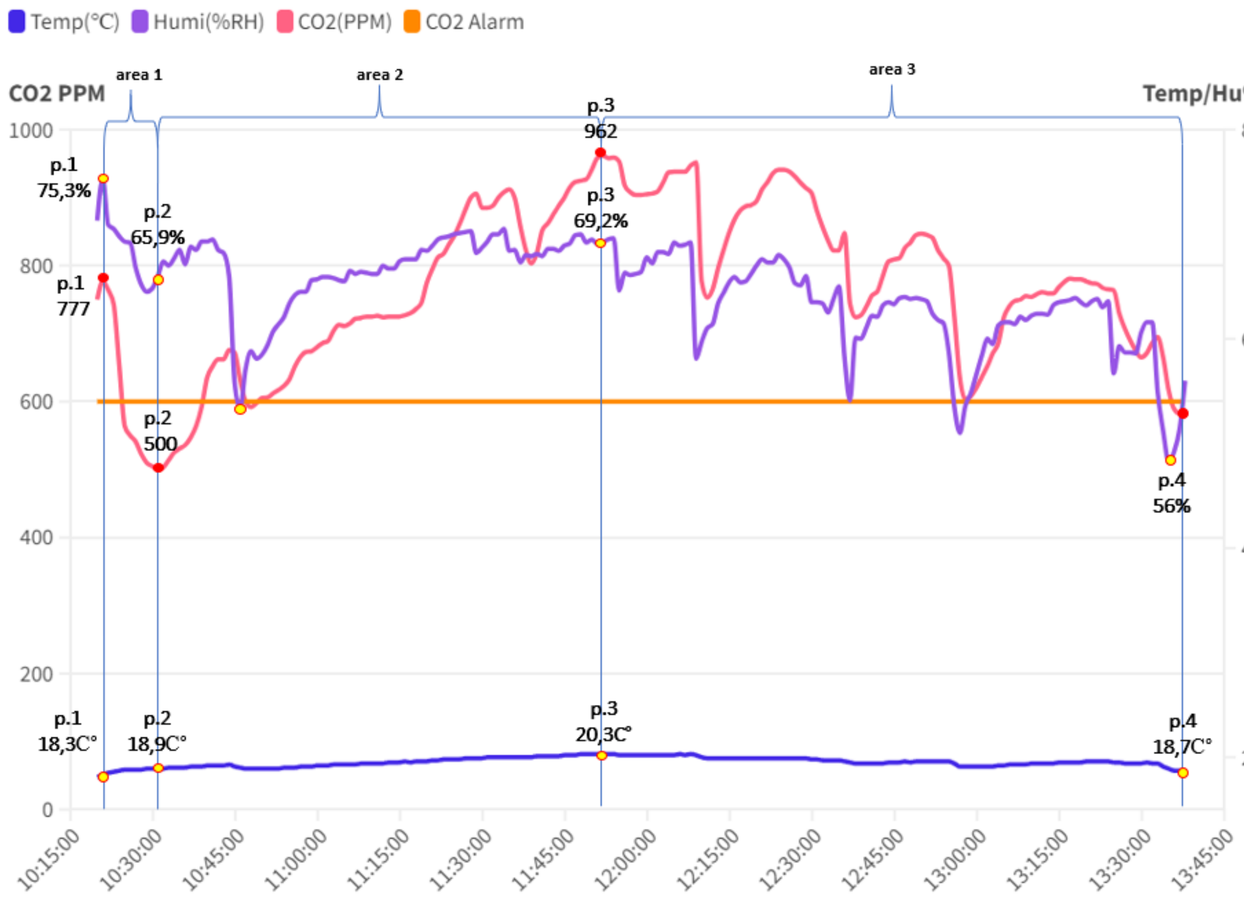


Fig. 1.10 Measurement results of building microclimate parameters

According to the results shown in Figure 1.10, during the measurement period, we can observe temperature fluctuations ranging from 18.1 °C to 20.3 °C, humidity fluctuations from 53.3% to 75.3%, and CO_2 concentrations ranging from 500 ppm to 962 ppm.

Table 1.2

Survey results

№	Time period	ppm	%	C°	Analysis/ conclusion
p.1	10:21	777	75,3	18,3	CO_2 concentration value at the beginning of the measurement. The highest value of air humidity.
p.2	10:31	500	65,9	18,9	Minimum CO_2 concentration due to ventilation of the room. Reduced air humidity.
p.3	11:52	962	69,2	20,3	Maximum CO_2 concentration before

					ventilation. Presence of more than five people. High levels of humidity and CO_2 concentration are caused by painting works.
p.4	13:38	584	56	18,7	Minimum value of CO_2 concentration as a result of room ventilation.
area 1	10 min	↓277	↓9,4	↑0,6	Drop in CO_2 concentration. Ventilation time. 10 minutes of complete ventilation was sufficient to achieve standard CO_2 concentration.
area 2	1 h 35 min	↑462	↑3,3	↑1,4	Increase in CO_2 concentration, which is higher than before ventilation. Conclusion: at this time, it is advisable to ventilate again.
area 3	1 h 46 min	↓378	↓13,2	↓1,6	Time for ventilation. Drop in CO_2 concentration and humidity during ventilation takes longer due to the presence of more people in the room Ventilation through the front door instead of full ventilation.

1.7.4 Conclusions and recommendations

The meter was installed indoors at a height of 1 m near the wall. The construction works (painting) were performed in the room. There was no direct sunlight or any exposure to direct sunlight. The measurement interval was every one minute, the measurements took 3 hours and 30 minutes.

The obtained measurement results allow us to assess the microclimate in the room (temperature, humidity and CO_2 concentration).

The conclusions from the data obtained are as follows:

Air quality. CO_2 level (ppm):

The value is comfortable for human breathing: ≤ 600 ppm

The measurement showed a fluctuation in CO_2 level from 500 ppm to 900 ppm. Such increase in CO_2 levels indicates a deterioration of indoor air quality. The reason is the painting works inside the building and insufficient ventilation.

Temperature:

Normative value: 20°C according to Appendix B of DBN B.2.6-31:2021.

The measurement results showed that the temperature level ranged from 18°C to 20°C. Under such conditions, the temperature regime meets the regulatory requirements.

Humidity:

Normative value: 45-60% according to Appendix B of DBN B.2.6-31:2021.

The measurement results showed fluctuations in humidity levels from 75% to 55%. High humidity levels are also associated with painting works, which can affect comfort and indoor air quality.

Conclusions: The overall assessment of indoor microclimate parameters shows that the air condition does not meet the standards and may affect the health and comfort of workers. Increased levels of CO_2 and humidity caused by painting works require attention and possible measures to improve the microclimate. Recommendations may include additional ventilation and humidity control during the repair works.

These findings highlight the need to manage indoor air quality in order to create a healthy and comfortable working environment for workers.

1.8 Example 2 - air quality survey report

1.8.1 General information on the building of the survey

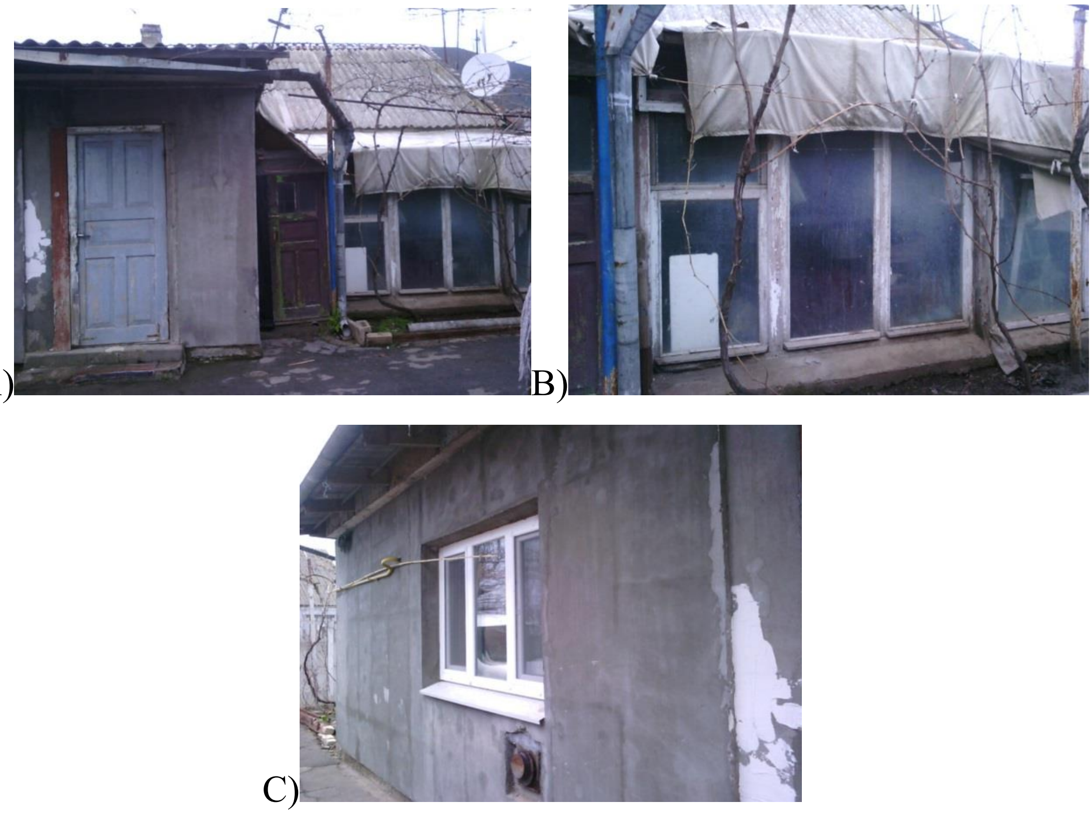


Fig.1.11 Picture of the residential house façade:

A) Entrance B) Greenhouse façade C)Extention facade

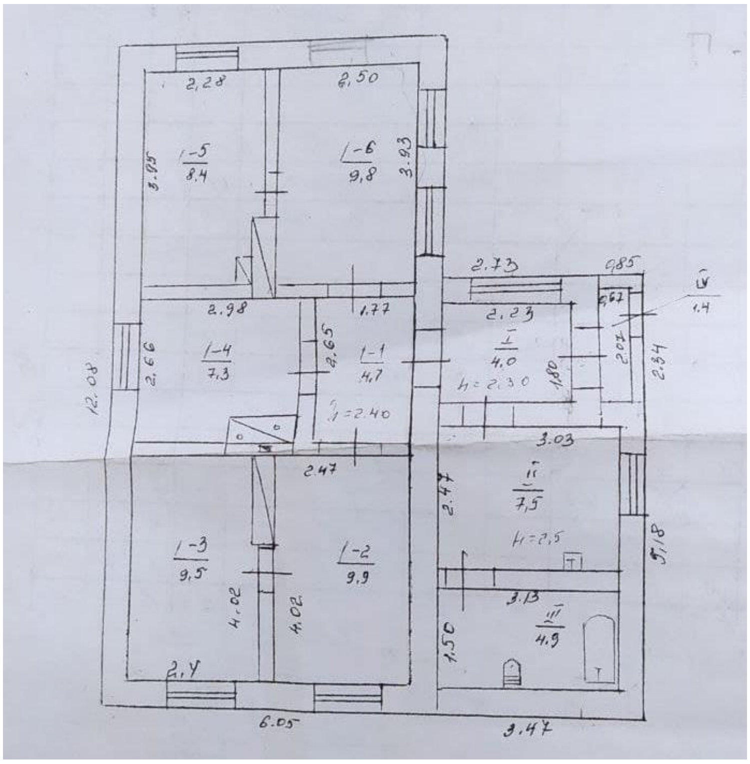


Fig. 1.12 BTI layout

Fig.1.13 Geographical layout of the building.

The red arrow marks the object location on the map.

1.8.2 Object parameters:

Table 1.3

Customer	Office and warehouse building
Address	Dnipro
Date	05.12.2023
Device model:	Testo535
Series number	-
Contractor	Full name

Description of the building structure	Residential building - a single-storey, complex shape in plan. The structural scheme - a cross arrangement of load-bearing walls. The exterior walls are solid masonry. The roof is pitched, the attic is not heated. Two-chamber metal-plastic double-glazed windows, one chamber filled with argon gas.		
Outdoor air temperature, C°	-1	**Indoor air temperature, C°**	20
Temperature difference between indoor and outdoor air, C°	21	**Weather conditions Other important factors affecting results**	dry no clouds no wind

List of premises is presented in Table 1.4

Table 1.4

Full name of the institution		Residential house			
№	Type of building	Location (address)	Purpose	Year of construction	Number of floors
1	house	Kherson	residential	1956	1
2	extension		residential	2007	1
3	greenhouse		non-residential	2015	1

The aim of the survey is to conduct instrumental control of the microclimate quality parameters of residential premises.

The object of the survey is a residential house located in Kherson. Kherson belongs to the second climatic zone. The building is located far from the highways in the suburbs, with an area of 69.9 m_2, of which 37.6 m^2 is living area. Five adults live in the house (six adults at the time of the experiment) and five pets. The building envelope consists of rubble masonry - the main building and extension No. 1, masonry made of Crimean shell rock - extension No. 2, kitchen and bathroom. The walls of the building are insulated with 50-mm thick foam panels in a one layer on plastic dowels. The windows were replaced with metal-plastic windows with two chambers, one of which is filled with argon gas. The floor of the main building is wooden with a technical underground, the floor in the extensions is cement screed. The roof is attic, gable. The attic is not insulated.

Survey plan. Measurements were taken in three rooms, two of which were living rooms. The meter was installed at a height of 1m to 1.5m, at a distance of 1.5m from the ventilation windows. The measurement interval was every 8 minutes, the duration of measurements was two days, and the total number of measurements was 360. The boundary values were set as follows: for temperature, the lower boundary was 16C°, the upper was 30C°; for humidity, the lower boundary was 40%, the upper was 85% (high boundary due to the problems with humidity in the premises); for CO_2 concentration, the upper boundary was 5000 ppm (due to the lack of ventilation and the airtightness of the building). Figure 1.14 shows the location of the meter.

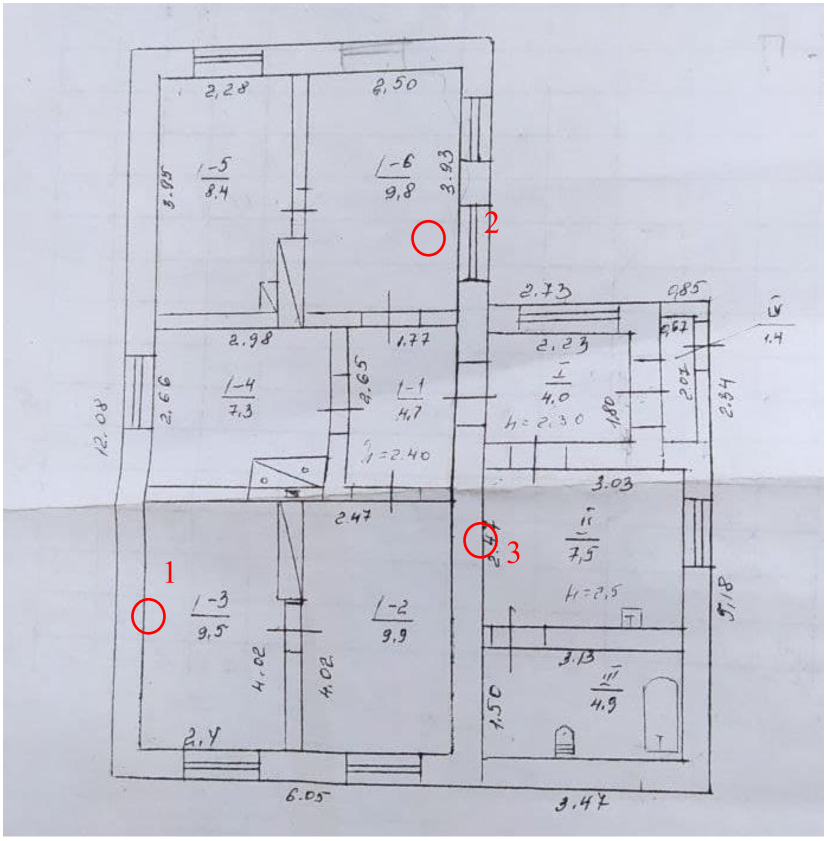


Fig1.14 Location of the meter on the house layout;
Numbers indicate the sequence of the survey.

A detailed description of the survey of the room № 1 is provided as an example.

1.8.3 Survey No. 1, room № 1.

The object consists of two rooms with no doors between them, the area is 19.4 m^2. Two adults live in the room, and at the time of the survey, 1 person is working remotely from 8:00 to 17:45. Thus, a desktop computer is running for two days during working hours. There are from one to four people in the room during the day. There are 4 pets in the premises all the time. The heating device «gas convector» is set at point 3 out of 7.

Date of the first day of the survey: 04.01-05.01.2021

Weather conditions: 04.01.21 23:00 t - +1C°, humidity 94%, cloudy, no precipitation. 05.01.21 maximum t - +4C°, minimum t - +1C°, humidity ranges from 91% to 97%, cloudy, no precipitation.

The measurement results are shown in Figure 1.15 and Table 1.5.

According to the results shown in Fig. 1.15, temperature fluctuations range from 18.2°C to 20°C, humidity fluctuations - from 58.3% to 67.2%, and CO_2 concentrations range from 944 ppm to 2931 ppm per day.

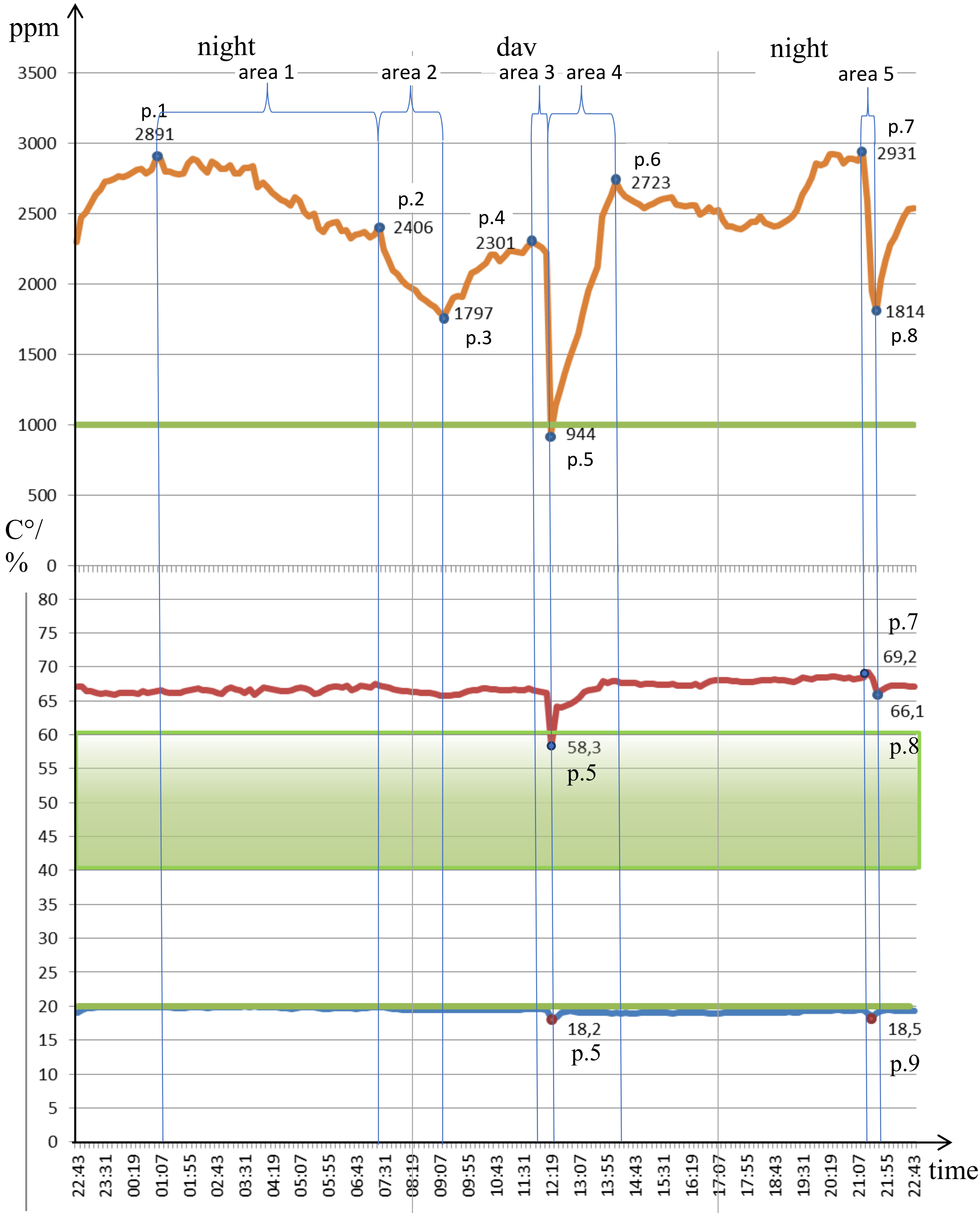


Fig.1.15 The graph of the survey, day 1, room 1

Blue color – temperature (C°), red– humidity (% RH), orange – CO_2 concentration (ppm), green – normative values

Table 1.5

Survey results, day 1

№	Time period	ppm	%	C°	Analysis/ conclusion
p.1	00:59	2891	66,4	19,9	Maximum CO_2 concentration reached overnight
p.2	7:23	2406	67,2	19,9	Minimum CO_2 concentration reached overnight
p.3	9:07	1797	65,8	19,5	Minimum CO_2 concentration without people
p.4	11:47	2301	66,5	19,6	Maximum CO_2 concentration before ventilation. Two people in the room.
p.5	12:19	944	58,3	18,2	The lowest value of the day. Period of ventilation.
p.6	14:11	2723	67,9	19	Maximum value after ventilation, two people in the room
p.7	21:15	2931	69,2	19,5	The highest CO_2 and humidity concentration of the day. Two people in the room.
p.8	21:39	1814	66,1	19,1	The values are taken at the time of ventilation. The time recorded is 9 minutes after closing the windows.
p.9	21:31	1949	68,3	18,5	Minimum temperature value at the time of ventilation.
area 1	6 h 24min	↓385	↑0,8	const	Drop in CO_2 concentration. We can observe the phenomenon of infiltration at night.
area 2	2 h 15 min	↓609	↓1,4	↓0,4	Drop in CO_2 concentration. We observe the phenomenon of infiltration without people.
area 3	15 min	↓1357	↓8,2	↓1,4	Ventilation. Conclusion: 15 minutes is sufficient to achieve the standard CO_2 concentration and humidity.
area 4	1 h 52 min	↑1779	↑9,6	1,2↑	Increase in CO_2 concentration and humidity which is higher than the level before ventilation. Conclusion: it is advisable to ventilate again.
area 5	15 min	↓1117	↓3,1	↓1	Ventilation. Drop in CO_2 concentration and humidity during ventilation does not reach the standard values, but compared to the previous ventilation, the drop is approximately the same for the same

					time despite the presence of two people. Conclusion: it is advisable to ventilate for 30 minutes in the evening without people in the room.

Date of the 2[d] day of the survey: 05.01-06.01.2021

Weather conditions: 05.01.21 23:00 t - +3C°, humidity 97%, cloudy, no precipitation. 06.01.21 maximum t - +10C°, minimum t - +2C°, humidity ranges from 63% to 100%, clear during the day, but cloudy in the evening, thick fog.

The measurement results are shown in Figure 1.16 and Table 1.6

According to the results shown in Figure 1.16, the temperature fluctuated from 17.7 °C to 20 °C, the humidity fluctuated from 66.8% to 71.5%, and the CO_2 concentration fluctuated from 1159 ppm to 3014 ppm.

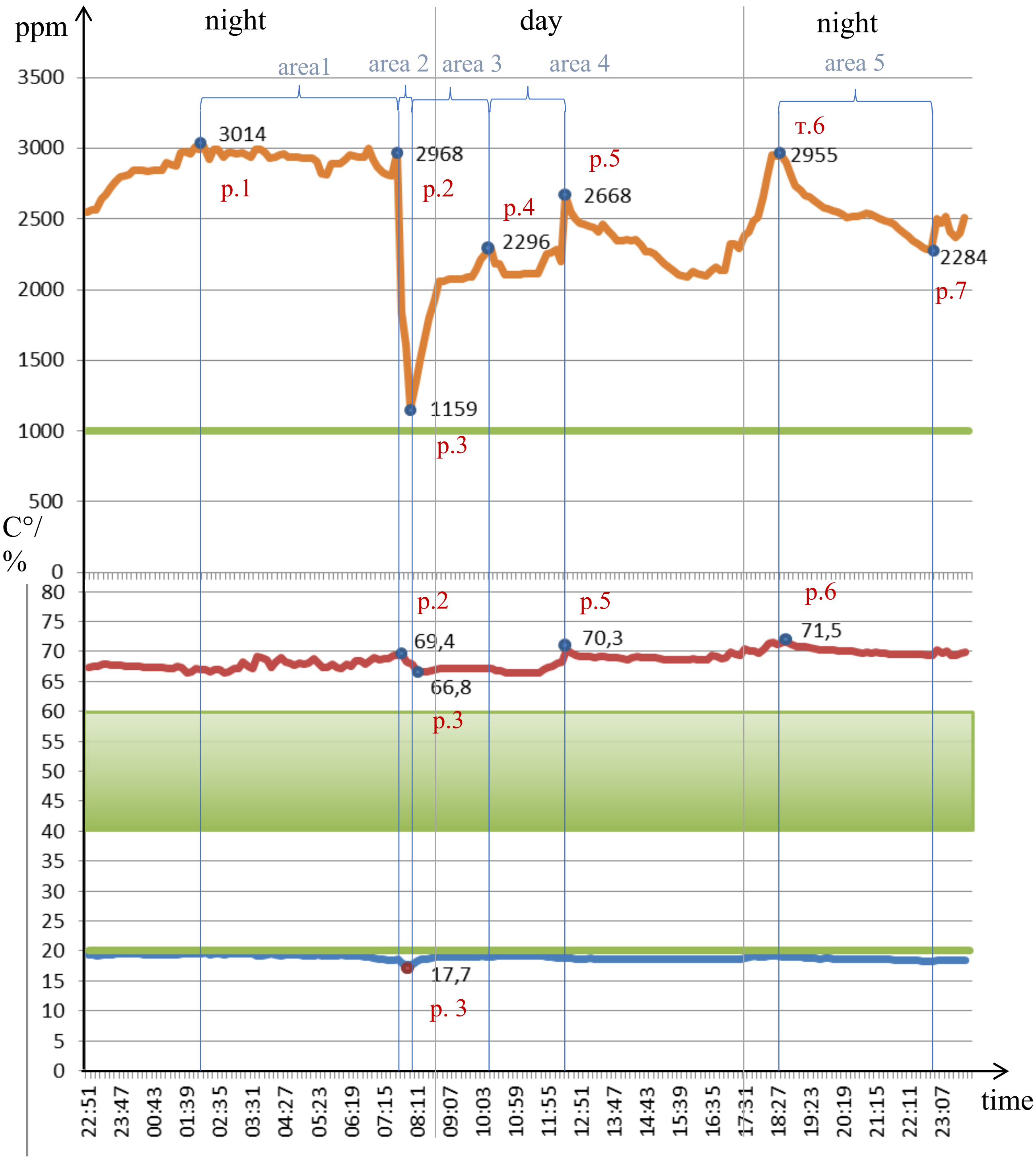


Fig. 1.16 The graph of the survey, day 2, room 1

Blue color – temperature (C°), red– humidity (% RH), orange – CO_2 concentration (ppm), green – normative values

Table 1.6

Survey results, day 2

№	Time period	ppm	%	C°	Analysis/ conclusion
p.1	2:11	3014	66,9	19,7	Maximum value of CO_2 concentration at night.
p.2	7:39	2968	69,4	18,6	Minimum value of CO_2 concentration at night.
p.3	8:03	1159	66,8	17,7	Minimum values are achieved during ventilation.
p.4	10:19	2296	67.2	19	The first peak in CO_2 concentration.
p.5	12:27	2668	70,3	18,8	The second peak in CO_2 concentration.
p.6	18:19	2955	71,5	19,1	CO_2 concentration, humidity and temperature are increased when a large pet and one person in the room. It is advisable to provide one more ventilation.
p.7	22:43	2284	69,4	18,3	Decrease in the values demonstrates absence of people.
area 1	5 h 28 min	↓46	↑2,5	↓1,1	No infiltration occurred during this period. Drop in CO_2 concentration is not indicative. Conclusion: ventilation is required.
area 2	25min	↓1809	↓2,6	↓0,9	Ventilation was not sufficient to achieve the standard values. Conclusion: increase ventilation time up to 30 minutes.
area 3	2 h 16 min	↑1137	↑0,4	↑1,3	Increase in CO_2 concentration and humidity. Conclusion: it is advisable to ventilate again.
area 4	2 h 8 min	↑372	↑3,1	↓0,2	The second increase in CO_2 concentration and humidity. There are two people in the room.
area 5	4 h 24 min	↓671	↓2,1	↓0,8	During this period of time, we observe the phenomenon of infiltration.

1.8.4 Conclusions

A practical instrumental survey of three microclimate parameters: temperature, relative humidity and carbon dioxide concentration was carried out simultaneously in a residential building in Kherson.

According to the results of the survey, we identified the maintenance stages of premises, which does not meet the standard conditions for a comfortable living.

The importance of microclimate is high, and the survey revealed the number of drawbacks that need to be addressed, namely:

The airtightness of the building due to the self-insulation and the installation of new windows. There are possible savings on heating, but the increased humidity and CO_2 concentration prove that such retrofitting without proper ventilation only harm the health of the people living in such building.

A very high humidity level due to heaters, even when the air in most rooms is dry. This indicator causes uncomfortable indoor climate and it is a clear threat to human health. There is already mould in the room, and humidity helps it to grow.

The main recommendation is to install mechanical supply and exhaust ventilation with heat recovery - an exhaust system for kitchen and bathroom, channels that will inject fresh air into the main building.

1.9 Example 3 - air quality survey report

1.9.1 General information on the object of the survey

Aparment in the apartment building

1.9.2 Object parameters:

Table 1.7

Customer	Apartment
Address	Dnipro
Date	09.06.24
Device model:	Testo 160
Series number	-
Contractor	Full name

Description of the building structure			
Outdoor air temperature, C^o		**Indoor air temperature, C^o**	
Temperature difference between indoor and outdoor air, C^o		**Weather conditions Other important factors affecting results**	dry no wind no clouds

Full name of the institution					
Person responsible for the survey (name, tel, e-mail)	Full name, contact details				
№	Type of building	Location (address)	Purpose	Year of construction	Number of floors
1					

1.9.3 Measurement results

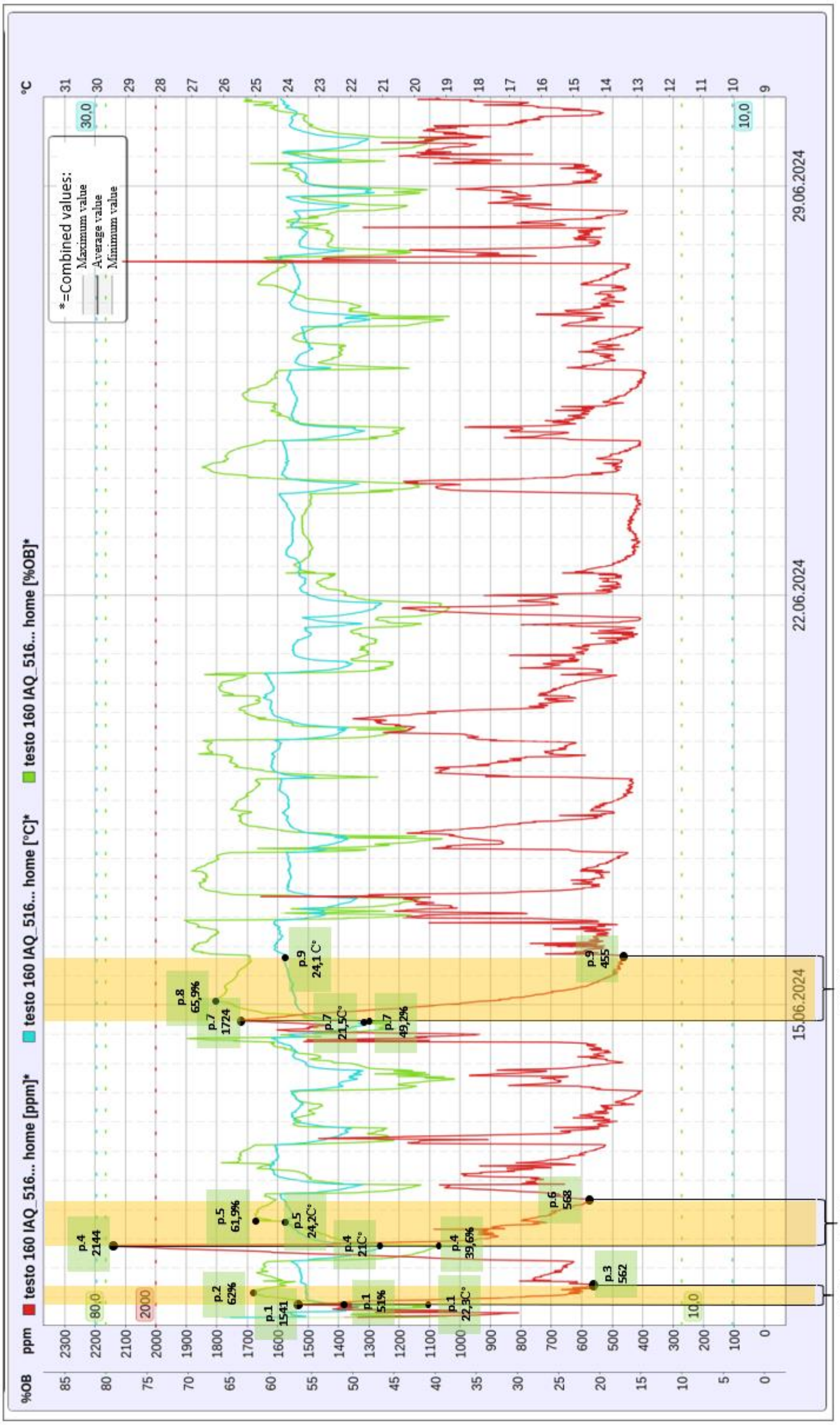


Fig. 1.17 Measurement results of building microclimate parameters

According to the results shown in Figure 1.17, during the measurement period, temperature fluctuations range from 20.9 °C to 26 °C, humidity fluctuations from 37.7% to 70.5%, and CO_2 concentrations range from 387 ppm to 2147 ppm.

Some fragments of the graph showing large fluctuations in microclimate parameters were selected for the analysis, which is presented in Table 1.8.

Table 1.8

Survey results

№	Time period	ppm	%	C°	Analysis/ conclusion
p.1-p.3	9.06 (21:00)-10.06 (5:00)	1541-562	51-58,2	22,3-23,4	High CO_2 concentration is observed during air conditioning, which is accompanied by a decrease in temperature and humidity. When the room is ventilated, the microclimate changes: CO_2 level decreases, temperature and humidity increase.
p.4-p.6	10.06 (21:00)-11.06 (15:30)	2144-568	39,6-59,6	21-24,1	High CO_2 concentration as a result of air conditioning and change of the parameters during ventilation.
p.7-p.9	14.06 (17:30)-15.06 (20:00)	1724-455	49,2-62,5	21,5-24,1	High CO_2 concentration as a result of air conditioning and change of the parameters during ventilation.
p.1	9.06 (21:09)	1541	51	22,3	The highest value of the CO_2 concentration at the beginning of the measurement.
p.2	10.06 (2:15)	638	62	23,4	Drop in CO_2 concentration as a result of ventilation and switching off the air conditioner. Increase in air humidity and room temperature.
p.3	10.06 (5:00)	562	58,2	23,4	CO_2 concentration after ventilation.
p.4	10.06 (21:00)	2144	39,6	21	Maximum value of CO_2 concentration during the measurement period. Value

					before ventilation of the room.
p.5	11.06 (8:45)	750	61,9	24,2	Drop in CO_2 concentration as a result of ventilation and switching off the air conditioner. Increase in air humidity and room temperature.
p.6	11.06 (15:30)	568	59,6	24,1	CO_2 concentration after ventilation.
p.7	14.06 (17:30)	1724	49,2	21,5	Value of CO_2 concentration before the room is ventilated.
p.8	15.06 (3:45)	767	65,9	23,8	Drop in CO_2 concentration as a result of ventilation. Increase in air humidity and temperature during the period of room ventilation.
p.9	15.06 (20:00)	455	62,5	24,1	CO_2 concentration after ventilation.
area 1	8 h	↓979	↑7,2	↑1,1	Drop in CO_2 concentration. Ventilation and switching off the air conditioner. Increase in room temperature and humidity.
area 2	18 h 30 min	↓1576	↑20	↑3,1	Drop in CO_2 concentration. Ventilation and switching off the air conditioner. Increase in room temperature and humidity.
area 3	26 h 30 min	↓1269	↑13,3	↑2,6	Drop in CO_2 concentration. Ventilation and switching off the air conditioner. Increase in room temperature and humidity.

1.9.4 Conclusions and recommendations

The graph shows the results of monitoring indoor climate parameters, including CO_2, relative humidity and temperature. The data was collected during a month using the Testo 160 device. The graph clearly shows changes in the parameters at different periods of time, which demonstrates the impact of various factors on the indoor climate.

The analysis shows that the air conditioner is in use makes the CO_2 level increase, while the temperature and humidity levels decrease. This indicates that the air conditioner, while cooling the air, does not provide sufficient air exchange in the room, which leads to the accumulation of CO_2.

On the contrary, when the room is ventilated and the air conditioner is switched off, the CO_2 level decreases and the relative humidity and temperature increase. This occurs because ventilation promotes air renewal, reducing CO_2 concentrations and increasing humidity levels due to the influx of outside air.

It is recommended that the room is adequately ventilated when using the air conditioner to reduce CO_2 levels. This can be achieved through regular ventilation or by installing a supply and exhaust ventilation system. Regular ventilation not only reduces CO_2 levels, but also helps to maintain optimal microclimate parameters, such as humidity and temperature.

Sensors to monitor CO_2, humidity and temperature levels can help quickly respond to changes in microclimate parameters and take timely action to correct them.

It is recommended that the air conditioning is switched off and the room is ventilated from time to time, especially if the CO_2 level increases significantly. This will maintain a balance between a comfortable temperature and indoor air quality.

CHAPTER 2. LIGHTING SURVEY

2.1 Introduction

This chapter of the guide provides clear and consistent guidance on the measurement of indoor lighting in buildings. The recommendations can be used by professionals in the field of construction, architecture, engineering and other related fields.

These recommendations and compliance with the requirements of the regulatory and technical documents of Ukraine about the lighting of premises will help ensure and improve the quality of lighting, comfort and productivity of employees.

Illuminance, measured in lux (lux), is an important parameter that affects visual comfort and overall well-being. Correct measurement and analysis of the light level make possible to optimise lighting conditions in different rooms, which contributes to improved work efficiency and working conditions.

2.2 Theoretical foundation. Terms and definitions

Light is a type of electromagnetic radiation perceived by the human eye. The main characteristics of light that affect illuminance:

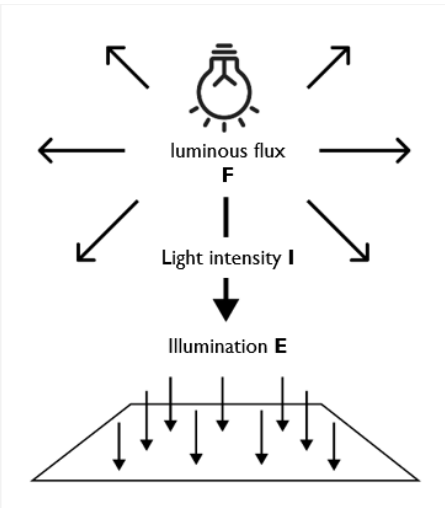


Fig. 2.1 Luminous flux, lfight intensity, illuminance.

1. Luminous flux F (lumen, lm) is the total amount of light emitted by a light source in all directions. (Fig. 2.1)
2. Light intensity I (candela, cd) is a measure of the light power emitted in a certain direction.
3. Illuminance E (lux, lx) - the amount of luminous flux per unit area. One lux is equal to one lumen per square metre. Luxes are used to assess the level of illuminance in rooms and open spaces.

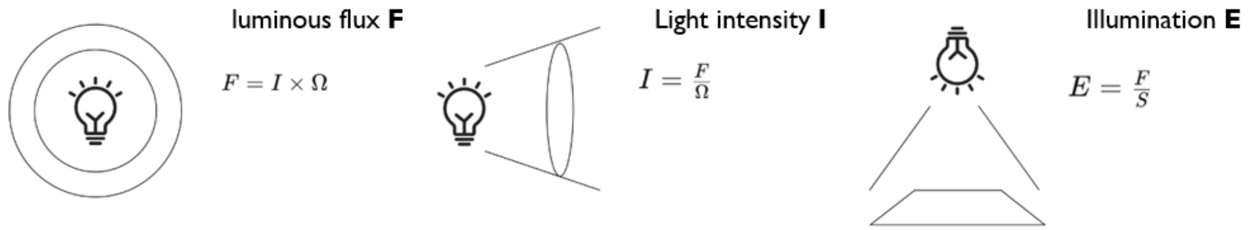


Fig. 2.2 Relationship between units of measurement

1. **Luminous flux F (lumen, lm)** is the total amount of light emitted by the light source. This is the basic parameter which the other indicators depend on.
2. **Light intensity I (candela, cd)** describes how much light energy is emitted in a certain direction from a light source. It is based on the luminous flux but takes into account the direction of emission.
3. **Illuminance E (lux, lx)** is the amount of light falling on a surface. Illuminance depends on the luminous flux and the distance from the light source to the illuminated surface.

Thus, the luminous flux in lumens gives the total amount of light, the lumen intensity in candela shows how this light is distributed in a certain direction, and the illuminance in lux indicates how effectively this light illuminates the surface. Together, these indicators help understand and evaluate the quality of lighting in different environments.

Illuminance in lux allows assessing how well a surface is illuminated.

Natural light coefficient (NLC) is the ratio of natural illuminance at a certain point inside the room to the simultaneous external illuminance on an open horizontal plane, expressed as a percentage.

Cylindrical illuminance is a characteristic of the light saturation of a room, defined as the average luminous flux density on the surface of a vertically located cylinder in the room, the radius and height of which tends to zero.

Application of cylindrical illuminance

- Assessing the quality of lighting in interiors: used to provide uniform lighting in areas where people move and interact to avoid shadows and create a comfortable lit environment.
- Museums and galleries: helps assess the lighting of exhibits by providing uniform illuminance from all sides.
- Street lighting: used to evaluate the effectiveness of lighting in streets and squares, where it is important to provide uniform lighting for safety and convenience.

Average illuminance is the illuminance averaged over the area of the illuminated premises, site, or work area.

Insufficient or excessive lighting can lead to eye fatigue, headaches and reduced concentration. For example, the optimal light level for office space depends on the type of work performed, but it is usually 500 lux for workplaces with computers.

Artificial lighting is divided into working, emergency, security, and duty lighting. Emergency lighting is divided into safety lighting and evacuation lighting. There are the following artificial lighting systems: general, local and combined.

It is forbidden to use only local lighting, as it gives uneven illuminance, which increases eye fatigue and can lead to nervous disorders.

When choosing indoor lighting, it is important to consider not only the basic parameters such as light levels and energy efficiency, but also additional characteristics that can have a significant impact on employee comfort and the overall office environment. These parameters include:

Color temperature, T_C:

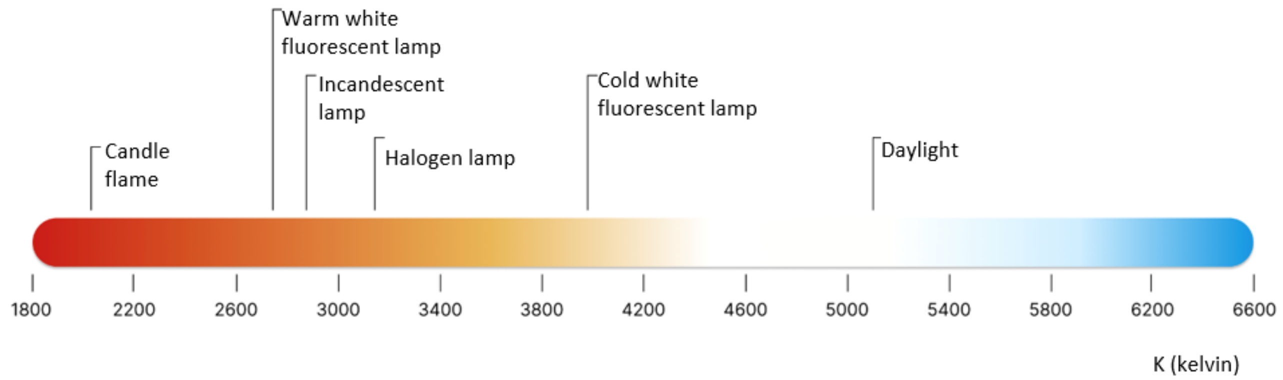


Fig. 2.3 Scale of color temperature

It is measured in Kelvin (K) and describes features of light emitted by a light source. A low temperature (2700K-3000K) creates a warm, cosy light, while a high temperature (5000K-6500K) provides cold, almost daylight-like lighting. Offices typically use light with a temperature of around 4000K-5000K, which promotes concentration and efficiency.

Unified Glare Rating – UGR measures the level of discomfort a person experiences from the glare of light on surfaces. A UGR of less than 19 is considered low and acceptable for office spaces where it is important to minimise glare discomfort, especially on computer monitors, also important for homes with computer work areas.

Color Rendering Index – CRI, R_a indicates the accuracy with which the light from the lamp renders colours compared to the light from a natural source (the sun). A high CRI (closer to 100) means that colours look more natural under the light, which is important for works where accurate colour matching is critical.

Color Fidelity is a relatively new metric that measures the colour rendering quality of light sources on a scale from 0 to 100. It is similar to CRI, but provides a more complete picture of how light affects the perception of different colours

Spectral composition of light describes the distribution of light energy across different wavelengths. The importance of this parameter is growing with attention to the impact of light on human circadian rhythms, and is especially important for rooms without access to natural light.

Luxmeter is a light measurement device that converts the luminous flux incident on its sensor into an electrical signal, which is then calibrated and displayed as an illumination reading on the device»s display.

2.3 Regulatory and technical documents of Ukraine on interior lighting of buildings

In Ukraine, lighting standards and indoor lighting measurements are controlled by **DBN B.2.5-28:2018** - «Natural and Artificial Lighting»[8], the current **DSTU B B.2.2-6-97 «**Buildings and structures. Methods of measuring illumination»[9] and **DSTU EN 12464-1:2016** «Light and lighting. Lighting of workplaces. Part 1: Indoor workplaces»[10].

DBN B.2.5-28:2018 - «Natural and artificial lighting»[8]

The standard provides requirements for the design of natural and artificial lighting systems in buildings and structures. The goal is to provide optimal lighting conditions that promote comfortable and safe work and preserve human health.

DBN B.2.5-28:2018 [8] is applied for the lighting design in residential, public and industrial buildings, as well as in the territories of settlements and beyond.

The minimum natural light standards are established for different types of premises to ensure sufficient daylight. The issues of insolation and measures to prevent overheating of premises in summer are also considered.

It specifies the requirements for artificial lighting levels to ensure visual comfort and safety. The standard defines the parameters of lighting devices, methods of their placement and ways to ensure uniform lighting of premises.

The requirements for emergency lighting to ensure the safety of people in case of of a power cut are described. This includes evacuation lighting, lighting of high-risk areas and other special conditions.

Measures to improve the energy efficiency of lighting systems are considered, including the use of energy-saving bulbs, automation of lighting systems and other modern technologies.

It presents the requirements for the preparation of project documentation and reports on the results of the lighting systems design. This includes data on lighting levels, materials used, calculation methods and justification of decisions.

DSTU B V.2.2-6-97 «Buildings and structures. Methods of measuring illuminance»[9]

The standard defines methods for measuring illuminance in the premises of buildings and structures, as well as in workplaces. The purpose is to ensure proper lighting conditions that meet safety and comfort requirements.

The standard covers the measurement of minimum, average and cylindrical illuminance, as well as the coefficient of natural light (CNL) in premises. It also gives methods for measuring minimum illuminance in outdoor workplaces.

It describes the methods of measuring illuminance, including the identification of measurement points, the conditions for making measurements, and procedures for obtaining accurate data. The importance of proper location of measurement points, installation of devices at a certain height, taking several measurements to obtain average values, etc. is provided.

The requirements for instruments used to measure illuminance, such as lux meters are given. The need for regular calibration of instruments to ensure the reliability of the results is emphasised.

The standard specifies the requirements for the preparation of reports on the results of measurements, which should include all the initial data, average illuminance values and comparison with the normative indicators. It includes conclusions on whether the lighting conditions meet the standards and recommendations for improving lighting, if necessary.

These standards apply to the lighting design of residential, public and industrial premises, both new buildings and existing ones undergoing renovation. The standards include requirements for natural and artificial lighting, including the use of light guides for natural lighting.

DSTU EN 12464-1:2016 «Light and lighting. Lighting of workplaces. Part 1: Indoor workplaces»[3].

This is a Ukrainian adaptated version of the European standard **EN 12464-1**[3]. This standard specifies requirements for workplace lighting solutions that are designed to meet visual comfort and productivity needs. It covers a number of criteria, including:

- Light (illuminance) levels: defines minimum light levels for different types of tasks and environments to ensure adequate visibility and comfort for tasks.
- Light quality: considers such factors as glare control, light direction and colour properties of light sources to provide a suitable visual environment for most users and tasks.
- Energy efficiency: even the focus is on light quality and comfort, the standard also considers the efficiency of lighting solutions in the context of wider environmental goals and energy consumption.

The standard provides detailed guidance on the recommended light levels for different tasks and how to achieve these levels through appropriate light fixtures, location and control systems. The standard aims to improve the working environment taking into account the health and safety aspects of lighting.

2.4 How the light meter works

A light meter converts the light incident on the sensor into an electrical signal. This signal is then calibrated and displayed as a luminance value on the device»s display. The sensors of these devices are typically sensitive to a wide range of light, covering the visible and near-infrared ranges.

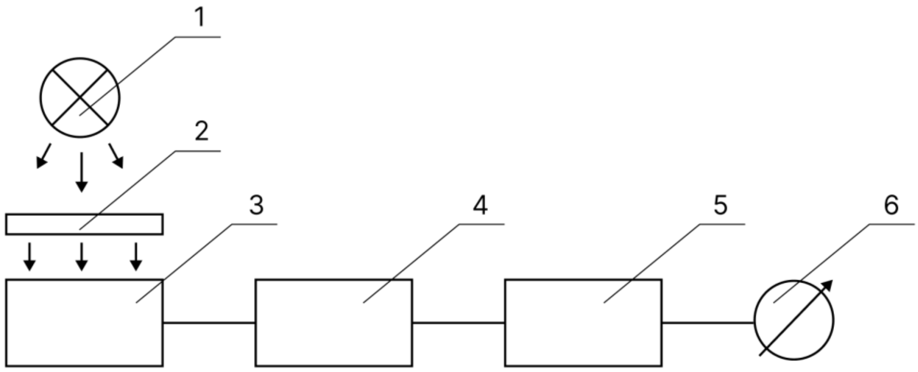


Fig. 2.4 Schematic diagram of the light meter 1– light source, 2– filter, 3– light sensor. 4 – amplifier, 5 – microprocessor, 6 – display

1. Light source
2. Filters: light filters are used to bring the measurement characteristics closer to the perception of the human eye. Most often, these are colour correction filters.
3. Light sensor: a photodetector that responds to light. The most common type of is a photodiode or photoresistor. It converts light energy into an electrical signal.
4. Electronic amplifier: it amplifies the signal received from the photodetector so that it can be measured and analysed.
5. Microprocessor: it processes the signal and performs the necessary calculations to determine the light level.
6. Display: shows the measurement results in lux (lux).

These devices serve as a bridge between the subjective perception of light and its objective measurement. Their calibration plays a critical role in maintaining their accuracy and reliability. Calibration of a light meter at the manufacturing stage is critical to ensure the accuracy and reliability of measurements in real-world applications.

2.5. Survey methods

When performing measurements, it is important to ensure that the lux meter is correctly positioned in the work area, avoiding direct glare and other factors that may affect the accuracy of the readings. Make sure that the device has been calibrated in accordance with the manufacturer»s instructions and has the appropriate certificate.

2.5.1 Types of light measurements according to DSTU B V.2.2-6-9[2]

● **Artificial lighting:** measurements are carried out in the absence of natural light (at night or with darkened windows). Assessment of the efficiency and uniformity of lighting from artificial light sources.

● **Natural light:** measurements are carried out exclusively in natural light (during the day, without lights on). The influence of weather conditions and time of day is taken into account.

● **Mixed lighting:** measurements are made using both natural and artificial light. Assessment of the total illuminance of the room, taking into account all light sources.

2.5.2. Location of measurement points

● Select multiple control points depending on the size and purpose of the room (central area, work areas, passage areas).

● In large rooms, it is better to use a grid with a spacing of 1-2 metres for a more accurate assessment. The minimum number of control points N for measurement is determined according to the size of the room and the height of the luminaires above the work surface with regard to Table 2 [9]. For this purpose, it is necessary to use the room index (RI), which is calculated using the following formula from this DSTU (formula 2.1) for rectangular rooms:

$$ІП = \frac{A \times B}{H_m \times (A + B)} \qquad (2.1)$$

where:

A – length of the room, m;

B – width of the room, m;

Hm – height from the working surface to the surface of the lighting device, m.

Appendix A (recommended) [9] provides diagrams of the location of the measurement points.

2.5.3 Measurement methods

● Measurement of the illumination on the work surface (0.75 m from the floor for offices, desks, workstations).

● For common areas and aisles, measurement is perfomed at a height of 1.2-1.5 m from the floor.

● Measurements on vertical surfaces are made at a height that is appropriate for the use of the surface (e.g. for blackboards in schools, at eye level of a person who is sitting or standing).

2.5.4 Measurement conditions

● Clean windows and lighting devices.

● No extra light (if possible) for accurate artificial lighting measurements.

● Check the operating status of all lighting devices.

● Measurements are carried out under stable conditions, without changing external lighting factors.

● The measuring photometric sensor must not be shadowed by a person.

● The measuring instrument must not be located near strong magnetic fields.

● Repeat measurements for accuracy (e.g. measuring three times at the same point).

2.5.5 Data processing

● Enter the data into the table in Appendix B [9] for further analysis.

● Determining the minimum and maximum illuminance values in the room to assess the uniformity of illuminance.

● Building a heat map of the illuminance distribution for a visual representation of zones with different light levels.

2.5.6 Comparison with standards

● Compare the obtained data with the normative values for a specific type of room and area of activity. Evaluation of the results of artificial light measurements should be carried out in accordance with Table 3 [9].

● Identify deviations and possible causes.

2.5.7 Measurement results report

● Prepare report with measurement results, comparing with standards and conclusions.

● Provide recommendations for improving lighting (e.g. adding light fixtures, replacing bulbs with more efficient ones, optimising the layout of working space).

● Make a supplement with a floor plan of the room with marks (measurement point numbers) and a description of the measurement according to the purpose of the room. This helps clearly demonstrate the measurement locations and facilitates the analysis of the results.

This general step-by-step plan help implement a systematic approach to measuring indoor illuminance, taking into account the specifics of each type of room and the relevant standards. Following this plan will help ensure comfortable and safe conditions for all indoor activities.

2.6 Lighting inspection using the Testo 440 device with remote sensor

Fig 2.5 Lux meter Testo 440 with remote sensor

Testo 440 is a versatile, multifunctional indoor climate monitoring device. With a remote light sensor, it can accurately measure light, making it suitable for a variety of applications, including workplace safety, building inspections, and ensuring proper lighting conditions in various environments.

Technical specifications

- Display: graphic display with backlight
- Memory: internal memory for 7,500 measurements
- Interfaces: USB for data transfer, bluetooth for wireless probes
- Power supply: AA batteries or optional battery pack
- Operating temperature: -20 to +50 °C
- Dimensions: 154 x 65 x 32 mm (without probe)
- Weight: approx. 250 g (without probe)

Light sensor (Probe for measuring light)

- Measurement range: 0 to 100,000 lux

- Accuracy: ±3% of the measured value (+10 to +30 °C, <75% RH)
- Resolution: 0.01 lux (up to 100 lux), 0.1 lux (up to 1,000 lux), 1 lux (up to 100,000 lux)
- Response time: 1 second
- Operating temperature: -10 to +50 °C
- Dimensions: probe head diameter: 40 mm, probe length: 200 mm
- Weight: approx. 100 g

Application

- Workplace safety: ensuring compliance with lighting standards at workplaces.
- Building inspections: inspecting lighting conditions in residential and commercial buildings.
- Quality control: monitoring lighting conditions in industrial and manufacturing environments.
- Educational facilities: inspecting lighting conditions in schools, universities and training centres.

The **Testo 440** with remote light sensor provides reliable and accurate measurements for a wide range of lighting conditions, making it an essential tool for professionals in a variety of industries.

When an office space has limited access to natural light through windows, it becomes necessary to develop a special lighting design that meets the standards for public spaces. This approach can improve employee comfort and productivity, as well as ensure compliance with safety and energy efficiency requirements.

2.7 Example of survey and measurement

Fig2.7 General view of the room

The room has 18 automated workplaces. The lighting is provided by 20 Brille 24W/864 E27 CW G95 (PL-SP) 220V LED lamps at a height of 2.8 m.

Inspection of the lighting system revealed the problem of spotlighting over individual workplaces and the lack of general lighting, which further reduces the illuminance of the room.

The measurements were carried out in sunny weather at 11 am on the second week of October. According to the room index formula and Table 2 [9], we divide the room into N=9 points.

$$\text{ІП} = \frac{A \times B}{H_m \times (A + B)} = \frac{11.3 \times 12}{2.8 \times (11.3 + 12)} = 2$$

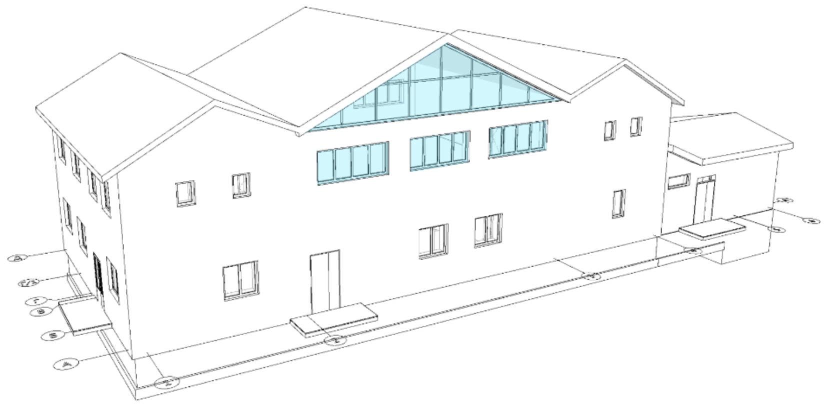


Fig2.8. General view of the building and attic windows where the survey was held

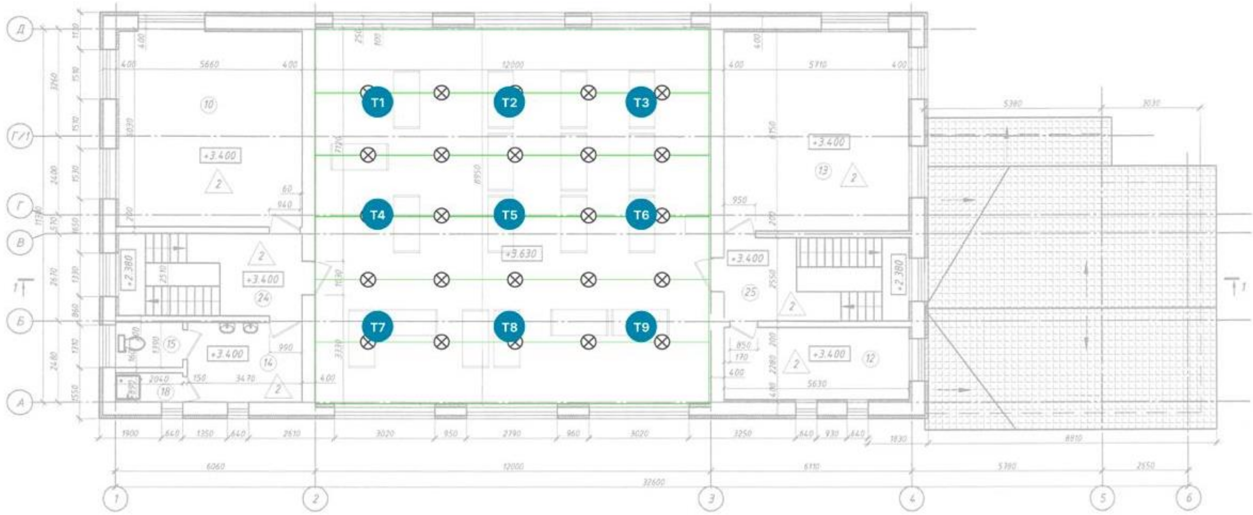


Fig.2.9 Layout of the lighting measurement points and location of the existing luminaires mounted to the metal roof trusses

Fig 2.10. Devices used for the survey
left -Testo 440, right Flus MT–91

Protocol for measuring lighting in industrial and public premises

Title (number) of premises «Ledum» Ltd, *premises № 1 (second floor - attic)*

Number of device ______________________________

Date of inspection *11.10.2023*

Network voltage _ *225V* (measuerement start) *225 V* (measurement end)

Current regulatory document: DBN V.2.5-28:2018, DSTU EN 12464-1:2016 DSTU B V.2.2-6-97

Condition of the light fixtures: *local lighting is working satisfactorily*

No. of checkpoints	Place of measurement, name of the work surface	Measurement plane (horizontal, vertical, inclined) - height from the floor, m	Measured, lx			Illuminance, lx actual			Standardised			Compliance of lighting in the workplace with applicable standards
			Combined lighting		General lighting	Combined lighting		General lighting	Combined lighting		General lighting	
			general	general + local		general	general + local		general	general + local		
1	2	3	4	5	6	7	8	9	10	11	12	13
1	Desk surface	horizontal 0.8 m	77	215.1	–	–	–	–	200–300	500	–	does not comply
2	Desk surface	horizontal 0.8 m	87	221	–	–	–	–	200–300	500	–	does not comply
3	Desk surface	horizontal 0.8 m	99	243	–	–	–	–	200–300	500	–	does not comply
4	Desk surface	horizontal 0.8 m	67	213.5	–	–	–	–	200–300	500	–	does not comply
5	Desk surface	horizontal 0.8 m	72	267	–	–	–	–	200–300	500	–	does not comply
6	Desk surface	horizontal 0.8 m	80	254.3	–	–	–	–	200–300	500	–	does not comply
7	Desk surface	horizontal 0.8 m	81	226	–	–	–	–	200–300	500	–	does not comply
8	Desk surface	horizontal 0.8 m	73	228	–	–	–	–	200–300	500	–	does not comply
9	Desk surface	horizontal 0.8 m	67	235	–	–	–	–	200–300	500	–	does not comply

Inspection conlusions: *The lighting level of working spaces does not comply with standards*

Contractor___________________ Customer________________

2.7.1 Measurement results and conclusions

Measurement results are the illuminance indicators of workplaces. The average illuminance of automated workplaces in a room with a permanent presence of people is 241 lux from mixed lighting (natural + local). According to the standards, it should be at least 500 lux. According to DBN B.2.5-28:2018 Natural and artificial lighting Table D.1 and DSTU EN 12464-1 2016 Light and lighting. Lighting of workplaces. Part 1: Indoor workplaces (EN 12464-1 2011, IDT - Table 5.26.4). The illumination of the room does not meet the standards.

In addition, measurements of natural light show weak insolation due to window structures, the building shaded by trees and the architectural design in general. In the dark, there is no general lighting at all.

The premises need to be updated with light fixtures to improve working conditions in accordance with regulatory documents.

The results are provided in the form of a protocol (see above). If the report is issued separately, it contains the signatures of the Contractor and the Customer. As a part of a comprehensive energy audit, the protocol is attached as an appendix.

2.8 Protocol for measuring lighting in industrial and public premises

Title (number) of premises ______________________________

Number of device ______________________________

Date of inspection ______________________________

Network voltage _

____

(measurement start) (measurement end)

Current regulatory document: ______________________________

Condition of the light fixtures ______________________________

No. of checkpoints	Place of measurement, name of the work surface	Measurement plane (horizontal, vertical, inclined) - height from the floor, m	Measured, lx			Illuminance, lx actual			Standardised			Compliance of lighting in the workplace with applicable standards
			Combined lighting		General lighting	Combined lighting		General lighting	Combined lighting		General lighting	
			general	general + local		general	general+ local		general	general		
1	2	3	4	5	6	7	1	2	3	4	5	6

Inspection coclusions:

Contractor____________________ Customer________________

CHAPTER 3. NOISE SURVEY

3.1 Introduction

This chapter of the guide provides theoretical and practical knowledge on measuring noise levels in building interiors. This chapter will help ensure compliance with the requirements of the regulatory and technical documents of Ukraine regarding noise levels, improve the comfort and safety of employees, and their working conditions.

Noise is an important microclimate parameter that affects people»s health and well-being. Correct measurement and analysis of noise levels allow nfinding sources of excessive noise and developing effective measures to reduce its impact on people.

3.2 Theoretical foundation. Terms and definitions.

Referring to a process that includes both measurements and in-depth analysis, followed by recommendations to reduce noise impact, the term «noise assessment» is the most appropriate.

Noise assessment is a term commonly used to describe the detailed analysis and evaluation of noise levels, especially when it comes to legal aspects or comprehensive studies to identify noise sources and their impact on human health or the environment.

Noise survey is a more general term that covers the process of measuring noise levels and is usually used in the context of routine inspection or monitoring.

Noise measurement is a precise term that describes the process of collecting noise data using specialised equipment. The term is used in technical documents and reports where specificity is required regarding the actions taken.

Noise pollution analysis - used in cases where it is necessary to assess not only noise levels, but also their impact on the environment or human health.

Noise is any unwanted sound that can cause adverse effects on human health or interfere with performance.

Noise intensity is a physical quantity that determines the amount of energy carried by a sound wave over a unit area per unit time. It is measured in watts per square metre (W/m^2).

Noise intensity level. To estimate the intensity of a sound perceived by the human ear, a logarithmic scale and the unit of measurement, decibel (dB), are used. Total noise level, measured on the A (dBA) or C (dBc) scale, takes into account frequency correction to match the perception of sound by the human ear.

Acoustic comfort is a condition in which the noise level does not exceed the established standards and does not cause negative sensations in humans.

Acoustic pressure is a change in air pressure caused by sound waves. It is measured in Pascals (Pa).

Decibel (dB) is a unit of sound level measurement. It is measured on a logarithmic scale, which allows expressing large ranges of sound levels.

Equivalent noise level (Leq) is the root mean square noise level over a period of time, which gives an indication of the overall noise exposure.

Maximum noise level (Lmax) - the highest noise level recorded during a certain period of time.

Measurement interval - the period of time during which the noise level is measured.

A sound level meter is a device for measuring noise levels. It converts acoustic pressure into an electrical signal, which is then processed to determine the noise level in decibels.

Acoustic calibration is the process of checking and adjusting a sound level meter to ensure measurement accuracy.

External noise sources - noise from vehicles, industrial facilities, construction sites, etc.

Indoor noise sources - noise from household appliances, ventilation and air conditioning systems, and human activity inside the premises.

Sound insulation is the feature of building structures to reduce the penetration of sound from one room to another or from the external environment to the interior.

Health effects of noise

Excessive noise levels can cause a number of negative health effects, including fatigue, reduced concentration, headaches, sleep disorders and even chronic illnesses.

Therefore, it is important to measure regularly noise levels in workplaces and take actions to reduce noise exposure.

In Ukraine, the regulation of noise levels and their measurement in premises is controlled by the following regulatory and technical documents:

3.3 Regulatory and technical documents of Ukraine on noise in buildings

The Order of the Ministry of Health of Ukraine No. 463 of 22 February 2019 [11] concerns the approval of the State Sanitary Norms for Permissible Noise Levels in Residential and Public Buildings and on the Territory of Residential Development.

Main provisions of the document:

Aim: to ensure limitation of the intensity or duration of noise impact on human health by establishing criteria for its permissible impact.

To prevent deterioration of the living environment in case of noise exposure by planning and implementing measures to reduce noise to the levels established by these Sanitary Norms.

Scope of application: the norms (standards) establish permissible noise levels that penetrate into the premises of residential and public buildings from external and internal sources, as well as permissible noise levels in residential areas.

These standards do not apply to special purpose premises (radio, television, film studios, etc.).

For the assessment of permanent noise, sound pressure levels in octave bands with geometric mean frequency values are used.

Equivalent sound levels and maximum sound levels are used to assess temporary noise.

Annexes to the standards:

- Permissible sound levels in the premises of residential and public buildings and on the territory of residential development.
- Permissible sound pressure levels depending on the NC criterion.

- Corrections to the permissible noise levels depending on additional conditions (nature of noise, location of the object, source of noise, etc.)
- The Order comes into effect from the date of its official publication, and the Ministry of Health of Ukraine is responsible for monitoring its implementation.

DSTU B B.2.2-39:2016 Methods and stages of energy audit of buildings [12].

The document **DSTU B B.2.2-39:2016** covers the methods and stages of energy audit of buildings, choosing the most approriate methods for measuring various parameters, including noise, if it concerns building engineering systems.

The main sections of the document related to noise measurement:

Choosing an audit method: methods for assessing the energy performance of buildings include the method based on design data, the method based on the results of technical surveys, the calculation and measurement method and the measurement (operational) method.

Equipment and instruments: Section 6 describes the equipment and instruments to be used to measure various parameters, including temperature, humidity, air velocity, etc.

Specialised measuring instruments are used to measure the actual values of various parameters such as temperature and energy consumption.

Noise measurements are not a core part of an energy audit under this standard, but acoustic measurements can be made when assessing ventilation and cooling systems to determine the noise levels from these systems.

For such measurements, sound level meters are used, which record sound levels in dB (decibels).

DBN B.1.2-10:2021 Basic requirements for buildings and structures. Protection against noise and vibration [13].

Scope of application: these standards apply to buildings and structures as a whole and their parts (structural and engineering systems) during design, construction and operation.

General requirements: Buildings should be designed and constructed so that noise and vibration perceived by occupants or people in the vicinity do not endanger their health and allow them to live and work in satisfactory conditions.

Fot the facilities subject to these requirements, compliance with noise and vibration protection standards should be approved.

- Оздоблення внутрішніх поверхонь приміщень звукопоглинальними матеріалами і конструкціями.

Methods to meet the requirements:

- Design of enclosing structures of premises with the required values of airborne and impact noise insulation indices.
- Use of space-planning solutions to separate rooms with noise sources from rooms with standardised noise levels.
- Use of design solutions to prevent the spread of structural noise from engineering equipment.
- Construction with the use of design solutions to reduce sound levels from external noise sources.
- Finishing interior surfaces of premises with sound-absorbing materials and structures.

Evaluation and verification of characteristics:

Measurement of noise and vibration levels is carried out in accordance with regulatory methods, including field and laboratory tests.

The reverberation time, as a characteristic of room echo, is calculated and verified by field measurements.

Compliance verification:

The compliance of buildings and structures with noise and vibration protection requirements is verified at all stages of their life cycle: design, construction, operation and decommissioning.

DBN B.1.2-10:2021 [13] provides comprehensive measures and methods to ensure protection against noise and vibration in buildings and structures. Measurement of indoor noise levels is an integral part of the process of compliance approval of buildings with these standards, including design, construction and operation.

3.4 How noise measurement device works

Noise measurement devices, called sound level meters, are used to assess sound pressure levels in the environment. The basic principle of a sound level meter is to convert acoustic waves into an electrical signal that can be measured and analysed.

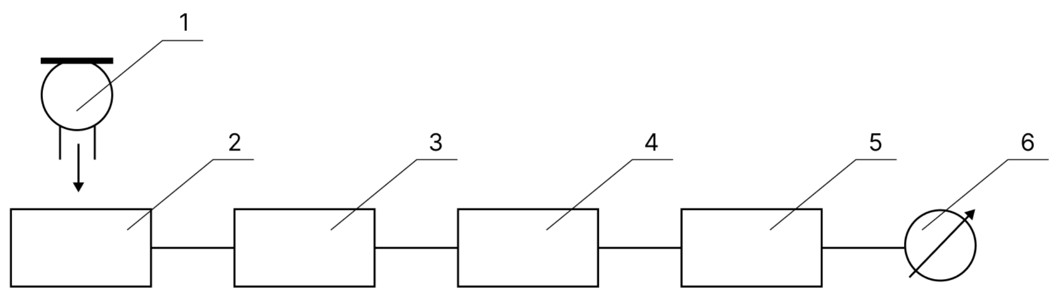


Fig. 3.1 Schematic diagram of a sound level meter 1 –microphone, 2– amplifier, 3 – filters 4 – ADC, 5 –microprocessor, 6 – display.

Microphone is the main sensor of the sound level meter that receives sound waves. The microphone converts the sound pressure into an electrical signal. The most common type is condenser microphones, which provide high accuracy and a wide frequency range.

Amplifier - an electrical signal received from the microphone is very weak, so it is amplified by an amplifier for further processing.

Filters - to measure accurately the noise, filters are used to isolate specific frequency ranges. For example, A-filters are often used for noise measurements because they bring the measurement characteristics closer to the perception of the human ear.

Analog-to-digital converter (ADC) –converts an analogue electrical signal, amplified and filtered, into a digital signal for further analysis and display.

Microprocessor processes the digital signal, calculates the noise level, stores data, and controls other functions of the instrument. The microprocessor can also perform corrections and calibrations.

Display shows the measurement results in real time. It can show various parameters such as equivalent noise level (Leq), maximum noise level (Lmax), etc.

Frequency correction of a sound level meter is a measurement device setting that takes into account the sensitivity of the human ear to different frequencies of sound. Since the human ear is not equally sensitive to all frequencies, sound level meters use different frequency filters to adapt their measurements to this perception. The most common types of frequency correction:

A-weighting simulates sensitivity of the human ear to different sound frequencies, being most sensitive to midrange frequencies (500 Hz - 6 kHz) and less sensitive to very high and very low frequencies. It is used for general measurement of noise levels in the environment, as it most closely matches human perception of sound. It is denoted as dB(A).

C–weighting is used to measure peak noise levels, as it more evenly reflects sensitivity to high and low frequencies compared to the A-filter. It is denoted as dB(C).

Z–weighting also known as flat weighting, does not apply any frequency correction, and measures sound as it is. It is used for scientific research and accurate measurement of sound without regard to human perception. It is denoted as dB(Z).

The partial corrections for the A-filter and C-filter are shown in Table 3.1.

Frequency correction in filters

Nominal frequency (Hz)	**Correction A (dB)**	**Correction C (dB)**	**Error limits (Class 2,dB)**
31,5	–39,4	–3	± 3
63	–26,2	–0,8	± 2
125	–16,1	–0,2	±1,5
250	–8,6	0	±1,5
500	–3,2	0	±1,5
1000	0	0	±1,5
2000	–0,2	–0,2	± 2
4000	1	–0,8	± 3
8000	–1,1	–3	± 5

Nominal frequency (Hz) is the frequency of the sound waves for which measurements are made.

Correction A (dB) shows how the A-weighting filter adjusts the sound pressure level at different frequencies. This filter is most sensitive to midrange frequencies (around 1000 Hz) and less sensitive to very low and very high frequencies.

Correction C (dB) shows how the C-weighting filter adjusts the sound pressure level at different frequencies. This filter is more uniform and is used to measure peak noise levels.

Error limits (Class 2,dB) indicates the permissible measurement error limits for Class 2 sound level meters.These are standard values that define the measurement accuracy at each frequency.

This table helps understand how different sound wave frequencies will be corrected when measuring with a sound level meter using either A or C filters. For example, at 1000 Hz, both filters make no correction (0 dB), while at low frequencies (e.g. 31.5 Hz), filter A significantly reduces the sound pressure level (-39.4 dB), while filter C does so less significantly (-3 dB).

In modern sound level meters, the frequency correction function is already built into the instrument, which simplifies the noise measurement process. Frequency correction is used to bring measurements in line with the perception of sound by the human ear. This allows for different hearing sensitivities to sounds of different frequencies.

3.5 Survey method

3.5.1 Measurement preparation

Check and calibrate the sound level meter before each measurement to ensure data accuracy.

Select the appropriate filters to correct the frequency response of the sound (e.g. A-filter to measure noise levels that are consistent with the human ear).

3.5.2 Measurement process

Set the sound level meter at the specified height and at the selected measurement point.

Start the device and conduct the measurement for a certain time to obtain a sufficient data.

3.5.3 Measurement errors prevention

A shell of a sound level meter and a person conducting measurements can create obstacles in the path of sound from various sources, as well as create sound reflections, which in turn can lead to serious measurement errors. In practice measurements at a distance of less than one metre from a person can make an error of up to 6 dB at a frequency of 400 Hz. At other frequencies, this error is less significant, but the minimum distance must be kept. The general recommendation is that the sound level meter should be at least 30 cm, and preferably 50 cm, from the human body.

3.5.4 Data registration

Collect noise level data, including equivalent noise level (Leq), maximum noise level (Lmax) and minimum noise level (Lmin).

3.5.5 Measurement conditions

Meteorological conditions:

- Take into account weather conditions that may affect the measurement results (wind, rain, temperature).
- Take measurements under stable weather conditions to ensure accuracy.

Measurement time:

- Take measurements at different times of the day to determine peak and average noise levels.
- Take into account working hours when noise sources are operating at full capacity.

3.5.6 Data processing

- Data analysis: process the collected data to determine average, maximum and minimum noise levels.
- Use specialised software to analyse and visualise the measurement results.

3.5.7 Comparison with standards

- Comparison of the data obtained with the established regulatory values to assess the compliance of noise levels with the requirements of standards and regulations.
- Determination of compliance: analysis of compliance of noise levels with regulatory requirements for residential, public and industrial premises.
- Identification of deviations and their causes.

3.5.8 Measurement results report

Preparation of the report according to DSTU B B.2.2-39:2016 [12]:

- reference time interval;
- long-term time interval;

for measurements - measuring instruments, results of their calibration, place of installation and duration of measurements;

- assessement level or adjusted level and its components; f) A description of the operating mode of the noise source(s);
- description of the site being assessed, including topography, building geometry, ground cover and other conditions;
- description of the procedures used to correct the effects of residual noise and a description of the residual noise;
- the results of a long-term assessment of the irritating effects of noise;
- weather conditions during the measurements, especially wind direction and speed, clouds and precipitation;

The report is generated with the measurement results, including all the initial data, calculated parameters and comparison with the standards.

It is recommended to provide graphs, tables and charts for a clear presentation of the results.

Conclusions and recommendations

Conclusions are made on the compliance of noise levels with the established standards. Recommendations are provided on measures to reduce noise impact and improve acoustic comfort.

3.6 Example of noise level measurement with the Testo 815 device

Fig. 3.2 Testo 815 sound level meter

The Testo 815 sound level meter is designed to measure noise levels in a various environments, such as industrial premises, construction sites, offices and other places where it is important to monitor acoustic comfort and noise compliance with regulatory requirements.

Specifications

Measuring range: 32 to 130 dB(A).

Resolution: ±1.0 dB.

Update: 0,5 c

Frequency filters: A-filter to measure sound levels that match the perception of the human ear. The C-filter is more uniform and is used to measure peak noise levels.

Measurement modes: Fast and Slow measurement modes for different conditions.

Application:

- Industry: to measure noise levels on production sites, monitoring compliance with regulatory requirements and ensuring worker safety.

- Construction: to monitor noise levels on construction sites to ensure compliance with noise pollution standards.
- Offices and public spaces: to assess acoustic comfort in offices, educational institutions and other public spaces.
- Environment: to monitor noise levels in the environment to assess the impact on residents and natural ecosystems.

Fig 3.3 Sound level calibrator for testing. Testo 815 and calibration procedure

The Testo 815 sound level meter is calibrated during the production. Recalibration is recommended to ensure the accuracy of the instrument, especially if it has not been used for a long time. The Testo 815 should also be checked with a calibrator before and after measurements in difficult conditions such as high altitude, high humidity, or in cases with special requirements for measurement accuracy.

Calibration is performed as follows

Preparation of the calibrator.

- Place the calibrator on the microphone of the sound level meter, ensuring tight contact and stability.

- Switch on the noise level meter and set the following parameters: measuring range 50-100 dB, time correction «Fast» and frequency correction «A».

Performing the calibration.

- Switch on the calibrator by moving the switch to the middle position (94 dB).

- If the sound level meter readings differ from the 94 dB value, it is necessary to perform additional calibration using the screwdriver supplied with the sound level meter.
- After that, check the second level of the calibrator by setting the measuring range of 80-130 dB. Make sure that the error does not exceed ± 0.2 dB.

In case of deviations.

- If the measurement results go beyond the permissible error limits, contact the manufacturer»s service department for further maintenance and setting of the device.

Table 3.2

Measurement dependence on the absolute pressure value

Altitude in metres above sea level, m	Pressure, mbar	Correction, dB
0 – 250	1013 – 984	0,0
> 250 – 850	983 – 915	–0,1
> 850 – 1450	914 – 853	–0,2
> 1450 – 2000	852 – 795	–0,3

Table 3.3

Temperature correction value

Temperature, °C	Correction, dB
–10	–0,8
50	1

Relative humidity: 65% RH

Reference value of the sound pressure level: 124 dB

Temperature range with a difference of < 0.5 dB: 0...+40 °C

Based on the results of the measurements, a protocol is drawn up as shown below.

3.7 Protocol for measuring noise in an office space

LEDUM Ltd, Dnipro, 1a Kyivska St.

Description of the place	Office of 100 square metres, open space without partitions. Second floor.
Floor covering	laminate
Ceiling height	From 3.6 to 10 m in the ridge part of the attic space
Reference time frame	Date: 10 June 2024 Time: from 09:00 to 17:00
Long-term time frame	Period: from 1 June 2024 to 30 June 2024
Measuring instruments	Testo 440 sound level meter №XXXXXXX
Calibration results	Calibration performed on 1 June 2024, accuracy ±0.5 dB
Installation location	In the centre of the office, at a height of 1.5 m from the floor
Measurement interval	Every 10 minutes during the working day
Estimated level or adjusted level and its components	
Average noise level (LAeq):	58 dB
Peak noise level (Lmax):	75 dB
Minimum noise level (Lmin):	42 dB
Description of noise source(s):	Computers, printers, employee conversations, phone calls
Operation mode of the noise source(s):	Continuous during working hours
Windows	closed during measurements
Weather conditions	
Air temperature:	22°C
Humidity	50%
Other	No wind or precipitation
Uncertainty of results	±1 dB

Regulatory documents	All measurements were made accoding to DSTU B B.2.2-39:2016 Assessment according to the standards of the Order of the Ministry of Health of Ukraine No. 463 of 22 February 2019 and DBN B.1.2-10:2021
Compliance and conclusions	
• The average noise level (LAeq) of 58 dB is within the permissible limits for office environments according to current standards. The noise level in the office is acceptable for comfortable working conditions. • The peak noise values (Lmax) do not exceed the permissible standards, which indicates the absence of significant noise loads. • To improve acoustic comfort, it is recommended to install additional sound-absorbing materials and optimise the placement of equipment. • Noise levels in the office are within the permissible limits, which ensures acceptable acoustic comfort for employees.	

Contractor ______________________

Signature _______________________

Customer ________________________

Signature______________________

3.8 Protocol for measuring noise in an office space

Description of the place	
Floor covering	
Ceiling height	
Reference time frame	Date: Time:
Long-term time frame	Period:
Measuring instruments	sound level meter №
Calibration results	Calibration performed
Installation location	
Measurement interval	Every _______ minutes during _________
Estimated level or adjusted level and its components	
Average noise level (LAeq):	dB
Peak noise level (Lmax):	dB
Minimum noise level (Lmin):	dB
Description of noise source(s):	
Operation mode of the noise source(s):	
Windows	open/ close
Weather conditions	
Air temperature:	
Humidity	
Other	
Uncertainty of results	
Regulatory documents	All measurements were carried out according to DSTU GOST 31296.1:2007

Compliance and conclusions

Contractor ____________________

Signature _____________________

Customer ____________________

Signature_____________________

CHAPTER 4. MONITORING OF VENTILATION SYSTEMS

4.1 Methods and devices for monitoring ventilation systems

Methods and devices for monitoring ventilation systems are widely used in various areas where air quality and efficiency of ventilation systems are important. Here are some of the most typical applications:

1. **Construction and repair**: in the process of building and renovation, it is important to ensure proper ventilation to avoid the accumulation of dust, harmful fumes and gases. Monitoring techniques and devices ensure that ventilation systems are working properly and providing clean air.

2. **Industrial enterprises (manufacturing):** in industrial environments, ventilation systems play a key role in removing harmful substances, dust and other pollutants from the air. Monitoring techniques can control pollution levels and track the effectiveness of ventilation systems.

3. **Medical facilities:** in hospitals, laboratories and other healthcare facilities, ventilation systems are essential to provide clean and safe air. Monitoring techniques ensure that hygiene standards are maintained and contaminants are controlled.

4. **Commercial premises:** in shopping centres, offices and other commercial premises, ventilation systems are important for the comfort and health of employees and customers. Monitoring ensures that the ventilation systems are providing adequate air quality and efficiency.

5. **Residential buildings:** in residential buildings, ventilation systems help remove odours, moisture and contaminants from the air. Monitoring techniques allow homeowners to ensure that their ventilation system works properly and provides a healthy living environment.

In all these areas, monitoring techniques and devices help detect ventilation problems in time, improve its efficiency, and ensure the safety and comfort of users.

4.2. Regulatory documents and standards for monitoring ventilation systems in buildings and premises in Ukraine

1. DBN B.2.5-67:2013 Heating, ventilation and air conditioning.

2. DBN B.1.2-11:2021 Energy saving and energy efficiency.

3. DBN B.1.2-7:2008 Basic requirements for buildings and structures. Fire safety.

4. DBN B.1.2-8:2008 Basic requirements for buildings and structures. Safety of human life and health and environmental protection.

5. DBN B.1.2-10:2008 Basic requirements for buildings and structures. Protection against noise.

6. DBN B.1.2-11:2008 Basic requirements for buildings and structures. Energy saving.

7. DBN B.2.6-31:2006 Thermal insulation of buildings.

8. DSTU B EN 13779: 2011 Ventilation of public buildings. Requirements for the performance of ventilation and air conditioning systems (EN 13779:2007, IDT).

9. DSTU B EN 15251:2011 Indoor climate parameters for the design and assessment of the energy performance of buildings with regard to air quality, thermal comfort, lighting and acoustics (EN 15251:2007, IDT).

10. DSTU 3.3.6.042-99 Sanitary norms of microclimate of industrial premises.

4.3. Terms and definitions

- **Ventilation**

Air exchange in the room to remove excess heat, moisture, harmful and other pollutants in order to ensure an acceptable microclimate and air purity in the working space or service area with an average shortage of 400 hours per year - for round-the-clock operation and 300 hours per year - for single-shift operation during the day[5].

- **Air quality monitoring**

The process of monitoring, evaluating and managing air parameters to ensure that it is safe and meets established standards and regulations. This process includes measuring levels of pollutants such as dust, gases, chemicals, and physical air parameters such as temperature, humidity, and air velocity [5].

- **Microclimate of the room**

Conditions of the indoor environment that affect the heat exchange of a person with the environment through convection, conduction, heat radiation and moisture evaporation; these conditions are determined by a combination of temperature, relative humidity and air velocity, the temperature of the surfaces surrounding the person and the intensity of thermal (infrared) radiation [5].

- **Working principle of ventilation systems**

Efficient and uninterrupted operation of the ventilation system, which ensures the required level of air quality, comfort and safety for people in the room, as well as meeting energy efficiency requirements. To achieve optimal performance, a number of technical and operational aspects must be taken into account.

- **Air handling equipment**

Technical means that ensure the movement and necessary processing of supply air and/or air that is removed or recirculated; terms and definitions of the concepts for the types of air conditioning and ventilation equipment according to DSTU 2264.

- **Air locking device**

A vertical section of air duct that changes the direction of movement of smoke (combustion products) by 180° and prevents smoke from penetrating from the lower floors to the upper floors in case of a fire.

- **Heat exchange (heat transfer)**

Physical process of transferring energy as a certain amount of heat from a body with a higher temperature to a body with a lower temperature until thermodynamic equilibrium is reached. It is impossible to stop the transfer of heat between neighbouring objects with different temperatures - it can only be slowed down [5].

- **Thermodynamic processes**

Processes during which changes in the state of a thermodynamic system occur due to changes in its internal energy, work or heat exchange with the environment. These processes may vary in nature and conditions, but they are all subject to the basic laws of thermodynamics.

- **Air circulation**

The process of air movement in a building or between a building and the outside environment. This process ensures that the air is constantly renewed, maintaining air quality, comfort and safety for the occupants. Air circulation can be natural or mechanical.

4.4. Theoretical part

Ventilation is a set of measures and devices aimed at organising an air environment in the premises that would ensure the comfortable stay of people in them and have a positive impact on the production process.

Hygienic tasks of ventilation are to maintain such parameters of the air environment in the premises that exclude the accumulation of excess harmful emissions (high temperature, excess heat, moisture, gases, dust, etc.) in the air of the room and create comfortable conditions for people to stay and work in them.

Technological tasks of ventilation are important, diverse and aimed at organising an air environment to increase productivity of workers and production. It should be noted that in many cases, the solution of technological problems with the help of ventilation leads to the solution of hygienic problems, and the use of ventilation to solve hygienic problems simultaneously allows solving technological problems. For example, reducing dust in the air for hygienic purposes protects from premature wear of rubbing parts in machines and workbenches, and as a result, increases the service life of technological equipment.

From the perspective of thermodynamics, thermal physics and ventilation, systems can be viewed as complex thermodynamic systems that enable the exchange of heat, mass and energy between different rooms, atmospheres and equipment. Here are some of the key aspects of this issue:

1. **Heat exchange:** ventilation systems are used to regulate indoor temperatures by removing warm air and introducing fresh, cool air. This process typically involves heat transfer through convection and heat transfer through equipment such as heat exchangers.

2. **Air circulation:** ventilation systems also play an important role in circulating air in a building, which helps create a comfortable microclimate and distribute heat and humidity.

3. **Ventilation and air quality:** effective ventilation ensures sufficient fresh air supply to the premises, which is the key to human health and comfort, as well as removal of contaminants and moisture from the air.

4. **Energy efficiency:** from a thermal physics perspective, it is important to ensure that ventilation systems are energy efficient by optimising heat transfer processes, minimising energy losses and using efficient control systems.

5. **Thermodynamic processes:** the principles of thermodynamics help understand and analyse the various processes that occur in ventilation systems, such as the compression and expansion of gases in ventilation systems, temperature and pressure changes during heat transfer, etc.

Understanding the principles of thermodynamics and thermal physics is essential for the design and efficient operation of ventilation systems that meet the requirements of comfort, safety and energy efficiency.

The ventilation monitoring system is an urgent problem in the development of any enterprise or institution where people work, the impact of air on people and production materials can be disastrous.

The ventilation monitoring system is designed to provide efficient operation of ventilation units and maintain optimal indoor conditions.

The purpose of such a system includes several key aspects:

1. **Air quality control:**
   - Measurement of air parameters such as temperature, humidity, CO_2 and other pollutants.
   - Ensuring that the air meets regulatory requirements and standards.
2. **Energy saving:**
   - Optimising the operation of fans and other components to reduce energy consumption.
   - Identifying inefficient equipment and timely reducing energy losses.
3. **Comfort:**
   - Maintaining a comfortable environment for occupants or employees by adjusting microclimate parameters.

- Regular monitoring and adjustment of ventilation system parameters according to user requirements

4. **Safety:**
   - Detecting and signalling faults or anomalies in the ventilation systems.
   - Ensuring safe operation of ventilation systems, preventing dangerous situations, such as high CO_2 levels or other hazards.
5. **Maintenance:**
   - Regular monitoring of equipment condition for timely maintenance and repair.
   - Fewer equipment downtime by predicting the need for maintenance.
6. **Reporting and analytics:**
   - Collecting data on the operation of ventilation systems for further analysis.
   - Generating reports on performance, energy consumption and other important parameters.

Based on the tasks set, the objectives of the ventilation monitoring system are to ensure efficient, safe and reliable operation of ventilation units. The main tasks include:

1. **Monitoring of air parameters:**
   - Measuring and tracking air quality indicators such as temperature, humidity, CO_2 concentration, pollution levels and other important parameters.

1. **Optimisation of energy use:**
   - Determining of the most energy-efficient operating modes of ventilation systems to reduce energy consumption.
   - Monitoring energy consumption and detecting energy losses.

2. C**omfortable conditions:**
   - Adjusting automatically air parameters to ensure comfortable microclimate for occupants or employees.

- Ensuring compliance with environmental conditions according to regulatory requirements and standards.

3. Detection of faults and anomalies:

- Detecting and signalling faults, deviations from normal operating conditions or abnormal situations in ventilation systems.
- Preventing emergencies and responding quickly to detected problems.

4. Safety:

Detection of dangerous concentrations of gases or other harmful substances in the air.

Timely notification and activation of safety measures in case of danger.

5. Maintenance and repair:

- Planning and coordination of maintenance based on collected data on ventilation system performance.
- Predicting the need for repairs to reduce downtime and extend the service life of the equipment.

6. Data collection and analysis:

- Collecting data on ventilation system performance for further analysis and improvement.
- Generating reports and analyses to assess performance and make informed decisions.

7. Remote monitoring and control:

- Remote monitoring and control of ventilation systems.
- Integration with other building management systems for comprehensive control.

These tasks focus on providing reliable and efficient operation of ventilation systems, maintaining high air quality, and ensuring comfort and safety for users of the premises.

Ventilation monitoring systems typically include various sensors, controllers, data analysis software and data visualisation tools to enable rapid response to changing conditions and maintain high efficiency of ventilation systems.

4.5. Devices for monitoring ventilation systems

Ventilation system monitoring devices are designed to measure and control various air parameters for optimal operation of ventilation systems. The main functions of such devices include:

1. Measurement of air velocity and volume:

Anemometers and flow meters are used.

Possibility to measure the air velocity in the ventilation ducts and calculate the air flow volume.

2. Measurement of differential pressure:

Manometers are used.

Pressure is measured at various points in the system to assess its efficiency and identify possible problems.

3. Temperature and humidity control:

Thermo-hygrometers are used.

Help maintain a comfortable microclimate and prevent condensation.

4. Air quality analysis:

Instruments for measuring CO_2, CO, volatile organic compounds (VOCs) and other pollutants.

Provide air quality monitoring to protect human health.

5. Thermal imaging diagnostics:

Thermographic cameras are used.

Allows visualisation of heat loss, overheating and other anomalies.

6. Electrical measurements:

Multimeters and current clamps are used.

Electrical parameters are measured to ensure that the electrical components of the ventilation systems are working properly.

4.6. Devices for technical control of ventilation. Measuring meteorological conditions in the room with Testo devices

The well-being of people depends primarily on the microclimate conditions in rooms and buildings. Comfortable conditions need to be maintained both in private homes and in the workplace.

The environment is considered comfortable only if certain physical, chemical and biological parameters meet the standard values.

In addition to well-being, a constant microclimate is important for different reasons: in museums - to protect artistic and cultural values, in laboratories - to provide clean filtered air that creates optimal conditions for research.

The task of the HVAC specialist is to maintain all the necessary microclimate parameters within the specified ranges.

Special instruments are used to measure each parameter of the air environment or air flow.

➲ Air temperature measurement

To measure the current temperature of a particular environment a special device **- a thermometer -** is used **to measure air temperature**.

Depending on the type and design, a thermometer can measure temperature of air, the human body, soil, water, and so on.

Modern thermometers are divided into several types. The gradation of devices, depending on the field of application, is as follows:

- household
- technical;
- research;
- meteorological and other.

Thermometers can also be:

- mechanical
- liquid
- electronic

- thermoelectric
- infrared
- gas.

Each of these devices has its own design, different working principle and field of application.

How thermometers work.

A liquid thermometer is based on the effect known as the expansion of liquid substance when heated. Most often, such devices use alcohol or mercury. Although the latter is systematically abandoned due to the increased toxicity of this substance. And yet, this process has not been fully completed, as mercury provides better measurement accuracy by linear expansion.

In meteorology, devices filled with alcohol are more commonly used due to the properties of mercury: at temperatures of +38 degrees and above, it begins to thicken. In its turn, alcohol thermometers allow assessing the temperature of a specific environment heated to 600 degrees. The measurement error does not exceed a fraction of one degree.

Types of thermometers

- Mechanical thermometer

Mechanical thermometers can be bimetallic or dilatometric (rod, baton). The principle of operation of such devices is based on features of metal bodies to expand when heated. They are highly reliable and accurate. The production cost of mechanical thermometers is relatively low.

These devices are used mainly in specific equipment: alarms, automatic temperature control systems.

Fig 4.1. Mechanical thermometer

- Gas thermometer

The working principle of the thermometer is based on the same properties as the devices described above. But in this case, an inert gas is used. Actually, such thermometer is an analogue of a pressure gauge, which is used to measure pressure. Gas instruments are used to measure high and low temperature environments (the range is -271 to +1000 degrees). They provide relatively low accuracy, the reason they are not used in laboratory measurements.

Fig. 4.2. Gas thermometer

- Electronic thermometer

It is also called a resistance thermometer. The working principle of this device is based on the change in the properties of the semiconductor built into the device»s construction when the temperature rises or falls. The relationship between both indicators is linear. In other words, when the temperature rises, the semiconductor resistance increases, and vice versa. The level of the latter directly depends on the type of metal used in the device: platinum «works» at -200 to +750 degrees, copper at

-50 to +180 degrees. Electric thermometers are rarely used, as it is very difficult to graduate the scale during production.

Fig. 4.3. Electronic thermometer

- Infrared thermometer

It is also known as a pyrometer. It is a non-contact device. The pyrometer works with temperatures from -100 to +1000 degrees. Its working principle is based on measuring the absolute value of the energy emitted by a particular object. The maximum range at which a thermometer is assessing temperature readings depends on its optical resolution, type of sighting device and other parameters. Pyrometers are characterised by increased safety and measurement accuracy.

Fig. 4.4. Infrared thermometer

- Thermoelectric thermometer

Thermoelectric thermometer is based on the Seebeck effect, which measures the potential difference when two semiconductors come into contact, resulting in electric current. The measuring temperature range is -100 - +2000 degrees

Fig. 4.5. Thermoelectric thermometer

➲ **Pressure measurement**

Principle of pressure measurement using a U-tube.

Pressure measurement involves measuring the pressure value in a liquid or gaseous medium. This is necessary to control technological processes and ensure production safety. In addition, this parameter is used for indirect measurements of other process parameters: level, flow, temperature, density, etc. In the SI system, the pressure unit is pascal (Pa).

In most cases, primary pressure transmitters have a non-electrical output signal in the form of force or displacement and are integrated into a single unit with the measuring instrument. If the measurement results need to be transmitted over a distance, an intermediate conversion of this non-electrical signal into a unified electrical or pneumatic signal is used. In this case, the primary and intermediate transducers are combined into one measuring transducer.

Types of pressure

There are the following types of pressure:

- atmospheric (barometric) pressure - pressure created by the mass of the air column of the Earth»s atmosphere;

- absolute pressure - pressure, which is measured from absolute zero. The pressure inside a vessel from which air has been completely removed is taken as the starting point;
- overpressure - the difference between absolute and barometric pressure;
- vacuum (rarefaction) - the difference between barometric and absolute pressure.

Types of pressure measuring instruments

Depending on the type of pressure to be measured, pressure measuring instruments are divided into:

- overpressure gauges - for measuring overpressure;
- absolute manometers - for measuring pressure with a readout from absolute zero;
- barometers - for measuring atmospheric pressure;
- vacuum gauges - for measuring vacuum (rarefaction);
- manovacuum gauges - for measuring overpressure and vacuum (rarefaction).

In addition to the above-mentioned measuring instruments, the following are widely used in pressure measurement practice:

- manometers - low overpressure gauges (up to 40 kPa);

- traction gauges - vacuum gauges with a measuring limit of up to -40 kPa;

- traction manometers - manometric vacuum gauges with a measuring range of +20...-20 kPa;

- residual manometers - vacuum gauges designed to measure deep vacuum or residual pressure, i.e. absolute pressures less than 200 Pa;

- differential manometers - instruments for measuring the difference in pressure;

- rhinomanometers - for measuring the pressure and volume of air during inhalation and exhalation.

Often the term «manometer» is used synonymously with any pressure measuring device.

Classification according to the principle of operation:

Pressure measuring instruments differ in their principle of operation. According to the principle of converting the pressure value into a signal about the measured value or according to the type of pressure, the devices are divided into:

- **Gravity-based**, which use gravity to directly measure pressure. They are divided into liquid and load cells:

In hydrostatically balanced *liquid manometers*, the height of the fluid column shows the measured pressure. An example is a U-shaped tube pressure gauge/ manometer (see Fig. 4.6). Such device was first used by H. Huygens in 1661. Mercury is sometimes used as a counterweight instead of a liquid column. The measured pressure range for U-shaped tube pressure gauges is: 10-5 MPa to 0.1 MPa. The range of such hydrostatically balanced pressure measuring instruments is significantly limited. In most cases, they are replaced by more advanced strain gauges. Liquid pressure (differential pressure and vacuum) measuring instruments with hydrostatic balancing, which are still used in process flows, include float and bell gauges (differential manometers), as well as compression gauges (vacuum gauges) used for laboratory metrological purposes.

Fig 4.6. Liquid manometer

o *Load piston gauge* is a manometer in which the measured pressure is balanced by the pressure of the piston mass with the load receiving device and the load, taking into account the forces of liquid friction. Such devices are used as exemplary means of reproducing a unit of pressure in the range from 10^{-1} to 10^{13} Pa, as well as for accurate pressure measurements in laboratories.

Fig. 4.7. Load piston gauge

➢ **Spring gauges**, where the measured pressure is judged by the degree of deformation of an elastic element under pressure. An elastic element can be:

- Bourdon tube - sensors are made in the form of a tube filled with liquid and bent in a circular arc (usually 250° angle). Under the influence of applied pressure, the tube straightens. The arrow of the manometer moves according to the deformation of the tube. When measuring high pressures, the tube is made of a helical or spiral design. The measuring range of such devices is from 10 Pa to 1000 MPa.
- Elastic membrane - works similarly to the Bourdon tube, but in this case, the sensing element is a membrane whose deformation is directly proportional to the applied pressure. The range of measured pressures is from 0.0016 MPa to 4 MPa.
- Bellows sensor (Sylphon) is a thin-walled metal tube or chamber with a corrugated (wavy) side surface, the change in length of which with the change in pressure of the medium in the chamber indicates the pressure value. The range of measured pressures is from 0.1 MPa to 60 MPa.

Fig. 4.8. Spring gauge

- **Electronic**, where electrical values such as electrical resistance, inductance, resonant frequency are measured and converted directly into pressure values using appropriate pressure sensors, widely used in automation systems.

Fig. 4.9. Electronic manometers

Today, in addition to traditional pressure measuring devices, the industry uses more sophisticated systems (mechanical or electronic). The advantage of electronic devices is the digital information and the features to interact directly with microprocessor-based control systems.

- **Micromanometers.**

The design of this device is based on the principle of coupled vessels, one of which is made in the form of a tank or cylinder and the other in the form of a conventional glass tube. A higher accuracy and expanded measurement range of micromanometers is achieved due to a significant difference in the volumes of these «vessels» - with a small change in the liquid level in the tank or cylinder, the liquid level in the tube changes very significantly, which makes possible to record even small changes in air flow pressure.

The change in the angle of the tube allows increasing the versatility of the device when measuring different pressures. The mobility of the tube is ensured in two ways: the first - the tube is attached to the cylinder of the device and changes its position simultaneously with it, this principle is implemented in devices of the CAGI design, the second - the tube is attached to the cylinder by means of a hinge, which makes it possible to change its angle of inclination, while the reservoir remains stationary. This principle is used in MMN devices.

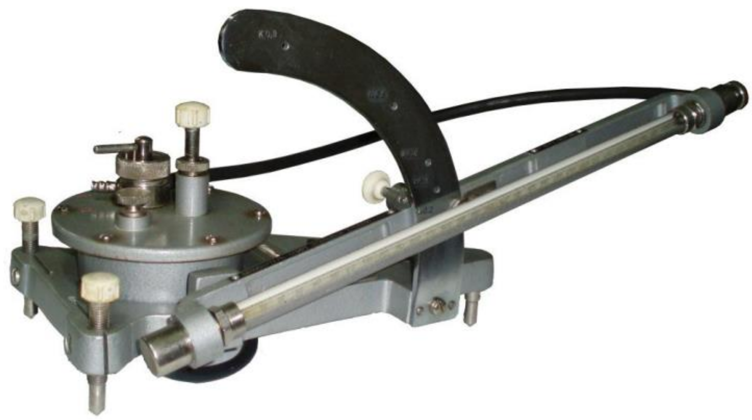


Fig. 4.10. Micromanometer

➲ Measurement of air velocity (mobility) in air ducts, rooms, air vents, ventilation grilles

Anemometer is an instrument for measuring the velocity and direction of air, gases and liquids. This applies to both flows in confined spaces, such as air movement in ducts, and flows in unconfined ones, such as atmospheric wind. Anemometers are primarily used for meteorological purposes, as changes in parameters such as wind speed and direction indicate changes in weather conditions. They warn of an approaching thunderstorm, storm, or other dangerous natural phenomena, which is very important for pilots, sailors, engineers, and for all of us. As a rule, these are lightweight portable devices that are easy to use even in difficult field conditions.

The principle of operation of an anemometer is to detect a change in some physical property of the flow, or the flow impact on a mechanical device placed in the flow. An anemometer can measure the total velocity, in-plane velocity, and velocity component in a particular direction. In addition, modern anemometers, depending on the model, can measure wind direction, air volume flow, humidity, temperature, and pressure. Thus, anemometers turn into portable weather stations.

Types of anemometers

Depending on the measurement method and the type of receiving device, anemometers are divided into the following types:

- Rotating (impeller, cup)
- Thermal
- Vortex
- Dynamometric (with Pitot tubes)
- Ultrasonic (acoustic)
- Optical (laser doppler)

➢ The most common are **rotary anemometers**, which differ in the type of receiving device (cup or impeller):

In <u>cup</u> anemometers, the sensing element is a crosspiece with four hemispherical metal cups that are fixed on an axis. If this device enters the flow, the air pressure on the inner surface of the cup exceeds the pressure on its outer surface, which causes the blade to rotate. The axis of the blade is connected to a measuring mechanism that counts the number of rotations over a certain period of time. Thus, cup anemometers measure the flow velocity in a plane perpendicular to the axis of rotation of the cups, either instant or average over a period of time. Cup anemometers are mainly used in meteorology for measurements in open areas, as they have a certain resistance to turbulent flows. The measuring range of cup anemometers is from 1 to 50 m/s.

Fig. 4.11. Cup anemometer

Impeller anemometers are used to measure flow velocities in pipes, ventilation shafts and ducts, in air conditioning systems, i.e. in cases where we are dealing with a constant direction of flow. These anemometers are more sensitive and can measure velocities from 0.1 m/s. The receiving device has the form of an impeller, which is driven by the gas flow. The impeller is attached to a tubular axis, which in turn is connected to a mechanism for counting rotations over a certain period of time. In simple models, the impeller is rigidly connected to the measuring unit, in other models it is connected with a flexible connection for measurements in hard-to-reach places.

Fig. 4.12. Impeller anemometer

➢ **Thermal** anemometers are less common but very accurate.

They are mainly used to measure the velocity of slow flows. They are characterised by low inertia but require constant calibration. The principle of operation of a thermal anemometer is to measure the temperature of a plate or filament which the wind blows on. Depending on the wind speed, different energy is required to keep the temperature constant. Therefore, the wind speed can be determined due to the plate temperature.

The air velocity can also be measured by determining the air pressure inside a glass L-shaped tube closed at one end. This is called a Pitot tube, in honour of its inventor. The velocity of the air is calculated by comparing the overpressure of the air inside and outside the tube. It is used to determine the relative velocity and volume flow rate in gas ducts and ventilation systems. They are so-called **dynamometric** anemometers.

The principle of operation of an **ultrasonic** anemometer is based on measuring the speed of sound between the transmitter and receiver depending on the wind speed. These are highly accurate modern anemometers that are also designed to measure wind direction. There are two-dimensional and three-dimensional ultrasonic anemometers. A two-dimensional anemometer can measure the speed and direction of horizontal air flows only. A three-dimensional anemometer can measure three components of the flow direction. In addition, an ultrasonic anemometer can measure air temperature using the ultrasonic method.

➲ **Measurement of indoor humidity**

Air humidity is determined by:

- moisture emission from household processes (cooking, washing and drying clothes, etc.), people;

- technological processes, i.e. the release and absorption of moisture in the production of products by the enterprise;

- ambient air humidity;

- building enclosures.

The mass of water vapour contained in a unit (1 m^3) of air is called absolute humidity, denoted by D and measured in kg/m^3.

Saturation of water vapour influence the increase in absolute humidity.

Such air is called saturated air, and the absolute humidity in this state is maximum.

As can be seen from the definition, the concept of absolute humidity is identical to the concept of water vapour volume mass P_p, which has the same unit of measurement (kg/m^3) and is numerically equal to the volume weight of water vapour $\gamma_п$, kg/m^3.

The inverse values of the volume weight of water vapour of unsaturated and saturated air are known as specific volumes.

Relative humidity characterises saturation degree of air with water vapour, i.e. it can be determined from the ratio of the previously mentioned values.

The mass of an air column throughout the entire thickness of the atmosphere with a unit area of 1 cm creates atmospheric pressure, often referred to as barometric pressure. Air humidity creates a barometric pressure equal to the sum of the partial pressures of dry air and water vapour, mmHg (kg/cm^2):

$$B = P_в = P + P_п \tag{4.1}$$

The partial pressure of water vapour P_p is commonly referred as its elasticity and is denoted by *e*. The elasticity of water vapour is characteristic of air humidity because it varies in proportion to the barometric pressure. At a constant temperature of changing air pressure and humidity, the elasticity of water vapour *e* can increase or decrease. The increase in elasticity depends on saturation of air with water vapour. In this case, it is called the maximum elasticity of water vapour and is denoted by E.

Therefore, relative humidity:

$$\varphi = \frac{D \cdot 100}{D_{max} \frac{\gamma_n \cdot 100}{\gamma_h} \frac{\rho_n \cdot 100}{\rho_h} \frac{V_n \cdot 100}{V_h} \frac{P_n \cdot 100}{P_h} \frac{e_n \cdot 100}{E}} \quad (4.2)$$

where $D, \gamma_n, \rho_n, V_n, P_n, e$ - are, respectively, absolute humidity, volume weight, volume mass, specific volume and partial pressure (or elasticity) of water vapour of unsaturated air;

$D_{\max}, \gamma_h, \rho_h, V_h, P_h, E$ - respectively, the same parameters of saturated air.

Humidity can be measured with hygrometers, hygrographs and psychrometers.

➢ **Гігрометр** вимірює вологість за рахунок зміни довжини пучка знежиреного волосся, яка передається через систему важелів на стрілку приладу, тобто це прилад що показує.

➢ A **hygrometer** measures humidity by changing the length of a bundle of defatted hair, which is transmitted through a system of levers to the hand of the device, i.e. it is a reading device.

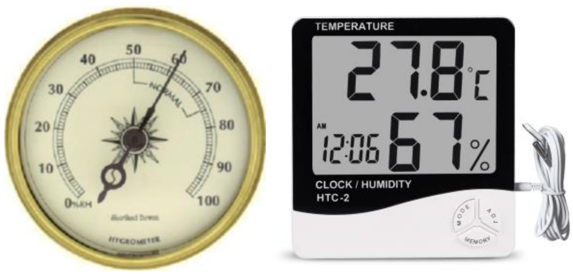


Fig. 4.13. Hygrometer

➢ A **hygrograph** works on the same principle, but the readings are transmitted to a continuously rotating drum, i.e. this device is a fixing one.

Fig. 4.14. Hygrograph

- Most often, relative humidity is measured with **psychrometers**.

This device consists of two thermometers (mercury or alcohol). There is a bottle of distilled water between them, which has a cup at the bottom and placed under one of the thermometers. The reservoir of this thermometer, called «wet», is wrapped with thin material (batiste or gauze) so that its lower part, hanging freely by 15...20 mm, is in water. The thermometer reservoir is located 2...3 mm above the water level.

The second thermometer, called «dry», shows the temperature of the surrounding air. The wet thermometer is affected by the evaporation of moisture from the surface of its reservoir, which results in heat loss. There is a difference between the readings of both thermometers, called the psychometric temperature difference. The drier the air, the more intensively moisture evaporates, and the greater the psychrometric temperature difference is. At a relative humidity of $\varphi = 100\%$, when there is no evaporation from the surface of the wet thermometer, the temperature will not decrease and will be the same in both thermometers. Therefore, the psychrometric temperature difference can be used to judge about the relative humidity of the air.

When the fan is running, air is sucked into the device, which flows around the thermometer reservoirs, passes through the tube to the fan and is discharged through the slots. At the moment of measurement, the thermometer tanks are in an air flow moving at a certain speed V, which is constant under any measurement conditions.

Fig. 4.15. Psychrometers

➢ A **mechanical** or ceramic moisture meter works by using the electrical resistance. Since the ceramic mass contains silicon and kaolin with metal particles, the mixture changes resistance as the air humidity changes.

Fig. 4.16. Mechanical moisture meter

As a result, the arrow on the device changes position with different vapour content, showing the humidity.

This mechanism allows ceramic devices to be compact, they are in demand for measuring air humidity at home.

➢ An **electronic** or room hygrometer is a modern high-speed device to measure the humidity in a room. It has the following features:

- measurement of the electrical conductivity of the ambient air;
- optoelectronic method, with dew point measurement;
- measurement of the electrical conductivity of the ambient air;
- optoelectronic method with dew point measurement;
- measurement of electrical resistance of polymers and salts;
- analysis of condensate capacity.

A digital moisture meter operates with the help of microcircuits, so calculations are carried out within a few seconds, and the output data has a minimum error.

Fig. 4.17. Electronic hygrometer

An electronic hygrometer provides accurate readings from are possible in the absence of drafts. Some models may have fluctuations of up to 2 m/s. Thus, it is necessary to read the technical documentation.

When measuring air humidity with this type of device, the ambient temperature must be taken into account. The slightest deviation from steady-state conditions affects the final readings, so the street door should be closed for 15 minutes before the measurement.

In addition to temperature fluctuations, the proximity to heaters affect the devices. Therefore, when placing hygrometers of any type, take into account the proximity of radiators and place them on the opposite wall or table located at a considerable distance from the heaters.

Meteorological conditions in the room

From a hygienic point of view, human well-being and performance are largely determined by temperature, humidity and air velocity.

Temperature characterises the degree of heating of the environment.

Indoor air humidity is caused by the following reasons: outdoor air humidity; moisture emission by people in the room; household and technological moisture emissions. Humidity can be absolute and relative. Absolute humidity D is the mass of water vapour contained in 1 m^3 of humid air, kg/m^3.

From the characteristic level, we obtain:

$$D = \frac{Ph}{RhT}, \qquad (4.3)$$

Knowing the partial pressure of water vapour and its temperature, you can determine the absolute humidity in the room at

$R_h = 470\ Pa{\cdot}m^3/(kg{\cdot}K)$

The ratio of the partial pressure P_h of water vapour in humid air to the partial pressure P_s of water vapour in saturated humid air at the same temperature is called relative humidity:

$$\varphi = \frac{P_h}{P_s} \cdot 100\% \qquad (4.4)$$

The pressure of water vapour in the saturated state P_s, Pa, for positive temperatures:

$$P_s = 479 + (11{,}52 + 1{,}62{\cdot}t_c)^2 \qquad (4.5)$$

where: t_c – air temperature (according to the readings of a «dry» thermometer), °C.

According to Dalton»s law, the total pressure of a mixture is equal to the sum of the partial pressures of several gases that make up the mixture. Because humid air is a vapour-air mixture, the total pressure of atmospheric air or barometric pressure is equal to the sum of the partial pressures of its dry part P_d and water vapour P_h:

$$P_b = P_d + P_h \qquad (4.6)$$

If humid air is cooled, depending on the water vapour content, condensation and moisture loss will occur when it reaches a certain temperature. The temperature at which the vapours in the air condense is called the dew point.

It known that under normal humidity and air mobility, the temperature of the surface of the enclosures has a significant impact on human health. The state of thermal comfort in a room is the result of the ratio between the ambient air temperature and the average temperature of the internal surfaces of the enclosures.

The average surface temperature of a room is commonly referred to as the radiation temperature. It is related to the radiant heat transfer in the room and depends on the size and surface temperature of the individual enclosures:

The average surface temperature of a room is commonly referred to as the radiation temperature. It is related to the radiant heat transfer in the room and depends on the size and surface temperature of the individual enclosures:

$$t_{\text{rad}} = \frac{(t_{\text{h}} \cdot f_1) + \dots + (t_{\text{h}} \cdot f_n)}{f_1 + \dots + f_n} \qquad (4.7)$$

where: f_i, $t_{вп}$ – area and temperature of the internal building enclosures.

The average radiation temperature that ensures a normal human thermal state in a room is determined by the formula:

$$t^{н}_{rad} = 29 - 0{,}5 \cdot t_c \qquad (4.8)$$

Testo devices for ventilation monitoring are known for their accuracy, reliability and innovative solutions. They are used to measure various air parameters and the efficiency of ventilation systems.

The main types of Testo devices used for monitoring ventilation systems:

1. **Testo 435** is a multifunctional device for measuring indoor climate parameters, as well as monitoring and adjusting supply and exhaust ventilation and air conditioning systems.

The IAQ (indoor air quality) indicator is used to characterise the air quality in rooms equipped with ventilation and air conditioning systems. According to this indicator, air quality is assessed not only by such parameters as temperature, humidity and air flow rate. It is very important to have information about CO_2, light and noise levels. Only in combination these parameters characterise how comfortable the indoor microclimate is.

With the Testo 435 device, you can measure almost all of the above mentioned parameters and monitor HVAC systems. A wide range of professional probes for the device allows solving almost any measurement task to analyze indoor air. For example, using a spherical probe and an IAQ probe, you can assess the comfort of the temperature regime, measure CO_2, temperature, absolute pressure and humidity. The pre-installed standard measurement programmes, or profiles, can be used for the most common tasks, such as measurements on ventilation grilles or IAQ.

The availability of ready-made profiles significantly speeds up the preparation of the measurement programme.

- Wide choice of probes, probe (IAQ), anemometer probes, thermoanemometers, wireless temperature and humidity probes
- Two connectors to connect probes
- Simple measurement programmes
- Large backlit display
- Software for analysing, archiving and data documentation

Fig. 4.18. Multifunctional device - ***Testo 435***

The device is unique because all the parameters required to maintain excellent indoor air quality through heating, ventilation and air conditioning (HVAC) systems are measured by a single device - Testo 435.

All devices have the option to connect wireless radio probes for measuring temperature or temperature and humidity.

It is used to measure:

✓ air velocity in a room, duct or exhaust pipe, using an impeller probe, a thermoanemometer probe and a Pitot tube with automatic averaging and calculation of the volume flow rate;

✓ indoor and duct humidity with automatic dew point calculation;

✓ concentrations of CO and CO_2 in enclosed spaces;

✓ velocities of air movement through the layers in a room.

Brief technical data:

- Temperature -200...1370 °C;
- Air velocity - 0...60 m/s;
- Relative humidity - 0...100%;
- Differential pressure - 0...25 mBar;
- Absolute pressure - 0...2 atm;
- CO_2 concentration in the air - 0...10 000 ppm;
- CO concentration in the air - 0...500 ppm;
- Illuminance- 0...100 000 lux.

Parameters to be calculated:

- Air volume flow rate
- Air density

Other data:

- Operating temperature - -20...+50°C

The Testo 435 device can be used with wireless temperature and humidity probes up to 20 metres. Up to 2 wired and 3 wireless probes can be connected simultaneously to the device. The measured data is stored in the device memory and can be transferred to a PC for processing, archiving and reporting.

2. Digital thermohygrometer with Bluetooth - Testo 605i.

A distinctive feature of Smart probes is the absence of a display. A smartphone or tablet with a touchscreen display is used to display and process the data measured.

Data is transferred from the Smart probes to the smartphone/tablet via Bluetooth wireless communication using the free Testo Smart probes App, which is available for Android and Apple IOS. Up to 6 Smart probes can be connected to one mobile device simultaneously.

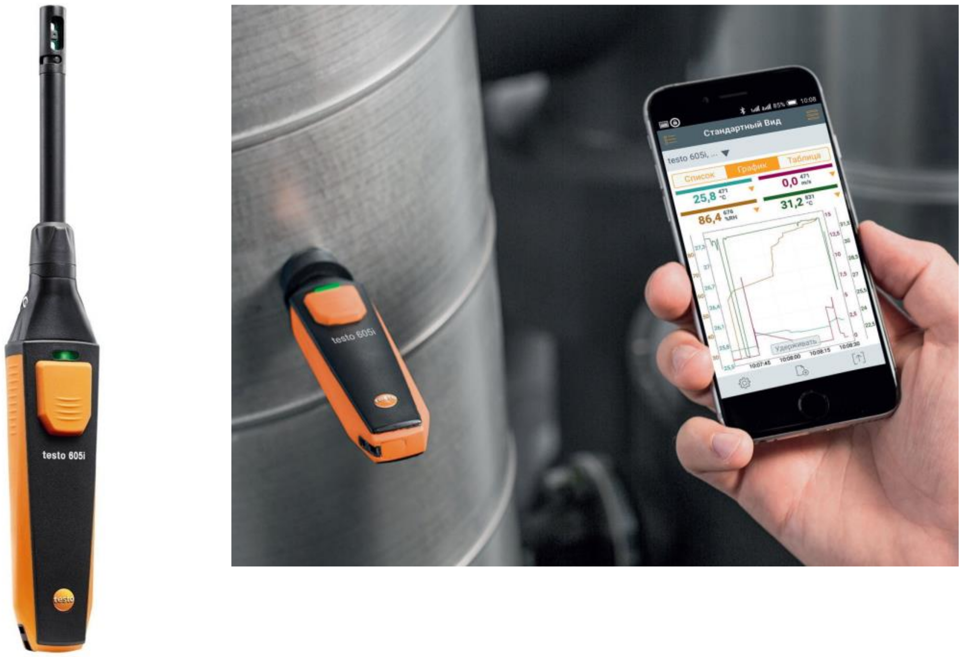


Fig. 4.19. ***Testo 605i*** *digital thermohygrometer with Bluetooth*

The Testo 605i digital thermohygrometer is one of the Testo Smart probe series - professional measuring instruments designed to work with Android or Apple IOS smartphone or tablet. To use the industrial hygrometer, you need to install the free Testo Smart App on your tablet or smartphone.

It is used to measure humidity and temperature in rooms and ventilation ducts with data transmitted to a smartphone. It can rotate the probe at 45° and 90°.

Brief technical data:

- ❖ Temperature - -20 ... +60 °C;
- ❖ Humidity - 0 ... 100 %;
- ❖ Accuracy:

- temperature - ±0.5 °C (0 ... +60 °C); ±0.8 °C (-20 ... 0 °C);

- humidity - ±2 %; (35 ... 65 %); ±3 % (10 ... 35 %, 65 ... 90 %); ±5 % RH (in the rest of the range)

The data from the Testo 605i digital hygrometer are transferred to a smartphone or tablet via Bluetooth at a distance of up to 100 m (depending on the smartphone model). Using the App, you can view the measured data on the display of your mobile device, create graphs and tables, and send the measurement results by email in Excel or PDF.

The Testo 605i portable thermo hygrometer is equipped with a probe that can be rotated at a 45 or 90°angle. This allows the device to be used in measurement locations with limited space. For example, in air ducts close to a wall.

The Testo 605i thermohygrometer automatically calculates the dew point and wet bulb temperature.

Up to 6 of any Testo Smart probes can be connected to one smartphone/tablet at the same time - six Testo 605i smart thermohygrometers or a combination of them with other Testo Smart Probes. For example, the Testo 605i device in combination with the Testo 405i thermoanemometer allows you to determine the efficiency of your heating/cooling system, and in combination with the Testo 805i pyrometer, you can identify areas at risk of mould and mildew.

In addition, the Testo 605i digital hygrometer can communicate with the Testo 550s and Testo 557s series of pressure manifolds and the Testo 440 and Testo 400 multifunctional anemometers.

The Testo 605i digital hygrometers are used to measure relative humidity, temperature and dew point in rooms and in the ventilation ducts of HVAC systems.

The Testo 605i portable hygrometer is a part of the Testo Smart Probe Kits for HVAC systems.

3. **Testo 915i** digital thermometer with air probe with Bluetooth, data transfer to smartphone, connectivity with other temperature probes.

The Testo 915i smart thermometer with interchangeable probes makes temperature measurement even faster, easier and more flexible. Due to its innovative attachment mechanism, which is compatible with all K-type thermocouples, the smart thermometer can be used in a wide variety of applications.

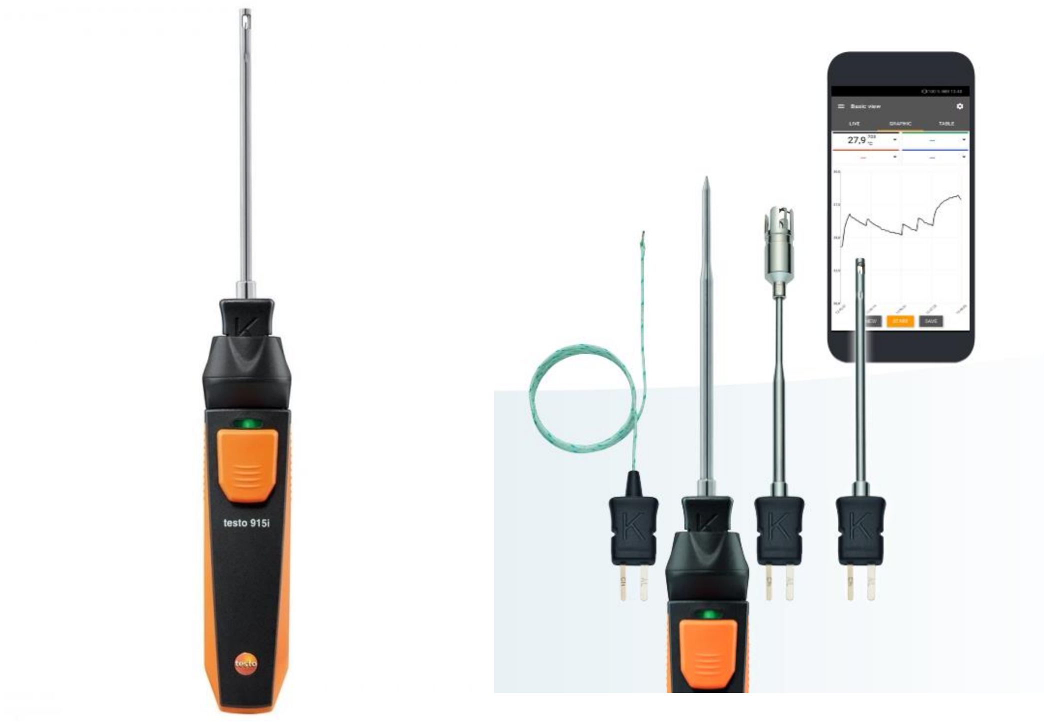


Fig. 4.20. ***Testo 915i*** *digital thermometer*

The Testo 915i smart thermometer with air probe is ideal for measuring ambient air temperature, temperature in air ducts or ventilation grilles. The Testo 915i wireless thermometer with robust, fast-response air probe allows taking daily temperature measurements with higher speed, flexibility and ease.

It is used to measure:

✓ ambient air temperature, temperature in air ducts or on ventilation grilles.

Brief technical data:

❖ Measuring range -50 ... +400 °C;

❖ Accuracy - ±1 °C (-50 ... +100 °C); ±1 % of the measured value (in the rest of the range);

❖ Operating temperature - -20 ... +50 °C.

The Testo 915i digital thermometer is designed for use with Android or IOS smartphone or tablet. To use the digital thermometer, you need to install the free Testo Smart App on your tablet or smartphone. Data from the device is automatically transferred to the smartphone or tablet via Bluetooth. The wireless data transmission range is up to 100 m, depending on the ambient conditions and the smartphone model.

The data measured is displayed in the App as values, table or graph. With the help of the App, you can create a professional digital report on the measurement results and send it by email.

For comprehensive measurements, the Testo 915i industrial thermometer can transfer measured data via Bluetooth to the Testo 550s, 550i and 557s smart manifolds as well as the Testo 440 and Testo 400 multifunctional devices.

The Testo 915i Smart thermometer has an innovative modular design: the device consists of a Bluetooth handle and an interchangeable probe. This allows you to add additional temperature probes and extend the range of applications according to your individual needs.

4. **Testo 405i** thermoanemometer with telescopic probe.

Smooth and efficient operation of ventilation and air conditioning systems help maintain high-quality indoor air. This requires regular monitoring measurements and, if necessary, system adjustments. For example, low air volume flow in air ducts detected during measurements indicates insufficient supply of fresh air and inefficient removal of old.

Fig. 4.21. Testo 405i thermoanemometer with telescopic probe

The Testo 405i thermoanemometer is a part of the Testo Smart probe series - professional measuring devices designed to work with Android or Apple IOS smartphone or tablet. To use the thermoanemometer, you need to install the free Testo Smart App on your tablet or smartphone.

It is used to measure:

- ✓ air velocity, temperature and volume flow rate.
- ✓ The retractable telescopic probe allows you to measure velocity and temperature both in rooms and in ventilation ducts.
- ✓ In combination with the Smart Probe - Testo 605i thermohygrometer, the Testo 405i thermoanemometer is used to evaluate the efficiency of heating and cooling systems.

Brief technical data:

- ❖ Speed - 0 ... 30 m/s;
- ❖ Temperature - -20 ... +60 °C;

- ❖ Operating temperature - -20 ... +50 °C;
- ❖ Accuracy:

- speed - ±0.1 m/s ± 5 % of the measured value (0 ... 2 m/s); ±0.3 m/s ± 5 % of the measured value (2 ... 15 m/s); ±0.5 m/s ± 5 % of the measured value (15 ... 30 m/s);

- temperature - ±0.5 °C.

The data from the Testo 405i thermoanemometer are transferred to a smartphone/tablet via Bluetooth at a distance of up to 15-20 m (depending on the smartphone model). Using the App, you can see the measured data on the display of your mobile device, create graphs, tables and send the measurement results by email in Excel or PDF.

In the Testo Smart app, you can set the duct cross-sectional parameters to calculate the volume flow rate and automatically calculate the average value over time or over the number of measurements.

Up to 6 of any Testo Smart probes can be connected to one smartphone/tablet simultaneously. These can be Testo 405i thermoanemometers only or in combination with other Testo Smart probes.

The Testo 405i thermoanemometers are used to measure air velocity, temperature and volume flow rate. The retractable telescopic probe helps measure velocity and temperature both in rooms and in ventilation ducts. When paired with the Testo 605i Smart Probe, the Testo 405i thermoanemometer is used to evaluate the efficiency of heating and cooling systems.

5. **Testo 410i** vane anemometer

Accurate measurement of air flow rate and volume flow rate is a challenge in many cases. This is particularly relevant when measuring the volume flow rate on ventilation grilles and diffusers. Turbulent flows are created on the grilles, which significantly affect the measurement accuracy. To ensure high accuracy in volumetric flow rate measurements, Testovent funnels are the solution.

Fig. 4.22. ***Testo 410i*** vane *anemometer*

The Testo 410i anemometer with 40 mm diameter vane is a part of the Testo Smart probe series - professional measuring instruments designed to work with Android or Apple IOS smartphone or tablet. To use the anemometer, you need to install the free Testo Smart App on your tablet or smartphone.

✓ It is used for non-wireless measurement of air velocity, temperature and volume flow rate.

✓ In the Testo Smart App, you can set the duct cross-sectional parameters for calculating the volume flow rate and automatically calculate the average value over time or over the number of measurements.

✓ In the app, the display of the volume flow rate across multiple ventilation grilles allows you to quickly assess the efficiency of your ventilation and air conditioning systems.

Brief technical data:

❖ Speed - 0.4 ... 30 m/s;

❖ Temperature - -20 ... +60 °C;

❖ Operating temperature - -20 ... +50 °C;

❖ Accuracy:

- Speed - ±0.2 m/s ± 2 % of the measured value (0.4 ... 20 m/s);
- temperature - ±0.5 °C.

The data from the Testo 410i anemometer are transferred to a smartphone/tablet via Bluetooth at a distance of up to 15-20 m, depending on the smartphone model). Using the App, you can see the measured data on the display of your mobile device, create graphs, tables and send the measurement results by email in Excel or PDF.

The Testo Smart App allows you to set duct cross-sectional parameters to calculate the volume flow rate and automatically calculate the average value over time or over the number of measurements. The display of the volume flow rate across multiple ventilation grilles allows you to quickly assess the efficiency of your ventilation and air conditioning systems.

Up to 6 of any Testo Smart robes can be connected to one smartphone/tablet simultaneously. These can be Testo 410i vane anemometers only or a combination of them with other Testo Smart probes.

6. **Testo 805i** industrial pyrometer with Bluetooth

In combination with a Bluetooth smartphone or tablet, the Testo 805i pyrometer functions as a compact device for measuring the surface temperature of walls or individual components of various systems. For example, air conditioning systems. The measuring area is precisely delineated by a laser marker in the form of a circle. The user can see the measured data on a smartphone or tablet screen using the App.

Fig. 4.23. Testo 805i industrial pyrometer with Bluetooth

- ✓ It is used for non-contact measurement of the temperature on surfaces in rooms and on components of heating or air conditioning systems;
- ✓ It refers to the Testo Smart probe series - professional measuring devices designed to work with a smartphone or tablet based on Android or Apple IOS.
- ✓ To use a digital pyrometer, it is necessary to install the free Testo Smart App on your tablet or smartphone.

Brief technical data:

- ❖ Measuring range -30 ... +250 °C;
- ❖ Operating temperature - -10 ... +50 °C;
- ❖ Accuracy:

±1.5 °C or ±1.5 % of the measured value (0...+250 °C);

±2 °C (-20...-0.1 °C);

±2.5 °C (-30...-20.1 °C).

The portable pyrometer features 10:1 optics for temperature measurements up to 5 m away and an eight-point circle laser marker for precise measurement coverage. The Testo 805i electronic pyrometer has a manual emissivity input function for highly accurate measurements. Alternatively, the emissivity can be selected from a list of different materials saved in the App.

The data from the Testo 805i infrared thermometer are transferred to a smartphone or tablet via Bluetooth over a distance of up to 15-20 m, depending on the smartphone model. In the App on your mobile device, you can view the measured data as graphs or tables. Using the App, you can generate a digital report of the measurement results in Excel or PDF and send it by email. The Testo Smart App allows you to attach a photo of the object taken with your smartphone to the report, showing the laser marker and the measured temperature.

Up to 6 Testo Smart probes can be connected to one smartphone or tablet simultaneously - 6 Testo 805i industrial pyrometers or pyrometers in combination with other Testo Smart probes. In combination with the Testo 605i thermo hygrometer, the Testo 805i industrial pyrometer is used to measure surface moisture without contact and to identify areas of potential mould.

7. **Testo 510i** pocket-sized differential manometer with Bluetooth

The ventilation and air conditioning system must constantly maintain the specified microclimate parameters in the premises (in production halls, clean rooms, etc.). In addition, HVAC systems must meet strict hygiene standards, which requires constant monitoring of the filters. All these issues are effectively addressed by Testo differential pressure gauges and tachometers. With the help of differential pressure gauges, you can quickly and easily determine the degree of filter contamination by comparing the pressure values before and after the filter.

Fig. 4.24. ***Testo 510i*** *pocket-sized* differential *manometer with Bluetooth*

It is used to measure:

- ✓ draft in chimneys and ventilation ducts,
- ✓ natural gas pressure on boiler equipment,
- ✓ pressure drops on filters and fans,
- ✓ flow rates using a Pitot tube.

Brief technical data:

Measuring range -150...150 hPa;

Operating temperature - -20...+50 °C;

Accuracy:

±0.05 hPa (0...1 hPa)

±(0.2 hPa + 1.5 % of the measured value) (1...150 hPa)

The data from the Testo 510i differential manometer is transferred to a smartphone or tablet via Bluetooth at a distance of up to 15-20 m, depending on the smartphone model. Using the App, you can see the measured data on the display of your mobile device, create graphs and tables, and send the measurement results by email in Excel or PDF. A special menu in the App is designed to enter a critical or alarm pressure value and perform a pressure drop test.

До одного смартфона або планшета можна одночасно підключити до 6-ти будь-яких Смарт зондів Testo. Це можуть бути тільки дифманометри Testo 510i або їх комбінація з іншими Смарт зондами Testo.

The Testo 510i differential manometers are used to measure draft in chimneys and ventilation ducts, natural gas pressure in boiler equipment, differential pressure across filters and fans, and flow velocity with a Pitot tube. In addition, this device can exchange data with the Testo 440 and Testo 400 multifunctional anemometers.

4.7. Examples of using devices in practice

Testo devices are used in a wide variety of applications to provide precise measurement and control. Here are some examples of how they are used in practice.

1. Analysis of indoor climate, monitoring and adjusting HVAC systems. The Testo 435 device automatically selects the measurement menu depending on the connected probes, and allows you to set up measurement programmes for various tasks (measurements on grids, continuous long-term measurements, etc.).Due to a wide range of probes, such as air turbulence probe, all parameters affecting indoor air quality can be easily measured

Fig. 4.25. Measuring comfort with the Testo 435 device

Testo 435 USB driver program

Testo 435 flow meter instruction manual

2. Measurement of humidity and temperature in rooms and ventilation ducts, with data transfer to a smartphone, calculation of dew point and wet thermometer temperatures, and 45° and 90° probe rotation using the Testo 605i Bluetooth digital thermo hygrometer.

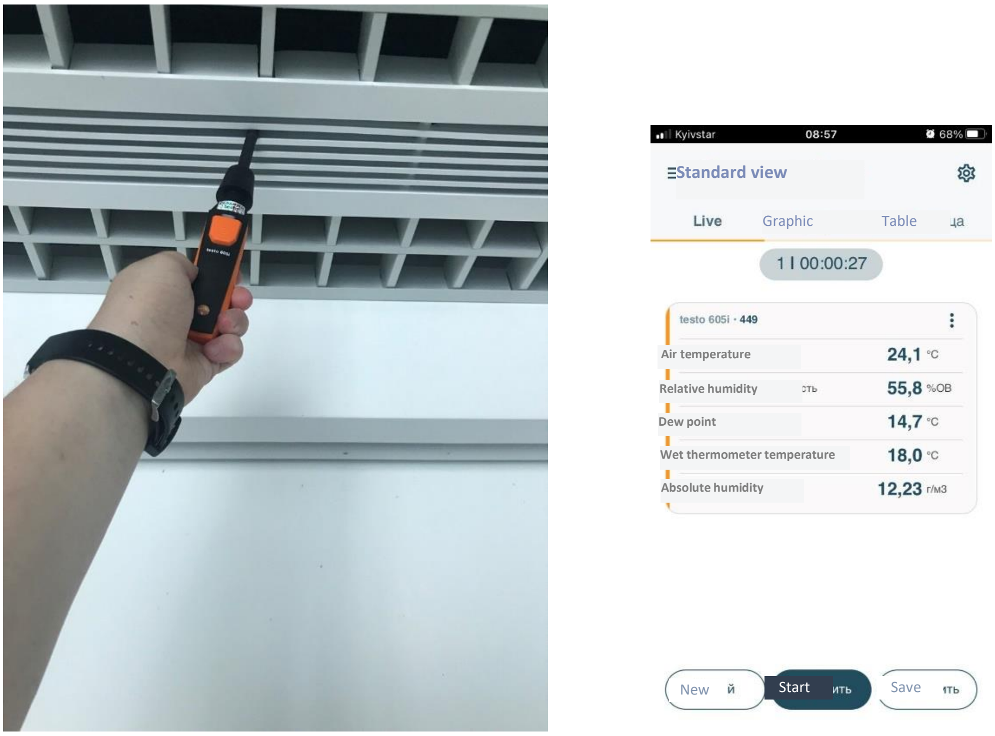


Fig. 4.26. Indoor humidity and temperature measurement with the Testo 605i digital thermohygrometer

[App for Testo 605i Smart Probes]

[User manual for the Testo 605i digital hygrometer]

3. Measurements in liquids, semi-solid and gel-like substances. Accordingly, the Testo 915i industrial digital thermometer has a wide range of applications, namely: measuring the temperature of process fluids, liquids, gels, grease, etc.

Fig. 4.27. Application of Testo 915i to measure substance temperature

App for Testo 915i Smart Probes

Instruction manual for digital thermometer Testo 915i

4. The Testo 405i Bluetooth thermoanemometer with telescopic probe is used to measure velocity, volume flow and temperature in rooms and ventilation ducts.

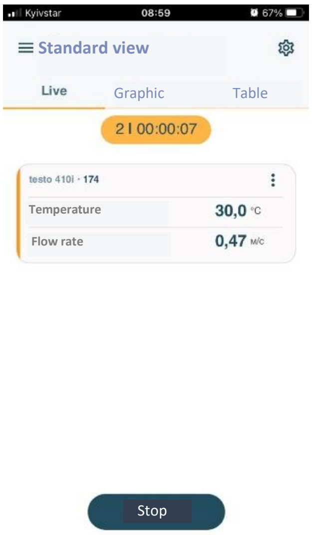
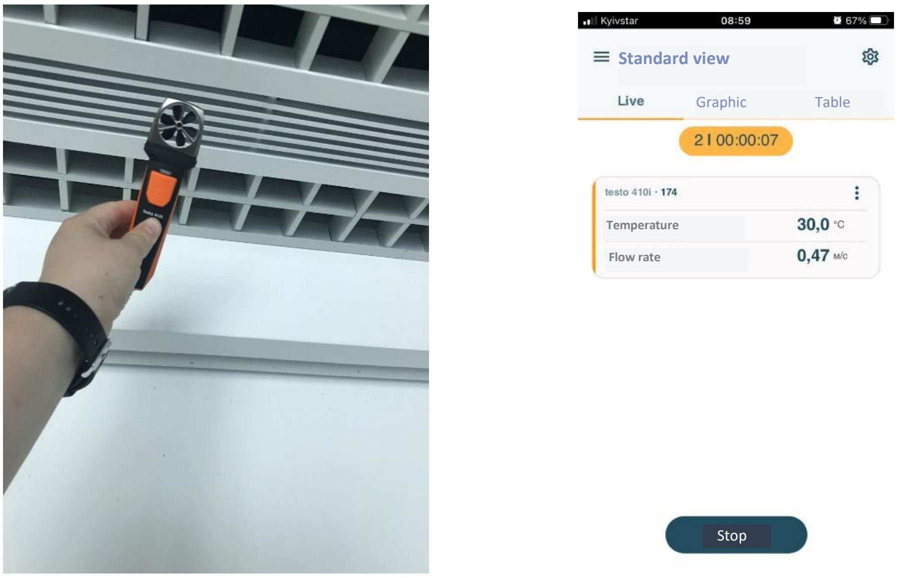


Fig. 4.28. Measurements with the Testo 405i thermoanemometer

App for Testo 405i Smart Probes

Testo 405i thermoanemometer instruction manual

5. The Testo 410i anemometer with a 30 mm vane is used to measure air velocity, volume flow and temperature in rooms and on ventilation grilles.



Fog. 4.29. Measurement of air velocity, volume flow and temperature in rooms and on ventilation grilles with the Testo 410i vane anemometer

[App for Testo 410i Smart Probes]

[User manual for the Testo 410i thermoanemometer]

6. For non-contact surface temperature measurement, with an 8-point laser marker, data transfer to a smartphone, and selection of emissivity from a list for different materials, the Testo 805i industrial mini pyrometer is used.

Fig. 4.30. Non-contact surface temperature measurement with the mini pyrometer Testo 805i device

[App for Testo 410i Smart Probes]

[User manual for the Testo 805i mini pyrometer]

7. The Testo 510i digital differential manometer with a magnet for metal surfaces is used to measure back pressure, gauge pressure and pressure drop.

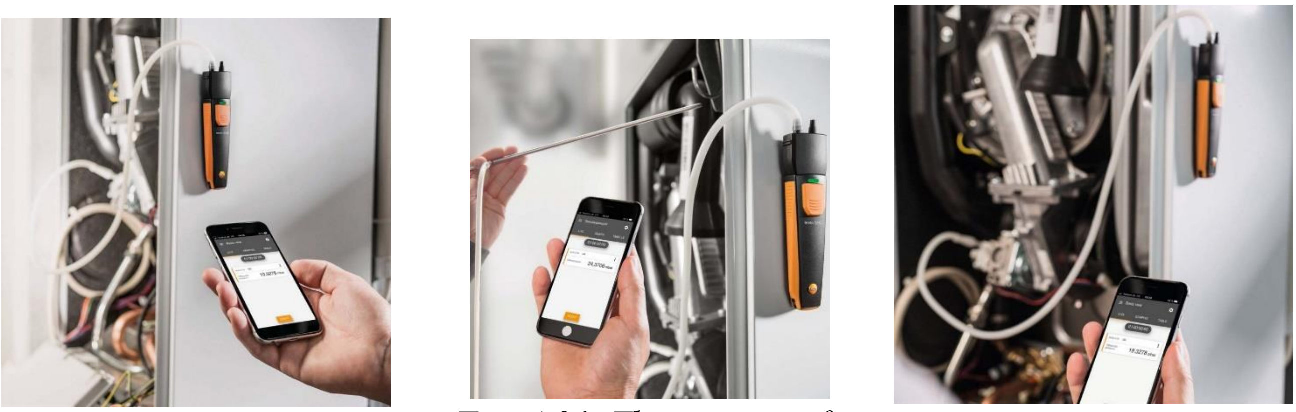


Fig. 4.31. The process of measuring backpressure, guage pressure and pressure drop with the Testo 510i differential manometer

[App for Testo 510i Smart Probes]

[User manual for the Testo 510i differential manometer]

4.8. Compliance report on inspected ventilation systems

The report on inspected ventilation systems is a document with the monitoring results of a ventilation system efficiency. It may include information on the condition of the ventilation ducts, air exchange efficiency and compliance with sanitary standards.

Key points to consider when drafting the report:

- ✓ Conformity check: the report (act) should reflect whether the ventilation system meets the established norms and standards.
- ✓ Duct inspection: it is important to inspect the smoke and ventilation ducts to ensure that they are safe and efficient.
- ✓ Certification: in order to obtain a permit to operate the premises, you may need not only a passport for the ventilation system, but also a certificate confirming its effectiveness.
- ✓ Regular inspection: the ventilation system should be inspected regularly, including automatic check valves.

The pre-assessment questionnaire is an important tool to ensure the efficiency and accuracy of the assessment process. There are several key benefits to use it:

- ✓ Collection of basic information. A questionnaire allows gathering preliminary information about the facility, ventilation system, its configuration, condition, and maintenance. This includes data on equipment types, dates of previous technical inspections, and problems or complaints available.
- ✓ Identification of problem areas. Potential problem areas that require special attention during monitoring can be identified by means of questionnaires. For example, complaints about air quality in specific rooms.
- ✓ Work planning: The collected data helps effectively plan the work of the team, prioritizing and allocating resources to the most critical areas.
- ✓ Assessment of compliance with norms and standards. The questionnaire may include questions about the ventilation system»s compliance with current norms and standards, which is important for ensuring safety and efficiency of its operation.

✓ Documentation and reporting. The results of the questionnaire can be used to document the current state of the system and create a report that will be useful for future inspections and maintenance.

✓ Communication with the customer. The questionnaire can help clarify the customer»s requirements and expectations, as well as identify specific needs or desires regarding the operation of the ventilation system.

The questionnaire helps systematize the approach to monitoring the ventilation system, ensure a comprehensive review, and increase overall operational efficiency.

Questionnaire sample is provided in Fig. 4.32.

After reviewing the results of the questionnaire, the contractor can proceed with a physical inspection of the building»s ventilation system and the preparation of an inspection report.

An inspection report of a ventilation system is a crucial part of the ventilation assessment process. The report should include all key aspects of the inspection and results to ensure complete and accurate documentation. A sample ventilation system inspection report is provided below (Figure 4.33).

A report will help to document the monitoring process in detail, ensure complete information, and facilitate further steps to improve the operation of the ventilation system.

QUESTIONNAIRE

Date (year, month, date)	
Full name of the object	
Type of the object	- office - industrial enterprise - residential house - other
Address	
Head Full name Tel e-mail	
Contact person Full name Tel e-mail	
Year of construction	
Total number of buildings on the site	
Co-owners/tenants of non-residential premises (if yes, please specify the list, availability of own energy metering units and purpose of premises (office, warehouse, production, etc.)	☐ Yes ☐ No If «Yes»: Office ☐ Warehouse ☐ Industrial☐ Commercial ☐ Other ☐______________________________

Information on the building and energy supply systems

Total floor area, m^2	
Heated floor area, m^2	
Total volume, m^3	
Heated volume, m^3	
Living area, m^2	
Non-living area, $м^2$	
Number of floors	
Number of entrances	

Floor height, м	
Number of residents/employees, people	
Number of apartments /rooms/ premises, pcs.	

Data on ventilation systems

Ventilation (according to the project)	- natural - exhaust - supply and exhaust (mixed)
Make and model of the main equipment	-
Availability of supply and exhaust unit	
Years in service	
Location of supply and exhaust unit (if any)	
Ventilation system operating hours	- 24h - in working hours - other
Air duct type	- round - rectangular
Location of air ducts	- on the ceiling - under the ceiling - other
Condition of air duct insulation	
Fans (number, capacity)	
Number of purification filters	
Date of last filter cleaning / replacement	
Date of the last monitoring / inspection / overhaul of the ventilation system	
The most important monitoring parameters	- temperature - humidity - CO_2 level
Complaints on air quality	- unsatisfactory smell - excessive humidity - dustiness
Any system failures fixed	-
If yes, measures taken to solve the problems	-

Condition/special features:

____

____

____

____

Fig. 4.32. Sample of a questionnaire

REPORT ON THE MONITORING OF THE BUILDING VENTILATION SYSTEM

Date of monitoring:____

Object of monitoring:____
address of the building inspected

____

Contractor:

- ____
  full name, position, company
- ____
  full name, position, company

Customer:

- ____
  company or client
- ____
  contact person, position, contact detaila

The purpose of the monitoring is to assess the condition of ventilation systems to ensure their proper functioning and compliance with applicable standards.

General information on the ventilation system

- Type of ventilation system: ________________________________
  mechanicak, natural, mixed
- Main equipment: ____________________________________
  make and model of equipment
- Service life of the system ________________________________
  years of operation
- Recent repairs/modernisations: ____________________________
  dates and description of the performed works

  ____

Technical parameters

- Air temperature: ____________________________________
  value, measurement unit
- Air humidity: ______________________________________
  value, measurement unit

- CO_2 level: ____
  value, measurement unit
- Other parameters: ____
  value, measurement unit

Operating conditions

- Opearion hours: ____
  24h, in working hours
- Description of operating conditions: ______________________
  notes on operating conditions

Monitoring results

- Compliance of parameters with standards: __________________
  list of relevant standards and deviations

  ____
- Problems: ____
  detailed description of problems, causes and consequences

  ____
- Assessment of the overall condition:_______________________
  good, satisfactory, unsatisfactory

6. Recommendations and measures

- Necessary measures to eliminate problems: _________________
  list of recommended actions, repairs, replacements

  ____

  ____
- Completion deadline: ______________________________________
  recommended term for implementing the measures
- Responsible person: _______________________________________
  contact details of responsible person

  ____

Signatures

Monitoring performed by:

- ____
  full name, position, signature, stamp
- ____
  full name, position, signature, stamp

Customer:

- ____
  full name, position, signature, stamp

Supplements

1. **Photos and schemes of ventilation systems**
2. **Copies of technical documentation**
3. **Measurement protocols**

This ventilation system monitoring report is drawn up in two copies, one for each of the parties, and shall come into force from the date of its signature.

Fig. 4.33. Sample of the report on the monitoring of the building ventilation system

QUESTIONNAIRE

Date (year, month, date)	10.07.2024
Full name of the object	Office of Climatech company
Type of the object	- **Office** - industrial enterprise - residential house - other
Address	Dnipro, Naberezhna Zavodska 44
Head Full name Tel e-mail	
Contact person Full name Tel e-mail	Havryliuk Serhiy Viktorovych
Year of construction	2018
Total number of buildings on the site	1
Co-owners/tenants of non-residential premises (if yes, please specify the list, availability of own energy metering units and purpose of premises (office, warehouse, production, etc.)	☐ Yes ☐ **No** If «Yes»: Office ☐ Warehouse ☐ Industrial☐ Commercial ☐ Other ☐____________________

Information on the building and energy supply systems

Total floor area, m^2	150
Heated floor area, m^2	150
Total volume, m^3	420
Heated volume, m^3	420
Living area, m^2	-
Non-living area, $м^2$	150
Number of floors	1
Number of entrances	1

Floor height, м	2.8
Number of residents/employees, people	up to 25 people
Number of apartments /rooms/ premises, pcs.	9

Data on ventilation systems

Ventilation (according to the project)	- natural - exhaust - **supply and exhaust (mixed)**
Make and model of the main equipment	SALDA Smatry XP/RIS XP
Availability of supply and exhaust unit	yes
Years in service	4 years
Location of supply and exhaust unit (if any)	
Ventilation system operating hours	- 24h - **in working hours** - other
Air duct type	- round - rectangular
Location of air ducts	- on the ceiling - **under the ceiling** - other
Condition of air duct insulation	new
Fans (number, capacity)	2 , each for 100 m^3
Number of purification filters	2 filters in air supply and exhaust systems
Date of last filter cleaning / replacement	10.01.2024
Date of the last monitoring / inspection / overhaul of the ventilation system	10.06.2023
The most important monitoring parameters	- **temperature** - **humidity** - **CO_2 level**
Complaints on air quality	- unsatisfactory smell - excessive humidity - dustiness
Any system failures fixed	No
If yes, measures taken to solve the problems	-

Condition/special features: The supply and exhaust system with heat recovery is operating in regular mode, no malfunctions of the system and equipment have been recorded.

Fig. 4.34. Example of filling in the questionnaire

REPORT ON THE MONITORING
OF THE BUILDING VENTILATION SYSTEM

Date of monitoring: 10.07.2024

Object of monitoring: Office of Climatech company
Dnipro, Naberezhna Zavodska, 44
address of the building inspected

Contractor:

- Climatech company
  full name, position, company
- Havryliuk Serhiy Viktorovych
  full name, position, company

Customer:

- ____________________
  company or client
- ____________________
  contact person, position, contact detaila

The purpose of the monitoring is to assess the condition of ventilation systems to ensure their proper functioning and compliance with applicable standards.

General information on the ventilation system

- Type of ventilation system: mixed, supply and exhaust with recuperation
  mechanicak, natural, mixed
- Main equipment: SALDASMARTYXP/RISXP
  make and model of equipment
- Years in service 4
  years of operation
- Recent repairs/modernisations: Flexible air ducts and external ventilation
  dates and description of the performed works

  grilles were replaced a year ago

Technical parameters

- Air temperature: ____________________20-22 ºC___________________________
  value, measurement unit
- Air humidity: ______________________55-60%___________________________
  value, measurement unit
- CO_2 level: ____________________________568___________________________
  value, measurement unit
- Other parameters: ____
  value, measurement unit

Operating conditions

- Opearion hours: ____________________in working hours __________________
  24h, in working hours
- Description of operating conditions: no special conditions for the operation of supply and exhaust unit.
  notes on operating conditions

Monitoring results

- Compliance of parameters with standards: Indoor air temperature, humidity, and CO2 levels are within the regulatory limits according to DBN____
  list of relevant standards and deviations
- Problems: The system has slightly clogged external ventilation grilles
  detailed description of problems, causes and consequences
- Assessment of the overall condition:________________Good______________
  good, satisfactory, unsatisfactory

6. Recommendations and measures

- Necessary measures to eliminate problems: External ventilation grilles must be cleaned
  list of recommended actions, repairs, replacements

Completion deadline: _____________________1 month______________________
recommended term for implementing the measures

- Responsible person: __________Havryliuk S.V._________________________
  contact details of responsible person

Signatures

Monitoring performed by:

- ____
  full name, position, signature, stamp
- ____
  full name, position, signature, stamp

Customer:

- ____
  full name, position, signature, stamp

Supplements

4. **Photos and schemes of ventilation systems**
5. **Copies of technical documentation**
6. **Measurement protocols**

This ventilation system monitoring report is drawn up in two copies, one for each of the parties, and shall come into force from the date of its signature.

Fig. 4.33. Example of the report on the monitoring of the building ventilation system

CHAPTER 5. PARAMETERS OF THERMAL PROTECTION OF ENVELOPES

5.1 Introduction

This chapter of the guide provides clear and consistent instructions for measuring the thermal performance of the building envelope. This data can be useful for the reconstruction of damaged buildings and thermal renovation of existing ones. To carry out thermal renovation at the initial stage, it is necessary to determine the thermal protection properties of the building envelope. Existing calculation methods have a number of assumptions that affect the final result, sometimes it is not possible to obtain all the initial data for calculation by non-destructive methods, thus the use of instrumental energy audit of buildings provides an opportunity to determine the real thermal protection characteristics of the structure, and as a result, thermal renovation.

5.2 Terms and definitions

Thermal Conductivity is the ability of bodies to conduct heat energy from more heated parts to less heated parts. The thermal conductivity is defined by the amount of heat transfer through a unit thickness of material per unit time.

Thermal Transmittance Coefficient (U-value) is the amount of heat transfer through a unit area of the envelope per unit time at a temperature difference of one degree between internal and external parts of the structure. It is measured in watts per square metre per kelvin (W/m^2-K). This value allows assessing how well a material or structure retains heat inside a building.

Heat Flux Measurement device is a device for measuring the amount of heat that passes through the surface of a material or building structure over a certain period of time and is an important tool to measure thermal properties of materials and structures in construction and industry.

Heat Flow through Building Envelope is the amount of heat energy transferred through a wall, floor, roof or other structural parts of a building per unit of time. This flow characterises the rate of heat transfer from the building»s interior to the exterior or vice versa. The heat flow is measured in watts per square metre (W/m^2) and depends on the building materials, their thickness, thermal conductivity, temperature gradient between the interior and exterior surfaces, and environmental conditions.

External Wall Envelopes is a set of opaque enclosing structures of the entire building that create a façade. They have common purpose, perform the same functions and standardised heat transfer resistance. At the same time, the external wall enclosure may consist of sections with different structural composition. [2]

Opaque Envelopes - structural elements of a building envelope (walls, coatings, floors, etc.), which include one or more layers of materials that do not transmit visible light. [2]

Building Envelopes are building structures that provide energy conservation for heating and/or cooling of premises, protection from climatic influences, division of a building into parts or premises with different temperature and humidity conditions. [2]

Thermal Resistance (R-value) is the feature of a structure to prevent the expansion of thermal motion of molecules. The R-value shows how a structure of a certain thickness resists heat transfer through itself. It is measured as the temperature difference in degrees (Kelvin or Celsius) on opposite surfaces of the structure required to transfer 1 W of energy through 1 m^2 of the structure»s area. It is measured in ($m^2 \cdot K$)/W.

Point Thermal Transmittance Coefficient - is a correction factor to determine the effect of a point heat-conducting inclusion of a thermally heterogeneous envelopes on its thermal insulation characteristics. It takes into account the amount of heat, in watts, that is transferred through the heat-conducting inclusion at a temperature difference of 1 K on both sides of the structure. [23]

Heat Flux is the amount of heat transferred to a system or systems per unit time. [25]

Thermal Conductivity Coefficient is a material property that determines the intensity of conductive heat transfer in the material layer of the enclosing structure under a stationary thermal regime. [25]

Pyrometer is a device used to measure the temperature at a specific point of an object, a certain area or even to obtain a two-dimensional temperature distribution over a given area. The principle of operation is based on the optical method of temperature measurement. It is known that all objects emit electromagnetic waves in the infrared range and the intensity of this radiation directly depends on the temperature of the object. [29-30]

Thermography is a non-contact measurement method that allows seeing the temperature distribution on the surface of the object under investigation. The human eye does not perceive infrared radiation, but due to a special device - a thermal imaging camera operating in the infrared spectrum - we are able to see how different areas of the object under investigation emit a different colour range depending on the temperature - from bright red and yellow (high temperatures) to blue, dark blue and black (low temperatures). [29-30]

Spot Thermometer is a device to measure temperature at a specific point or small area of a surface. It is commonly used to quickly obtain accurate temperature measurements at specific locations. [29-30]

Thermal Imaging Camera is a device that visualizes temperature distribution on the surface of objects. It works on the basis of infrared radiation, which is emitted by all objects with a temperature above absolute zero. The thermal imaging camera converts infrared radiation into a visible image where different temperatures are displayed in different colours. This allows quickly and accurately detect problems such as heat loss, overheating or defects in building structures or electrical equipment. [29-30]

5.3 Normative and regulatory documents of Ukraine for calculating the thermal protection properties of building envelopes.

In Ukraine, the calculation of thermal protection properties of enclosing structures is based on the following regulatory documents:

- **DSTU 9191:2022 Selection methods of thermal insulation material for building insulation [23].** This standard provides a methodology for measuring the thermal performance of building enclosing structures and provides values for the calculated thermal and physical properties of building materials. [23]

- **DBN B.2.6-31:2021 Thermal insulation and energy efficiency of buildings [2].** These standards establish requirements for energy efficiency indicators of buildings, thermal performance of enclosing structures (thermal insulation envelope), energy efficiency indicators of engineering equipment of buildings during their design and construction, and criteria for the rational use of energy resources for heating and cooling of buildings to ensure the normative sanitary and hygienic parameters of indoor microclimate, and the durability of building envelopes during buildings operation. [2]

- **DSTU ISO 9869:2007 Thermal insulation. Building elements. In-situ measurements of thermal resistance and heat transfer coefficient.** This standard describes a method for measuring heat transfer characteristics of flat building components using a heat flux converter. [24]

In Ukraine, there are minimum regulatory values for the coefficient of thermal conductivity (U-value) for different types of building envelopes. Compliance with these standards is mandatory to obtain permission for the construction and operation of buildings.

According to Ukrainian standards, heat transfer resistance (R-value) is used to calculate thermal protection properties of building envelopes, which is the inverse of thermal conductivity U-value. The R-value determines the property of a material to resist heat transfer. The higher the R-value, the better the material insulates heat, and vice versa, a low U-value of thermal conductivity indicates a high energy efficiency of the structure. Therefore, it is important to consider both of these parameters to understand thermal insulation properties of building materials.

- **DSTU B V.2.2-39:2016. Methods and stages of energy audit of buildings.** This standard provides requirements for the methods of energy audit of buildings that are put into operation and maintained, their engineering systems, selection of audit objects, the scope of work on energy audit of buildings, analysis of the results obtained, and preparation of reporting documentation on energy audit of buildings or their separate parts.

- **DSTU B V.2.6-101:2010. Method for determining the heat transfer resistance of enclosing structures. [28]** This standard describes a method for the experimental determination of the heat transfer resistance of building enclosing structures and assessment of the compliance with regulatory requirements.

5.4 Thermal conductivity coefficient U

When designing new buildings or renovating existing ones, it is important to consider the U-value to ensure the required level of thermal insulation. This makes possible to choose the best materials and construction solutions to ensure the required level of thermal insulation and helps reduce energy consumption for heating and cooling the building.

For example, to calculate a multilayer wall consisting of an external brickwork, an insulation layer and an internal drywall, you can calculate the thermal conductivity by summing the thermal resistances of each layer.

Comparing the U-values of walls made of different materials (brick, concrete, wood) allows choosing the best materials for the best thermal insulation.

Thermal conductivity of materials is influenced by a number of factors:

- Material type: different materials have different levels of thermal conductivity. For example, metals have high thermal conductivity, while insulating materials such as mineral wool or polystyrene foam have low thermal conductivity.
- Material moisture content: moist materials conduct heat better than dry materials, so controlling moisture content is critical for effective insulation. In addition, the structure of the material, including the pores and air spaces, can significantly affect its thermal conductivity.

Proper thermal insulation ensures a stable temperature regime inside the building, which increases the comfort of occupants. It also helps prevent condensation and mould growth, which has a positive impact on human health.

Energy-efficient buildings consume less energy, which reduces greenhouse gas and other harmful emissions. This helps reduce the impact of buildings on climate change and environmental pollution.

Investments in insulation with high energy efficiency can have a short payback period due to significant savings in energy costs.

5.5 Methods to determine the thermal conductivity coefficient

The calculation of thermal conductivity U-value can be carried out using theoretical or instrumental methods.

1. The calculation method is the calculation of the thermal conductivity coefficient U-value based on the thermal resistance (R-value), which is determined according to the current Ukrainian regulations.

2. The instrumental method involves measuring the heat flow through the structure using special equipment, such as a U-value meter. The U-value measurement can identify weaknesses in thermal insulation and develop recommendations for their improvement. The use of calculation and instrumental methods to determine the U-value provides accurate calculations and optimal solutions to reduce heat loss and improve building comfort.

This guide provides an example how to calculate the coefficient of thermal conductivity using both the calculation and instrumental methods. The calculation method involves calculation of thermal protection properties of a building envelope according to the current standards in Ukraine. The instrumental method involves measuring the heat flow through a building envelope using the Testo 635-2 heat flow meter. Both methods make possible to obtain more accurate data on the thermal insulation properties of the building envelope and compare the results.

5.6 Thermal imaging camera, pyrometer and spot thermometer to inspect the building envelope.

To measure the temperature on the surface of a structure, we use a pyrometer, a non-contact method that also has some error. The most accurate way to measure temperature is to use a spot thermometer. It allows getting the most reliable data, which is especially important when you need to check the readings obtained from a thermal imaging camera or pyrometer. Based on the data from the spot thermometer, you can calibrate the thermal imaging camera and pyrometer by adjusting the emissivity and the displayed temperature. [29-30]

Pyrometer

Pyrometers are a type of device used to measure the temperature at a specific point of an object, a certain area, or even to obtain a two-dimensional temperature distribution over a given area. The principle of their operation is based on the optical method of temperature measurement. It is known that all objects emit electromagnetic waves in the infrared range and the intensity of this radiation directly depends on the temperature of the object. A pyrometer is shown in Figure 5.1

Pyrometers use this physical principle to measure temperature without contact by recording the intensity of thermal radiation. This provides accurate temperature measurement even from a distance without the need for physical contact with the surface. Due to this technology, pyrometers are indispensable devices in many industries where it is important to measure temperature quickly and accurately, for instance, in industry, construction or during equipment maintenance.

A non-contact measurement method used by pyrometers has significant advantages, particularly in conditions where direct contact with the object is impossible or dangerous. [29-30]

Fig. 5.1. Testo 835 pyrometer

Technical data

Measuring range: -30...+600 °C, IR; -50...+600 °C, contact; 0...100 % RH (relative humidity);

Accuracy: from ±1.0 °C (infrared), from ±0.5 °C (contact), ±2 % RH (relative humidity);

Built-in memory: 200 values;

- Optics: 50:1;
- Laser marker: 4-point;
- Connection to external probes
- Calculation of dew point temperature
- Display of maximum and minimum values
- Operating temperature: -20...+50 °C;
- Dimensions: 193 x 166 x 63 mm;
- Battery type: AA, 3 pcs;
- Dimensions: 193 x 166 x 63 mm
- Weight: 514 g.

The Testo 835-H1 infrared pyrometer is designed to measure relative humidity and ambient temperature.

Pyrometer is equipped with powerful 50:1 optics and a precise 4-point laser target pointer that delimits the measured area. The device measures temperatures in the range up to 600 °C with an accuracy of 1% (or 1 °C) without contact.

The device has a built-in memory for 200 parameters. In addition, the Testo 835-H1 infrared pyrometer has table data on emission factor for 20 different materials.

It measures relative humidity and temperature in a room and calculates the dew point. Using the calculated dew point value, the pyrometer automatically detects places where moisture and mold may appear when scanning the surface of building structures. If potentially dangerous areas are detected, the device will beep.[31]

Settings

1. Touch the surface with the contact thermometer;
2. Wait until the readings stabilise;
3. Record or memorise the temperature value;
4. Change the emission coefficient of the IR thermometer (just like on a thermal imaging camera) until the difference between the results of the contact and remote thermometers is minimal. When using the materials with different reflectivity, the procedure must be repeated.

Optical resolution (visibility ratio) is one of the key parameters of a pyrometer that shows how accurately the device can measure the temperature on a given surface. It is calculated as the ratio of the diameter of the measuring spot (circle) on the object to the distance from the device to this object. For example, modern pyrometers can have a 300:1 visibility ratio, which means that at a distance of 300 cm, the diameter of the measuring spot will be 1 cm. However, in practice, a lower magnification ratio is often enough, depending on specific conditions. The measurement principle and resolution of a pyrometer is shown in Figure 5.2.

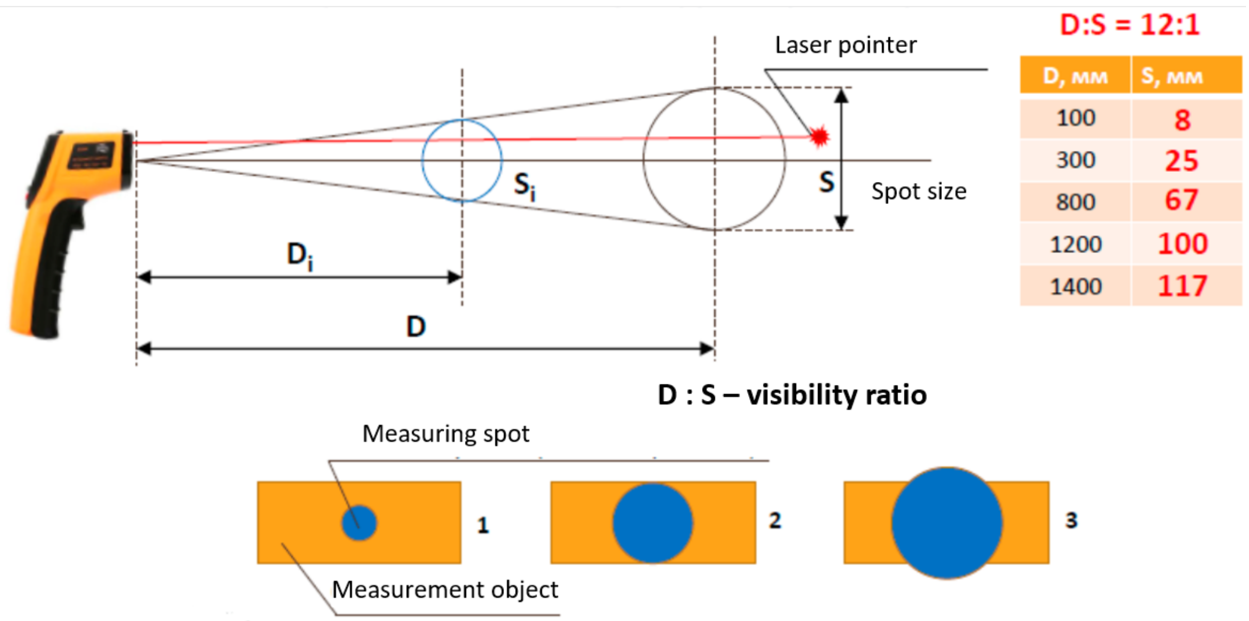


Fig. 5.2. Measurement principle and resolution of a pyrometer

It is important to choose a correct zoom factor, taking into account the distance to the object and the size of the area to be measured. If this parameter is selected incorrectly, the accuracy of the measurement may be questionable. To obtain accurate data, the diameter of the measuring spot should be smaller or, in extreme cases, equal to the area the readings are taken from. The best option is when the diameter of the spot is half the size of the object. If the spot is larger, neighbouring objects can get to the measurement area, which will significantly distort the results. How to measure the diameter of the imaging spot and the distance to the object is shown in Figure 5.3. [29-30]

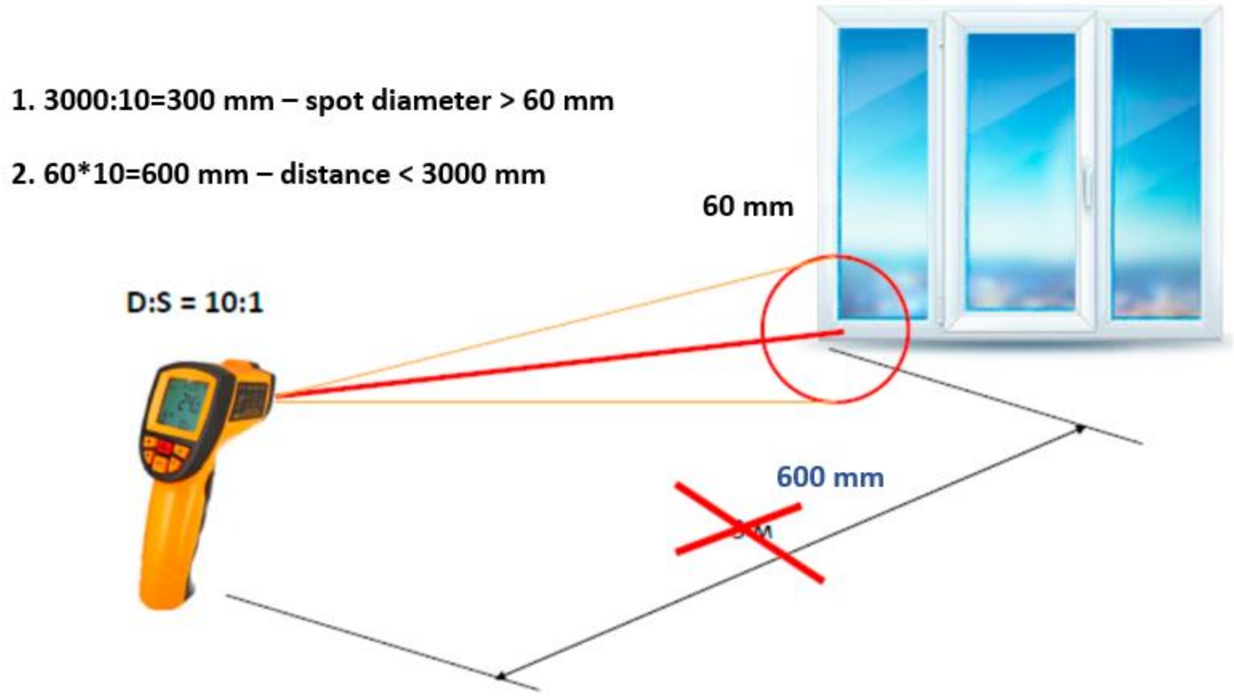


Fig. 5.3. Measuring the diameter of the imaging spot and the distance to the object

If the resolution of the pyrometer is 10:1, this means that the diameter of the measuring spot will be 1 metre at a distance of 10 metres. For example, if you need to measure the temperature at a distance of 3 metres, the diameter of the measuring spot will be approximately 30 cm.

If you understand this ratio, you can determine the optimal distance to the object for accurate results. If the distance to the object is too large and the spot diameter exceeds the size of the area , the results may be inaccurate due to some close objects.

If the optical resolution of the pyrometer is improved to 12:1, measurements can be made at a greater distance. For example, with this resolution the diameter of the measuring spot will be 60 mm at a distance of 720 mm. This allows obtaining accurate data even at greater distances, which is especially important when working with objects that are difficult or dangerous to reach. [29-30]

Spot thermometer

Spot thermometer during the instrumental inspection of building envelopes can accurately measure the surface temperature of building elements. This is important for detecting thermal anomalies that may indicate defects in the insulation or other structural problems. A spot thermometer provides fast and non-contact measurement, which is especially useful for analysing hard-to-reach areas. Its use can increase the accuracy of the survey and the efficiency of detecting possible heat loss. An example how to use a spot thermometer is shown in Figure 5.4.

Fig.5.4 Spot thermometer measurement

For surface measurements, a sensor head is placed vertically on the surface. Ensure that both the contact surface of the sensor head and the object to be measured is even, otherwise the measurement can be distorted.

Tips for measuring surface temperature:

- Place the probe tip flat on the surface;
- Do not move the probe during the measurement;
- Apply a constant and sufficient planting force;
- Use low-mass surface sensors;
- Ideally, the temperature value is reached after about 3 seconds. [29-30]

Thermography (thermal imaging)

A thermal imaging camera, Fig. 5.5, provides qualitative assessment of the structure condition, i.e. identifying problem areas and assessing the overall thermal conditions. However, to obtain quantitative data, such as surface temperature or heat loss, we use a pyrometer, spot thermometer, and heat flow instruments. These tools help measure how much heat is lost through the structure under specific conditions, which is a key to accurate calculation of the energy efficiency of a building. [29-30,32]

Fig. 5.5 Thermal imaging camera

Thermography is a non-contact measurement method that allows seeing the temperature distribution on the surface of the object under investigation. The human eye does not perceive infrared radiation, but due to a special device - a thermal imaging camera operating in the infrared spectrum - we can see how different areas of the investigated object emit different colour range depending on the temperature - from bright red and yellow (high temperatures) to blue, dark blue and black (low temperatures).

This measurement method makes it possible to identify the places of the greatest heat loss in a building, cold bridges, structural and other defects in walls and foundations, leaks and ruptures in engineering systems, places of moisture and condensation accumulation. In addition, the thermal imaging camera helps check the quality of building insulation, etc.[29-30]

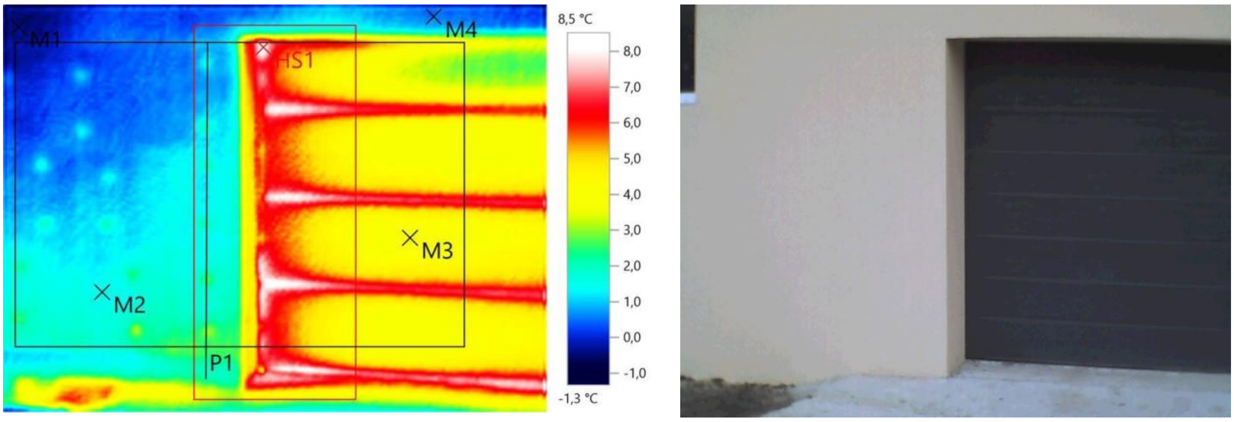


Fig. 5.6. Thermal imaging camera measurement

Principle of operation and settings of a thermal imaging camera

Figure 5.7 shows the components of thermal radiation when using a thermal imaging camera: *reflectivity (ρ), transmittance (τ) and* emissivity *(ε)*

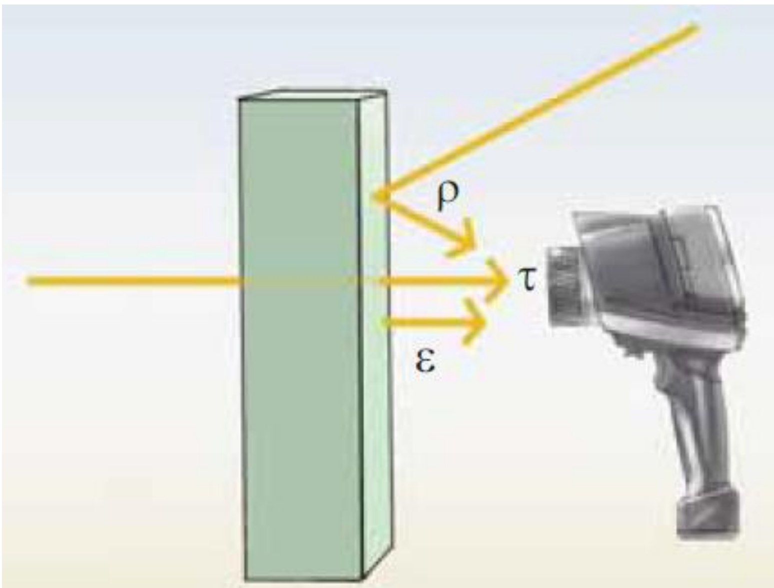


Fig.5.7. Components of thermal radiation using a thermal imaging camera: reflectivity (ρ), transmittance (τ) and emissivity *(ε)*

To take into account all 3 components recorded by the thermal imaging camera, you need to set the appropriate coefficients:

1. Emissivity (ε)
2. Reflectivity (ρ)
3. Transmittance (τ)

If you want to use the automatic dew point calculation, you must also set:

- relative humidity;
- air temperature.

Emissivity

Emissivity depends on surface properties, material and temperature. In long-wave cameras, the emissivity is independent of the colour of the object. Most building materials have an emissivity between 0.85 and 0.95. Figure 5.8 shows the thermal emissivity of common materials. Tables with emissivity coefficients can be used, but carefully.

Material	Thermal Emissivity	Material	Thermal Emissivity
Asphalt	0.90...0.98	Black fabric	0.98
Concrete	0.94	Human skin	0.98
Cement	0.96	Foam	0.75...0.80
Sand	0.90	Charcoal (powder)	0.96
Earth	0.92...0.96	Paint	0.80...0.95
Water	0.92...0.96	Matte paint	0.97
Ice	0.96...0.98	Wood	0.94
Snow	0.83	Plastic	0.85...0.95
Glass	0.90...0.95	Lumber	0.90
Ceramics	0.90...0.94	Paper	0.70...0.94
Marble	0.94	Chromium oxide	0.81
Plaster	0.80...0.90	Copper oxide	0.78
Lime	0.89...0.91	Iron oxide	0.78...0.82
Brick	0.93...0.96	Textile	0.90

Fig.5.8. Thermal emissivity (Ɛ) of common materials

Influence of emissivity

High emissivity ($\varepsilon \geq 0.8$): apparent temperature is very similar to the actual temperature of the object (you can trust what you see).

Low emissivity ($\varepsilon \leq 0.6$): apparent temperature is more like the ambient temperature (reflection!). Measuring the temperature with a thermal imaging camera is possible, but you need to examine the results very carefully. It is extremely important to set the reflected temperature compensation (RTC) correctly. You cannot trust what you see!

An infrared camera does not measure temperature, but infrared radiation. Figure 5.9 shows the effect of incorrect emissivity of the thermal imaging camera on the temperature measurement results.

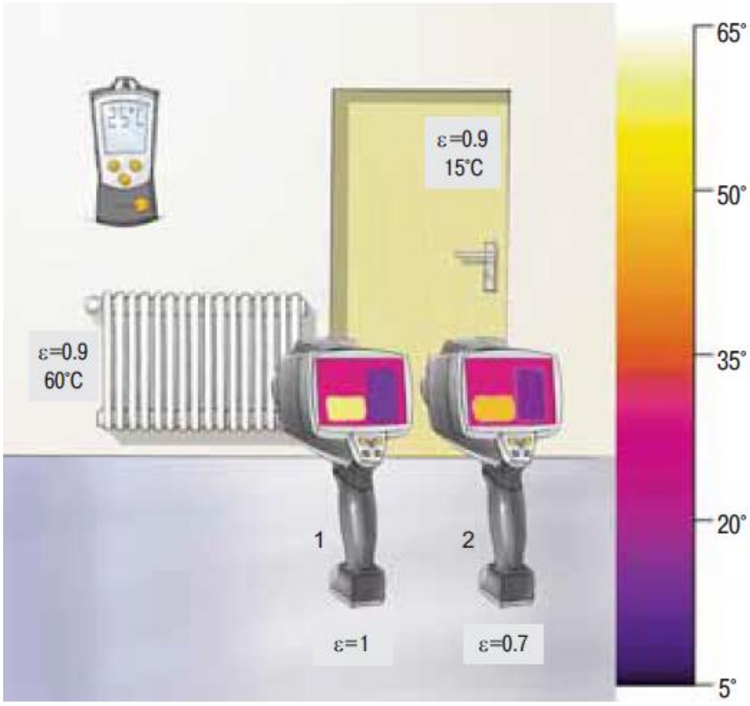


Fig.5.9 Effect of incorrect emissivity setting on temperature measurement results

When the temperature of the object to be measured is higher than the ambient temperature (e.g., radiator temperature is 60°C), it is important to set correctly the emissivity of the thermal imaging camera.

- If the emissivity is overstated, it will result in higher temperature. For example, the thermal imaging camera may show 65°C instead of real 60°C.

- On the other hand, if the emissivity is too low, the temperature on the thermal imaging camera will be lower. In this case, the thermal imaging camera may display 50°C instead of real 60°C.

In cases where the temperature of the measured object is lower than the ambient temperature (e.g. a door has 15°C), it is necessary to pay attention to the settings of emissivity.

- Overstated emissivity will lead to lower temperature readings. The thermal imaging camera may display 10°C instead of real 15°C.

- If the emissivity is too low, the thermal imaging camera will show higher temperature readings, for example, 20°C instead of real 15°C. [29-30]

High emissivity: when the emissivity is set to a high level, the temperature readings will be very close to the actual temperature of the object. In this case, you can rely on the readings displayed by the thermal imaging camera as they accurately reflect the real surface temperature of the object.

Low emissivity: if the emissivity is too low, the thermal imaging camera may show a temperature that is closer to the ambient temperature than the real temperature of the object. This occurs due to the reflection of thermal radiation from other surfaces, which distorts the actual readings. In this case, you cannot trust the readings on the display because low emissivity can mislead you and provide incorrect data. [29-30]

Reflectivity

The quality of an object»s surface has a significant impact on emissivity and reflectivity.

- Directional reflection is a type of reflectivity where light or heat radiation is reflected from a surface in a specific direction, similar to the way light is reflected from a mirror. This type of reflection is typical of smooth, polished surfaces such as glass, metal, shiny paint, flat plastic, polished wood, or even calm water. Visually, you can observe directional reflection in the visible spectrum when you see your reflection on these surfaces.

- Reflection in the infrared spectrum. Just like visible light, infrared radiation is also reflected from polished and smooth surfaces. This means that objects placed in front of such surfaces can be reflected in the infrared spectrum, giving a false impression of the surface temperature. For example, a mirror in the infrared range can show objects in front of it but not provide information about its own temperature.

Diffuse reflection is characterised by light scattering in all directions. This type of reflection is often observed on rough, oxidised or dusty surfaces, which generally have a higher emissivity.

Matte white color is used in fluorescent lamps to diffuse visible light. If you look at such a reflector, you will see a white surface but will not be able to see light tubes clearly. In the case of infrared radiation, paper, wood, and surfaces covered with matte paint are excellent examples of diffuse reflectors that scatter radiation rather than reflect it like a mirror. An example of surface reflection of different materials is shown in Figure 5.10 [29-30].

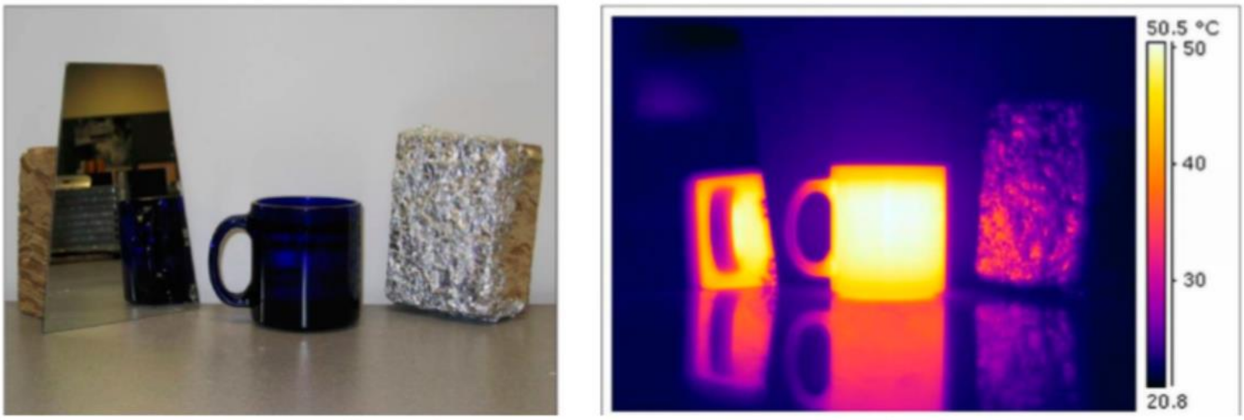


Fig.5.10 Surface reflectivity of different materials (example)

Figure 5.10 shows a directional reflector on the left and a diffuse reflector for a coffee cup on the right.

The apparent temperature is an uncompensated temperature reading of the camera. It includes all the radiation that is captured by the camera, regardless of its source. Thus, the apparent temperature is the temperature reflected by the object measured.

To measure the apparent temperature, the emissivity must be set to 1.0 (no compensation/correction will be performed).

In order to measure correctly the actual temperature, the effects of emissivity and reflected radiation must be compensated for.

5.7 Testo 635-2 for measuring heat flow

The Testo 635-2 heat flow meter, shown in Figure 5.11, is used as one of the diagnostic tools to measure thermal conductivity, e.g.how much heat is entering or leaving your building. Instrumental diagnostics determines the amount of heat loss and provides an opportunity to take action to improve the energy efficiency of the building by processing the information.

Fig 5.11 Testo 635-2 to measure heat flow

Application

• Calculation of energy losses and thermal conductivity coefficient for walls, floors and roofs.

• Inspection of buildings: detection of heat loss locations and thermal protection indicators in cases with no information on the building»s thermal insulation potential and construction material during an energy audit, such as architectural monuments, damaged buildings, and outdated housing stock.

• Quality control: verification of the compliance of the completed insulation works with the design requirements by comparing the calculated values of the thermal conductivity coefficient with the actual measured values.

Technical characteristics

Device: Testo 635-2.

- Display: graphic display with backlight;
- Built-in memory: 10,000 values;
- Interfaces: USB for data transfer, Bluetooth for wireless probes;
- Operating temperature: -20...+50 °C;
- Protection class: IP 54;
- Battery type: AA, 3 pcs;
- Dimensions: 220 x 74 x 46 mm (without probe);
- Weight: 428 g (without probe);
- Connectivity to external probes;
- Display of maximum, minimum, average values;
- Connectivity to a PC;
- Portable printer for printing data: optional.

Temperature probe

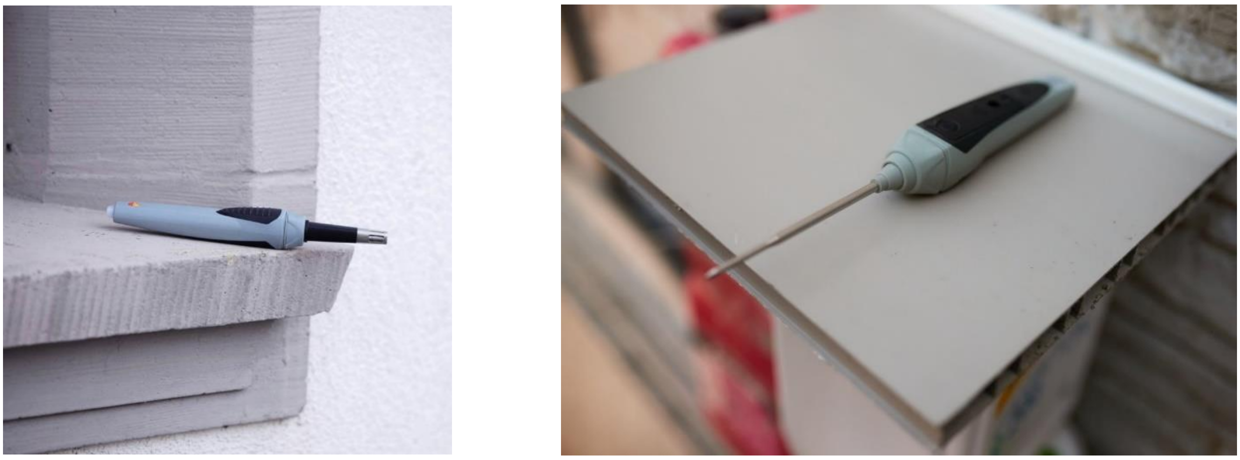


Fig. 5.12 Temparature probe

Temperature probe is designed to measure the surface temperature. It consists of a sensing element that converts data into an electrical signal for transmission to the control panel.

Setting up the radio probe - how to operate it:

1) **<u>Transmission speed 05 seconds</u>** (switch on with a short press).

The lamp lights up for 2 seconds and then blinks every 2 seconds. After 1 hour of operation, the probe switches off by itself, the auto-off function works.

2) **Transmission speed 10 seconds** (hold until the light comes on).

The lamp lights up for 2 seconds and then blinks every 10 seconds. The auto switch-off does not work.

3-wire temperature probe

Temperature of the inner surface of the wall is measured by a 3-wire temperature probe, and the temperature inside the room is measured by a sensor built into the device.

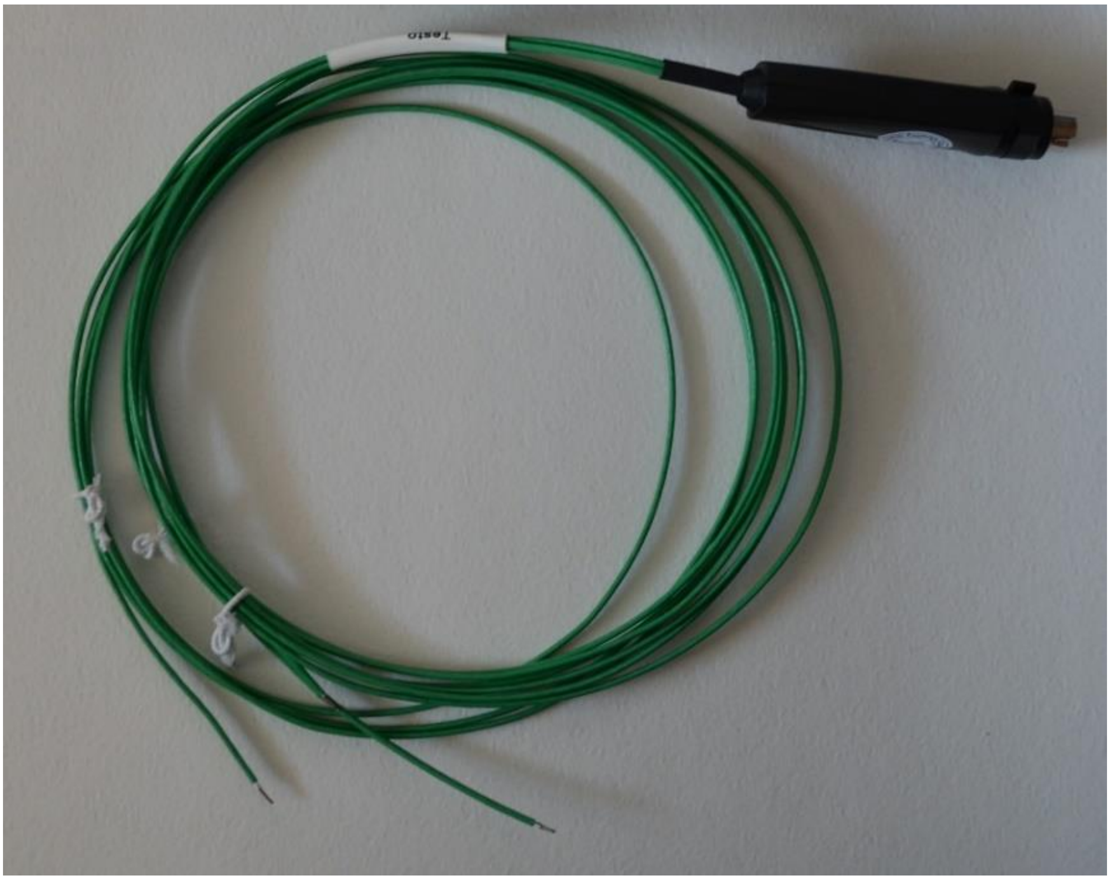


Fig. 5.13 3-wire temperature probe

Measurement parameters

To detect heat loss, 3 temperature values must be measured:

1) Indoor air temperature (θi): via an additional sensor in the U-value probe plug.

2) Indoor wall surface temperature (θw): using a U-value probe with sensors

fixed to the wall surface.

3) Outside temperature (θe): using a temperature probe.

The location of the measuring device is shown in Figure 5.14. The U-value is calculated by formula 5.1

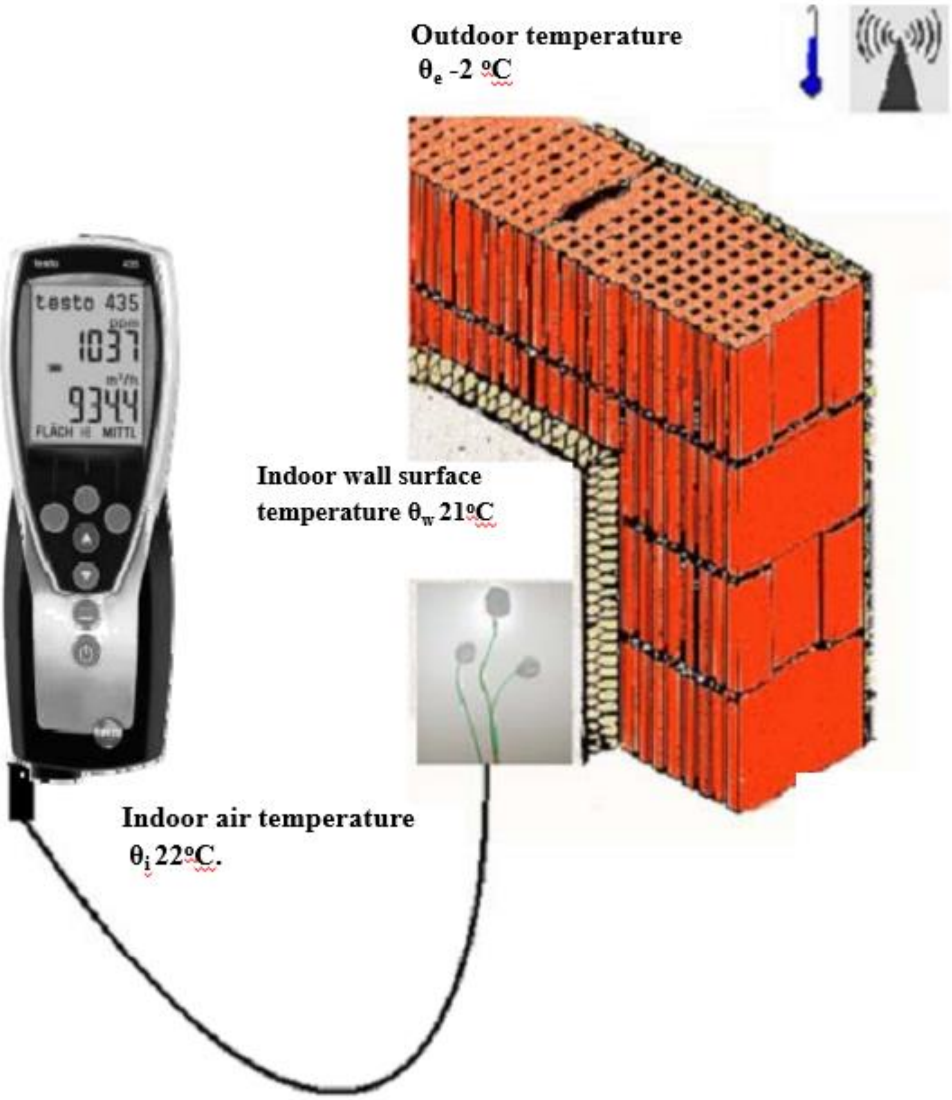


Fig. 5.14 Calculation of heat loss U-factor

$$U - value = h_{si} \cdot \frac{\Delta\theta_1}{\Delta\theta_2}, W/m^2 \cdot K \quad (5.1)$$

$$\Delta\theta_1 = \theta_i - \theta_w$$

$$\Delta\theta_2 = \theta_i - \theta_e$$

where

θ_i – indoor temperature

θ_e – temperature outside the room

θ_w – temperature of the wall surface inside the room;

h_{si} – heat transfer coefficient W/(m2·K), according to Appendix B [23].

Measurement conditions

Measurement conditions must be as follows:

- sufficient air temperature difference inside or outside the room (ideally at least 15C^o);
- stable temperature value (stationary conditions);
- correct heat transfer coefficient of the building enclosure in the device (for wall enclosure h_{si} = 8.7 W/(m^2·K);
- not touch the wires and plug of the heat loss probe during the measurement. [27]

Measurement duration

Based on our practical experience, we provide recommendations for measuring process with this device to ensure the most accurate results. These tips will help you to achieve correct and reliable data.

In order to obtain accurate results, it is important to stabilise the temperature indicators. This usually takes 20 minutes or more.

Measurements should be carried out under stable weather conditions without sudden changes in temperature, wind or precipitation. The temperature difference between indoor and outdoor temperatures should be 15°C or more (θi- $\theta e \geq 15°C$).

It is recommended to measure for 2-3 hours to obtain accurate and stable results. In some cases, if necessary, the measurement duration can be reduced. This will ensure the accuracy and reliability of the data obtained to determine the thermal conductivity of building enclosure.

Measurement locations

- Position the device during measurement (in a place protected from heat radiation and warm/cold air) at the same height as the probe for the U-value.

- Select typical areas of the entire building for measurement. Avoid areas with special conditions that may distort the results, such as heat or cold sources (radiators, air conditioners).
- Measurements in corners and at wall junctions, as they are often the weakest areas of insulation.
- Measurements on walls with different orientations (north, south, east, west) as they may have different thermal characteristics due to the influence of solar radiation.
- Measurements on different floors of the building, if possible. This will allow you to assess the variations in thermal performance over the height of the building.

5.8 Measuring thermal conductivity of a building envelope with the Testo 635-2 device.

In order to study the parameters of any building enclosure, such as a wall, window, roof or floor, several important steps are required. First, a thermal imaging camera should be used to inspect the surface of the structure. This allows you to detect inhomogeneities that may indicate problems with thermal insulation or other characteristics. An example of a thermographic inspection report is provided in Section 5.10. Based on this inspection, the most suspicious areas are identified where heat flow measurement devices will be installed. An example how to use a thermal imaging device to find problem insulation areas is shown in Figure 5.15.

Fig.5.15 Using thermal imaging device to find problem areas in the building insulation

If the thermal imaging camera detects temperature differences on the building envelope of more than 4 degrees, it may indicate such problems as heat loss or poor insulation. It is important to note that even with proper setup and correct parameters, a thermal imaging camera has an error of approximately ±2°C.

Heat flow sensors are installed at selected locations and the surface temperature is measured with a pyrometer. It is important that the temperature indicated by a heat flux meter will be the same as the temperature measured by a pyrometer. If the values do not match, time must be allowed for the temperature to equalise to ensure accurate measurements.

An external temperature probe also needs to have enough time to adapt to the surrounding conditions to ensure that the results are as accurate as possible, with a stabilisation time of 10 minutes. It is important to avoid any errors that could affect the accuracy of the final data.

In order to obtain correct data for short-term measurements, it is recommended to take readings at least 20 minutes after setting up the device. This period of time is usually sufficient to obtain correct and reliable data that will allow making reasonable conclusions about the thermal insulation properties of the structure inspected.

1) Choose a typical location or a location identified with a thermal imaging camera for the measurement that is not affected by heat and cold sources (radiators or air conditioners).

Make sure that the sensors are installed on clean and dry surfaces (clean if necessary). Using mastic, fix the ends of 3 wires of the U-value probe on the inner surface of a wall, they should be located in the form of an isosceles triangle at a distance of 10-15 cm from each other, as shown in Figure 5.16. [26] Measurement at 3 points allows taking into account a mixed nature of masonry. Connect the U-factor probe to the device.

Fig 5.16 Example of fixing a 3-phase probe

2) Switch on the device. It will automatically display the wall surface temperature as shown in Figure 5.17. [26]

Fig. 5.17 Measuring wall surface temperature

3) While measuring, it is possible to check, for example, the surface temperature with a pyrometer and compare it with a heat flux device, as shown in Figure 5.18.

Fig. 5.18 Comparison of measurement readings with pyrometer and device

3) Enter the heat transfer coefficient of the building structure h_{si} = 8.7 into the device, according to Appendix B of DSTU 9191:2022 «Methods of selecting heat-

insulating material for building insulation»as shown in Figure 5.19. [23]

Fig. 5.19 Thermal conductivity coefficient of the enclosure

4) Place the radio probe outside the room to measure the outdoor temperature as shown in Figure 5.20 [26].

Fig. 5.20 Possible location of the radio probe

5) Leave the device to stabilise for 5-10 minutes. The device will automatically display the U-value as shown in Figure 5.21.

Fig. 5.21 Calculation of the actual thermal conductivity of the envelope by a device

6) An example of the location of the connected devices is shown in Figure 5.22 [26].

Fig. 5.22 Example of connected devices location

After completing steps 1-6 (setting up the device, switching on the radio probe), connect the device to the computer and open the software, as shown in Figure

5.23 [26].

Fig. 5.23 Process of measuring the thermal conductivity coefficient

Set up of the measurement program in the absence of a computer and software.

The setup of the device is shown in Figure 5.24 step by step.

1) Select «measurement programme» in the menu

2) Select the measurement programme «auto»

3) Set up the measurement interval (for example, every 5 minutes) and the number of measurements (in the device it is shown as a «number», enter the number of measurements depending on time, i.e. if the measurement lasts 60 minutes with a recording interval of every 5 minutes, the number will be 60/5=12 measurement records)

4) After set up on the main panel, press «start», the device will automatically complete the measurement after the time set, if you need to complete the measurement, press «stop» and the device will save the amount of data that it has recorded.

The device saves the measurement record in its memory and allows you to view a detailed report using the software.

a) Select «measurement programme» in the menu

b) Select the measurement programme «auto»

c) Set the measurement interval

Fig. 5.24 Setting up the measurement application in the absence of a computer and software

Setting up the measurement application

8) The first thing you can see when you open the application is a blank sheet and a setting where you can make an «Online start», after turning it on, the live measurement starts and shows the measurement value immediately.

On the left side of the screen, a list of measurements is saved (you made one measurement, saved it, changed the settings or the measurement location, and made the next measurement), as shown in Figure 5.25. Measurements are saved on a computer or in the device.

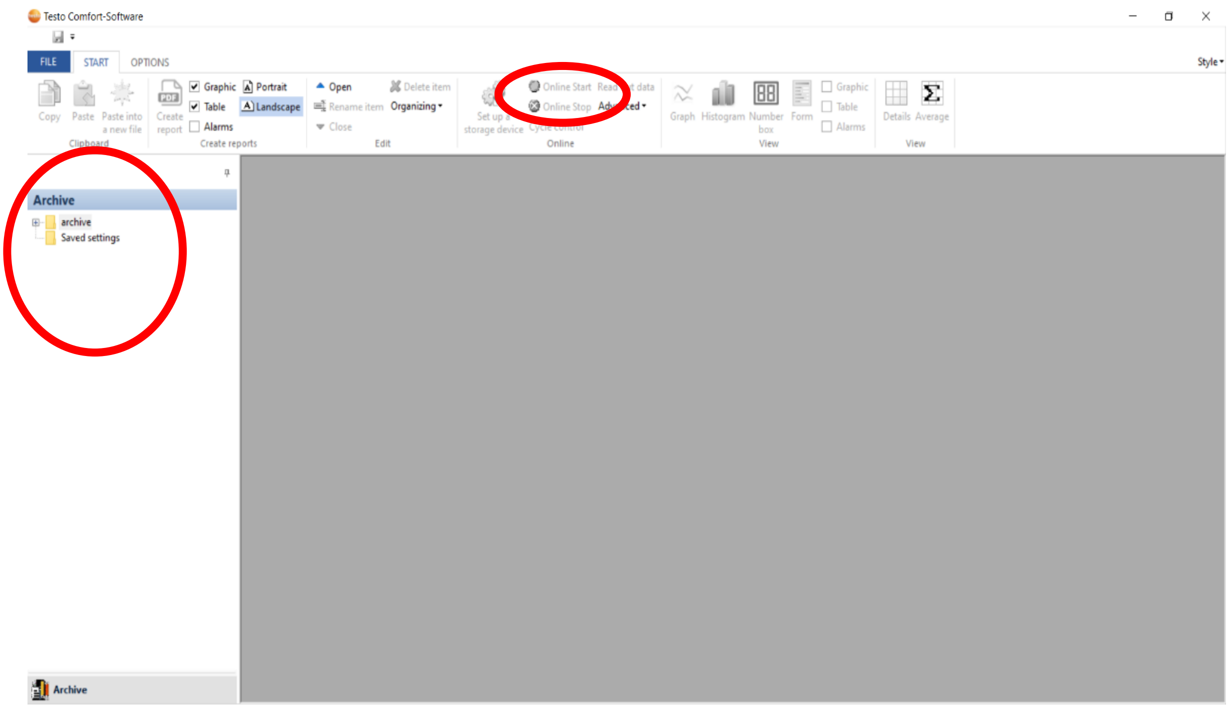


Fig. 5.25 Measurement application

9) When you start the measurement with «Online start, you can see a chart that measures 4 values shown in the table below. It shows the date, time, measurement interval, as well as the calculated actual value of thermal conductivity indicated in the table as C1, wall surface temperature C2, indoor temperature C3, outdoor temperature C4, shown in Figure 5.26-5.27.

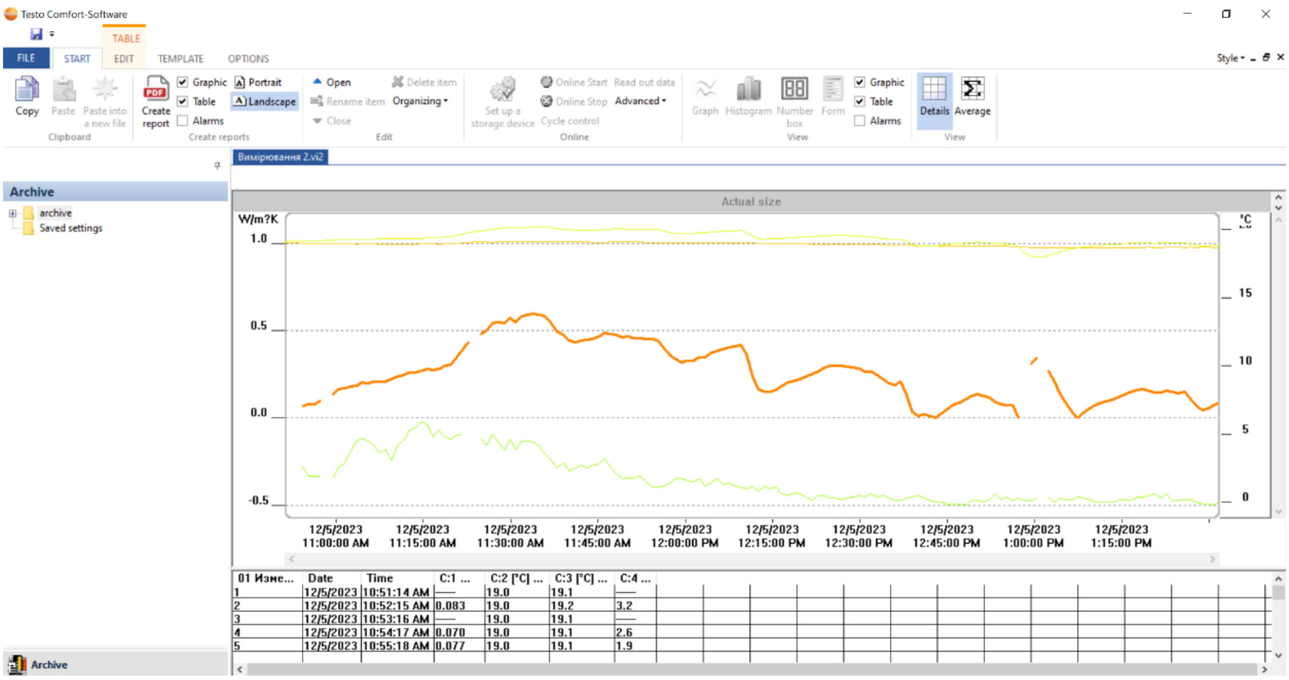


Fig. 5.26 Measurement data

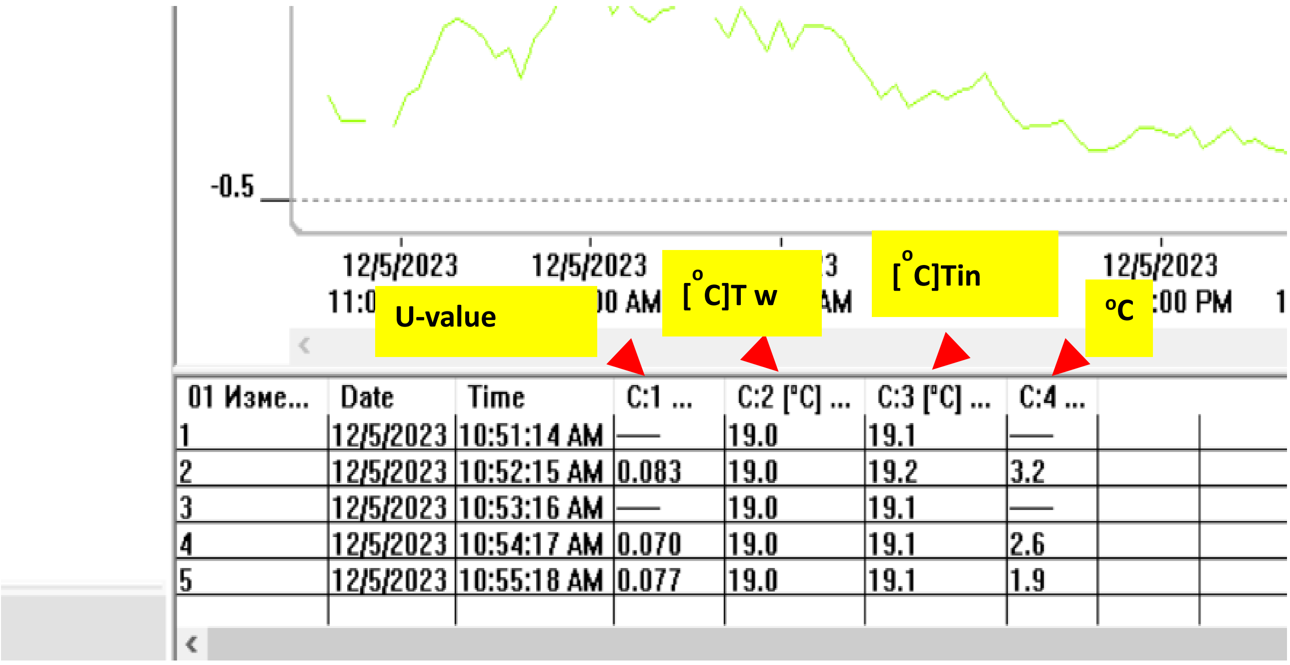


Fig. 5.27 Measurement data

In order to see more detailed information about each measurement point (C1....C4), click on them to open adjustment window where you can see the static calculation (minimum, maximum, average).

You can adjust the measurement interval by selecting «measurement interval». At the beginning of the measurement, the device automatically measures every second, which is not very correct for the final report. Set a longer interval, for example, 1, 5, 15 minutes, etc.

By selecting «Set up a storage device» and going to «Settings» tab, we can set the interval and number of measurements. For example, the figure shows measurements with a recording interval of 15 minutes and the number of measurements of 10, shown in Figure 5.28.

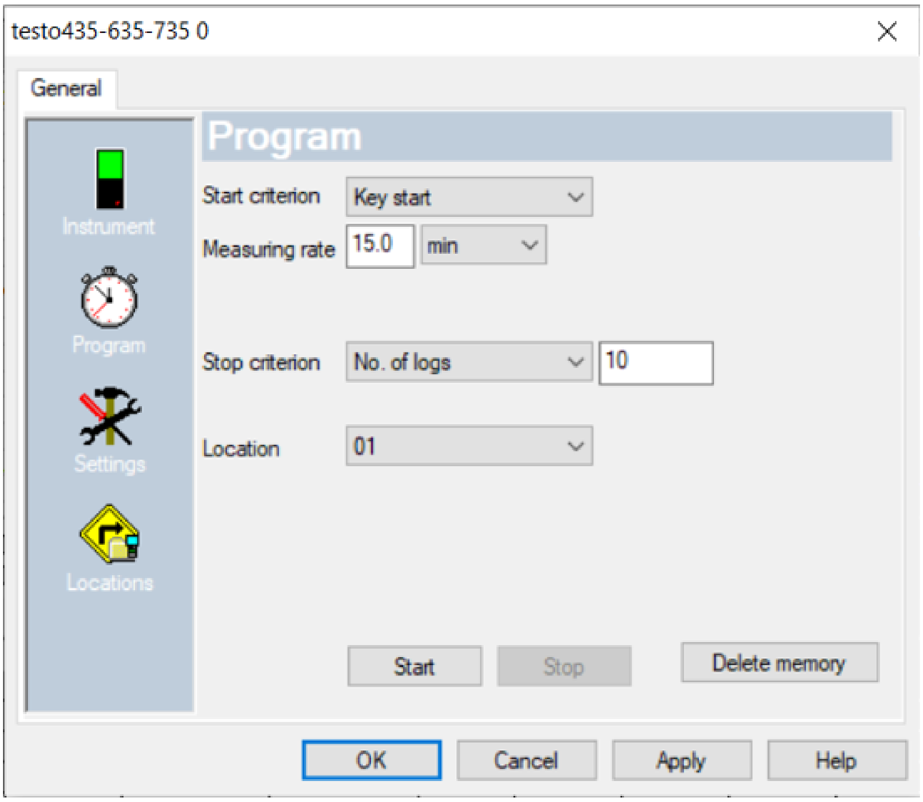


Fig. 5.28 Measurement settings

The average value «Average» is shown in Figure 5.29. This table shows the overall results (minimum, maximum, average unit value) obtained throughout the measurement.

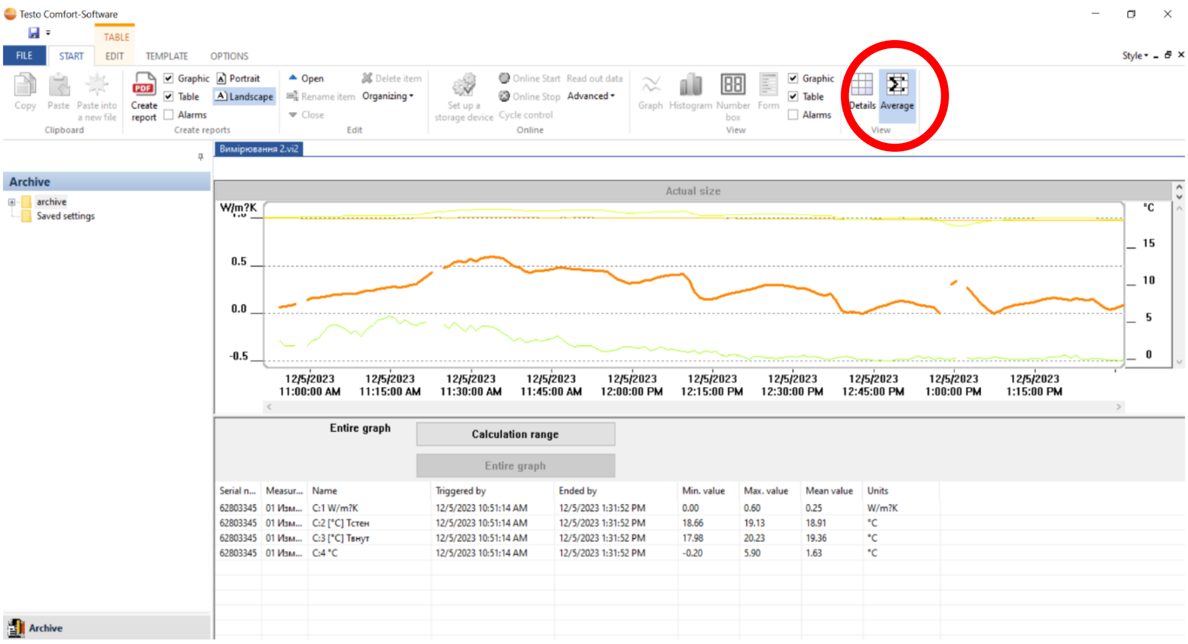


Fig. 5.29 Average obtained results («Average»)

To save the results in PDF format, select «Create report».

As a result of the measurement, we get the actual data on the thermal conductivity of the building wall.

A video tutorial on how to measure the heat flow using the Testo 635-2 device is available at https://youtu.be/v0gLEOGJ4ig

5.9 Report on thermal conductivity measurement of a building envelope (example)

Report on the measurement of the thermal conductivity coefficient OK

office and warehouse building

(full name of the institution)

Object
O.K.

Contents

5.9.1 Scope of application and legal framework

This report on the results of the inspection of the thermal protection properties of the building has been prepared in a diligent way and is based on the available data and information provided by the client.

- The purpose of this report is to verify the quality of the building façade insulation and measure the actual thermal conductivity of the building walls.
- The owner of the building is responsible for the further implementation and success of the recommended insulation measures.
- The report on the results of the survey cannot replace a thorough design and planning of the implementation of measures, but only provides data that can support them. The final decision on the implementation of energy efficiency measures should be made by the client on the basis of technical expertise and design as well as estimate documentation developed by certified experts and designers.
- By using an instrumental method to measure thermal conductivity of the building envelope, it is possible to identify heat loss areas and thermal protection indicators in cases without any information on building»s thermal insulation potential; to verify the compliance of the completed building insulation works with the design requirements by comparing the calculated values of the thermal conductivity coefficient with the actual measured values.
- This survey report was provided to the client.
- Access to the object to inspect was provided by the client according to the terms of the project.

5.9.2 General information on the object to inspect

Fig.5.30 General view

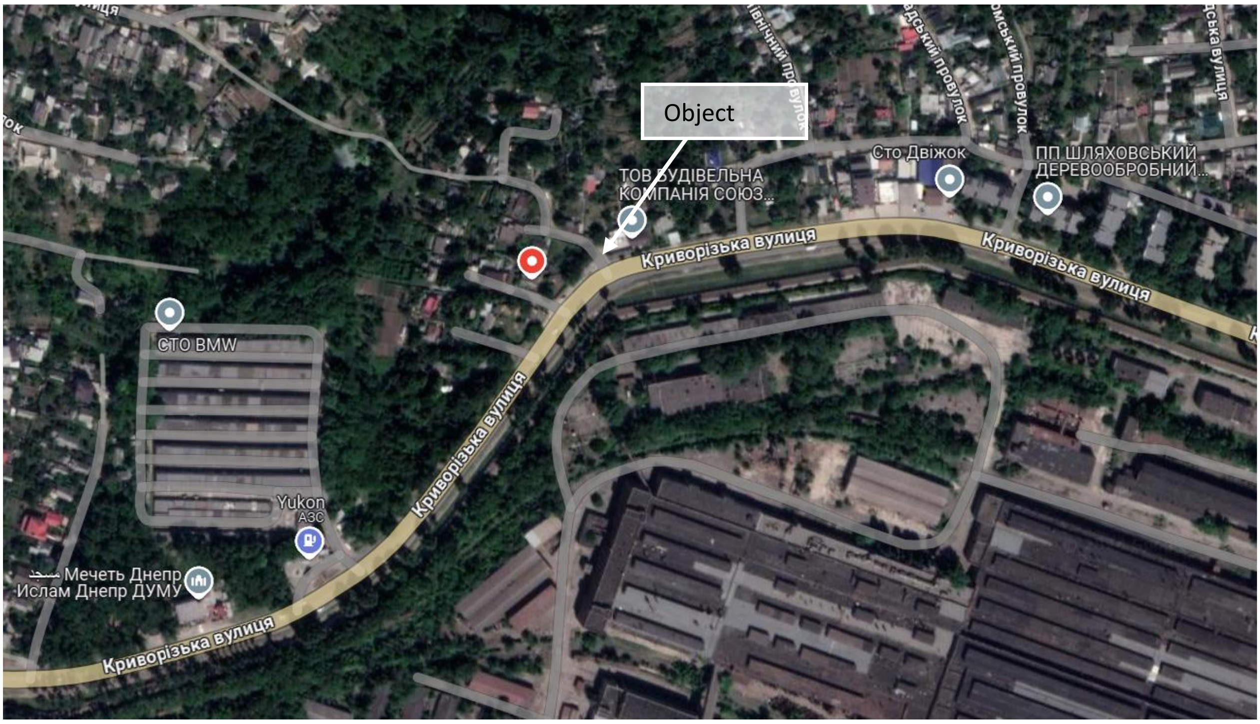


Fig.5.31 Situational plan of the area

5.9.3 Object parameters:

Table 5.1

Customer	office and warehouse building
Address	Dnipro
Date	05.12.2023
Device model:	Testo 635-2
Series number	№ 62803345
Contractor	Full name

Table 5.1(part2)

Description of the building structure	Office and warehouse building Two-storey building, total area - 206 m2, height of the ground floor is 3m height of the first floor is 2.8m. The building is frameless, with load-bearing external and internal walls and floor slabs. Foundations are strip, reinforced concrete. Attic floor is made of 220 mm thick reinforced concrete slabs. Walls are of 380 mm silicate bricks. The interior of the building is covered with 20 mm gypsum plaster. The exterior of the building is insulated with mineral wool insulation of ρ0=150kg/m^3 density and 190mm thickness.		
Outdoor temperature, C^o	1,6	**Indoor temperature, C^o**	19,4
Difference between indoor and outdoor temperature, C^o	17,8	**Weather conditions. Other important factors affecting results**	dry no clouds no wind

Table 5.1(part3)

Full name of the institution		office and warehouse building			
Responsible person for the survey (name, phone)		Full name, contact details			
№	Type of building	Location (address)	Purpose	Year of construction	Number of floors
1					

5.9.4 Measurement results

The measurement results of the actual value of thermal conductivity of the building walls are shown in Table 5.2. The measurement results in graphical form are shown in Figure 5.32 to assess visually the changes in the indicators and their dynamics throughout the measuring process.

Table 5.2

Measurement results

	Min:	Max:	Average:
K:1 U[W/m^2·K]	0.167	0.596	0.39
K:2[°C] T walls	18.7	19.1	18.9
K:3[°C] T indoor	18.0	20.2	19.4
K:4°C	-0.2	5.9	1.6

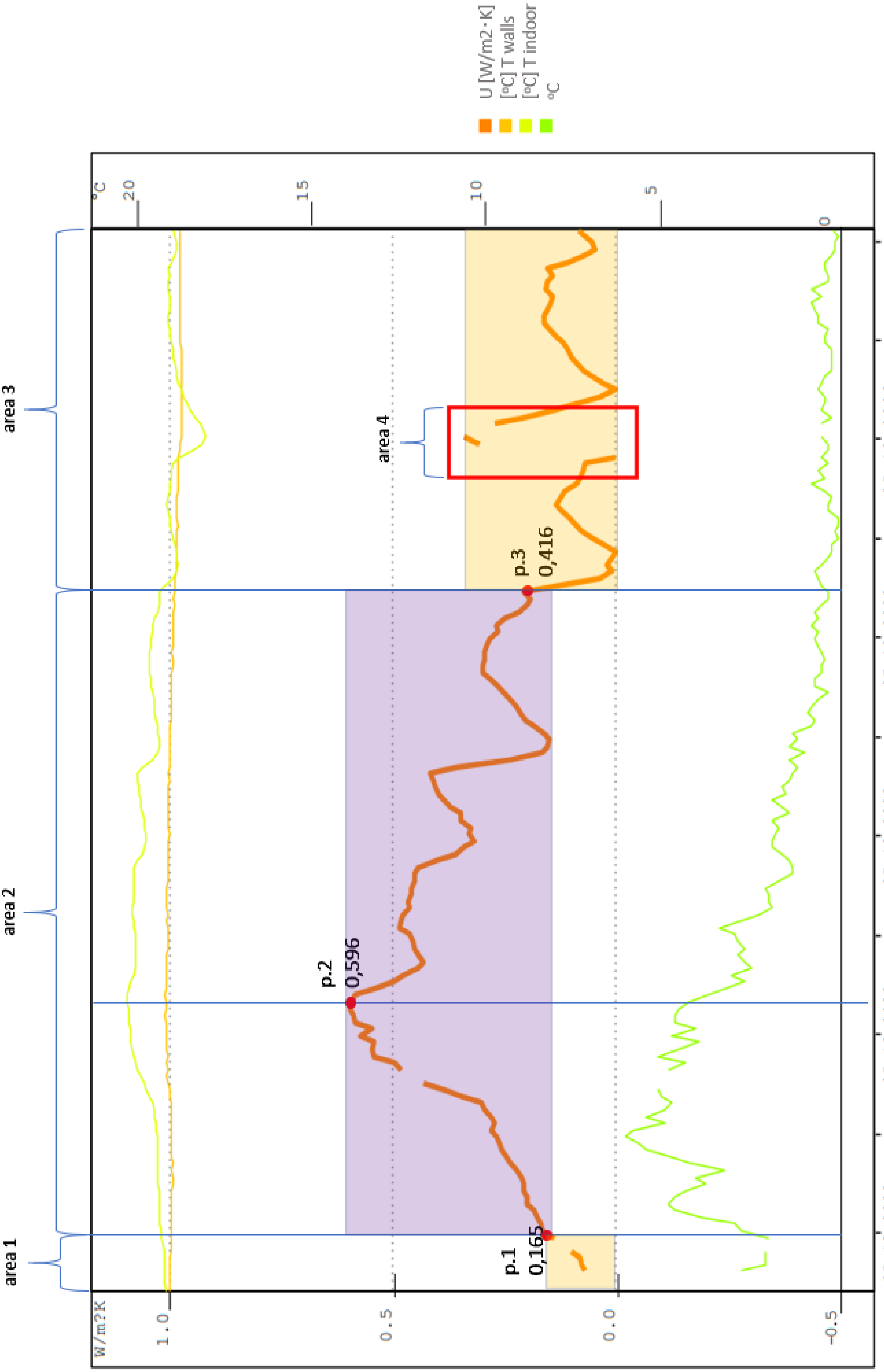


Fig. 5.32 Measurement results

According to the results shown in Fig. 5.32, we observe fluctuations in the thermal conductivity coefficient in the range from 0.01 U-value to 0.59 U-value during the measurement.

The analysis of the survey results of the building envelope is given in Table 5.3

Table 5.3

Survey results

№	Time period/ time	U-value	[℃] Twalls	[℃] Tindoor	[℃] Toutdoor	Analysis/Conclusions
p.1	11:00	0,165	18,9	19,3	2,6	Initial measurement value
p.2	11:34	0,596	19,1	20,2	4,4	The highest value achieved during the entire measurement period. The increase is due to an increase in the difference between the wall surface temperature and the internal room temperature.
p.3	12:09	0,416	19	19,9	1,1	The values of the thermal conductivity measurement achieved at the end of the measurement. The following data have already been obtained while the room is ventilated and without any connection with the device
area 1	10 min	↑0,165	↑18,9	↑19,3	↑2,6	Device calibration time. No connection with the temperature probe that measured the outdoor air temperature.
area 2	1 hour 9 min	↑0,251	↑0,1	↑0,6	↓1,5	U-value measurement period without any external factors
area 3	1 hour 22 min	↓0,4	↓0,3	↓1,2	↓0,8	The period of ventilation of the room and changes in the temperature difference between the air inside the room and the wall surface temperature, which affects the quality of the result.
area 4	10 min	0,001	18,7	18,7	0,3	No connection with the temperature probe that measures outside air temperature.

5.9.5 Conclusions

According to the survey results of the office and warehouse building, the calculated value of the building»s heat transfer resistance coefficient is $R_{\Sigma} = 4.02$, which meets the minimum requirements for the I temperature zone of Dnipro $R_{\Sigma} \geq 4$ in accordance with DBN B.2.6-31:2021 Table 1[2]. According to the results of the instrumental measurement, the value of the thermal conductivity coefficient U = 0.38 or $R_{\Sigma} = 2,63$,, which does not meet the minimum permissible insulation standards in accordance with the current standards in Ukraine and the value of the insulation calculation for the building.

Taking into account technical condition of the building structures and the service life of the building, the quality of the building insulation with 170-mm thick mineral wool was checked. The inspection revealed no defects.

5.10 Example of measuring thermal conductivity coefficient of a building envelope by calculation method.

An office and warehouse building of 380-mm silicate bricks is an example of calculation. The interior of the building is made of gypsum plaster, which is a popular material for wall and ceiling finishing.

Mineral wool insulation was chosen for the exterior of the building, which is one of the most common materials for external thermal insulation.

To calculate the required insulation thickness, the first climatic region I was chosen. According to DBN B.2.6-31:2021 [2], the minimum permissible value of the reduced heat transfer resistance for opaque parts of external walls for the first temperature zone of operation in Ukraine is $R_{q\ min} = 4$ м^2 ·K/W. The required thickness of insulation was calculated according to DSTU 9191:2022.[23]

The composition of the wall envelope is given in Table 5.4.

Table 5.4

Composition of the wall envelope (main layers)

Name of the i-th layer of the structure	Thickness, m (δ_i)	Thermal conductivity W/(m•K) (λ_{ip})	U-value, W/(m^2•K)
Gypsum plaster (density ρ_0=400kg/m^3)	0,02	0,81	0.02
Silicate brick masonry	0,38	0,87	0.43
Mineral insulation (density ρ_0=150kg/m^3)	0,17	0,05	3.8
heat transfer coefficients of the inner surface of the building envelope,W/(m^2 .K) (h_{si})		8,7	0.11
heat transfer coefficients of the outer surface of the building envelope, W/(m^2 .K) ($h_{зe}$)		23	0.04

Calculating the value of the thermal conductivity of building walls

U-value of the external walls is determined according to the formula 5.2:

U-value of the external wall in the main field:

$$R_{\Sigma} = \frac{1}{h_{si}} + \sum_{i=1}^{I} Ri + \frac{1}{h_{se}} = \frac{1}{h_{si}} + \sum_{i=1}^{I} \frac{d_i}{\lambda_{ip}} + \frac{1}{h_{se}} =$$

$$= 1/8,7+0,02/0,81+0,38/0,87+0,17/0,05+1/23=4,02,\ (м^2K)/Bm; \qquad (5.2)$$

h_{si}, h_{se} – heat transfer coefficients of the inner and outer surfaces of the building envelope, W/(m^2 ·K);

Ri –thermal resistance of the i-th layer of the structure, m^2 ·K/W;

di – thickness of the i-th layer of the structure, (thickness of the material), m;

λip – thermal conductivity of the material of the i-th layer of the structure in calculated operating conditions (thermal conductivity),W/(m·K).

$$U = \frac{1}{R_{\Sigma}} = \frac{1}{4.02} = 0{,}25, Вт/м^2К \qquad (5.3)$$

where, U - coefficient of resistance to heat transfer of an element of the building envelope, which is measured in W/m^2·K.

R_{Σ}– total thermal resistance of a building envelope consisting of several different materials. It allows estimating the total resistance to heat transfer through the entire structure, taking into account the resistances of all layers.

5.11 Thermographic survey report (example)

The building was inspected by means of a thermographic survey using a Testo 875 thermal imaging device to detect defects.

Certain requirements must be met to conduct the survey:

- weather conditions: no sun, no wind, no precipitation;
- the difference between the external temperature and the internal temperature of the object must be at least 20 degrees (if necessary, the building can be heated or cooled depending on the time of year when thermographic survey takes place).

The results of a thermal imaging survey cannot replace a thorough design and planning of measures, but only provide data that can support them. The final decision on the implementation of energy efficiency measures should be made on the basis of technical expertise and design and estimate documentation developed by certified experts and designers.

Date and time of the inspection - Dec 5, 2023 (11:00)

Table 5.5

Object parameters

Description of the building structure	Object - a two-storey office and warehouse building with unheated attic. The building has a rectangular geometric shape. The building is of brick with reinforced concrete structures and slabs. The external envelope of the building consists of brick walls and windows. The height of the building is 8.3m. The height of the floors is 3m-2.8.		
Outdoor temperature, C°	-0,2 C°	**Indoor temperature, C°**	20 C°
Difference between indoor and outdoor temperature, C°	20 C°	**Weather conditions. Other important factors affecting results**	dry no clouds no wind

Address	Dnipro
Thermal imaging camera model:	Thermal imaging camera Testo 875-1i

Table 5.6

Thermal imaging of the building

File: IV_00127.BMT
Date: 05.12.2023 Time 12:15:23

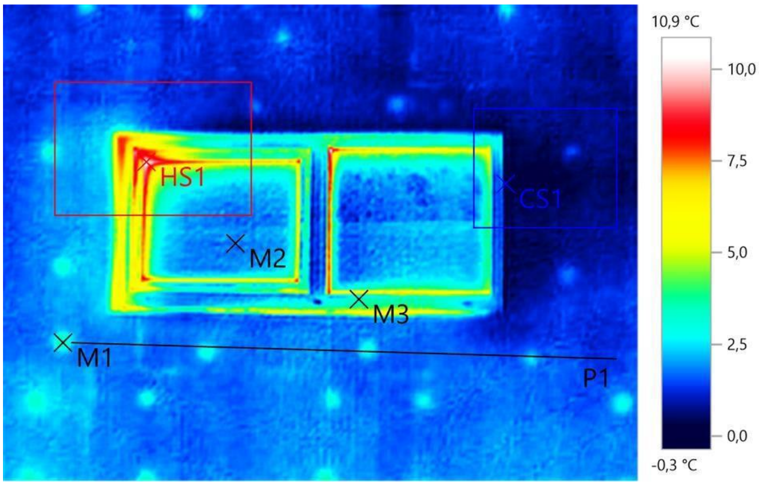
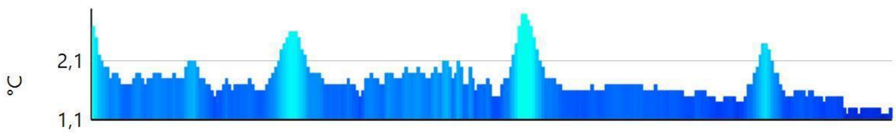


Image parameters:
Emissivity coefficient: 0.93
Displayed temp. [°C]: 0

Measured objects	**Surface temperature, °C**	**Emissivity coefficient**	**Ambient temperature, °C**
Point 1	3,4	0,93	0,0
Point 2	1,9	0,93	0,0
Point 3	3,7	0,93	0,0
The coldest point 1	-0,3	0,93	0,0
The warmest point 1	10,9	0,93	0,0

Minimum: 1,2 °C Maximum: 2,9 °C Average value 2,9 °C



Nores:	The window is in satisfactory condition.

Table 5.6 (part 2)

File: IV_00128.BMT
Date: 05.12.2023 Time12:15:55

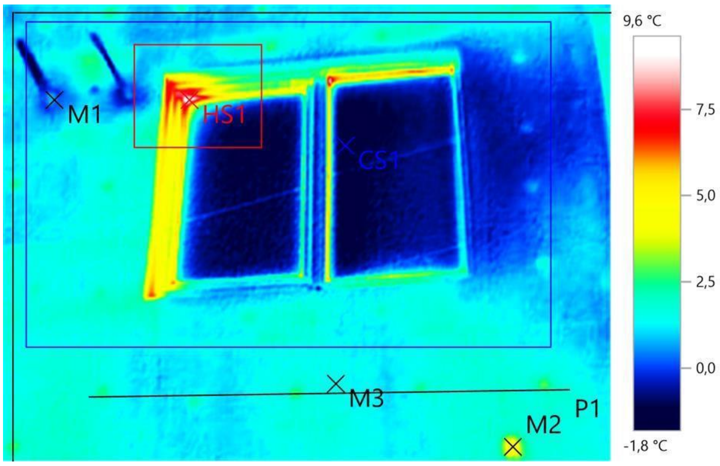
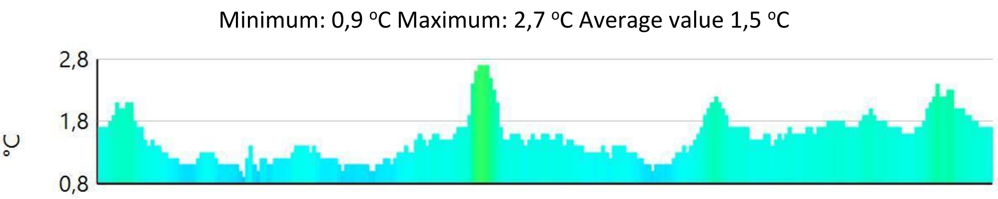


Image parameters:
Emissivity coefficient: 0.93
Displayed temp. [°C]: 0

Measured objects	Surface temperature, °C	Emissivity coefficient	Ambient temperature, °C
Point 1	0,5	0,93	0,0
Point 2	4,5	0,93	0,0
Point 3	1,4	0,93	0,0
The coldest point 1	-1,8	0,93	0,0
The warmest point 1	9,6	0,93	0,0



Notes:	The window is in satisfactory condition.

Table 5.6(part3)

File: IV_00175.BMT
Data: 05.12.2023 Time 12:50:13

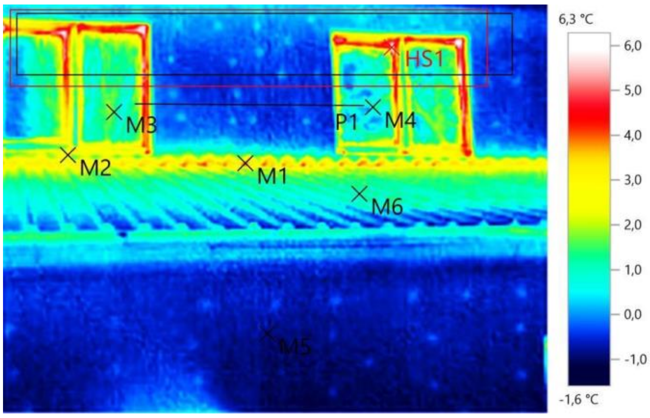
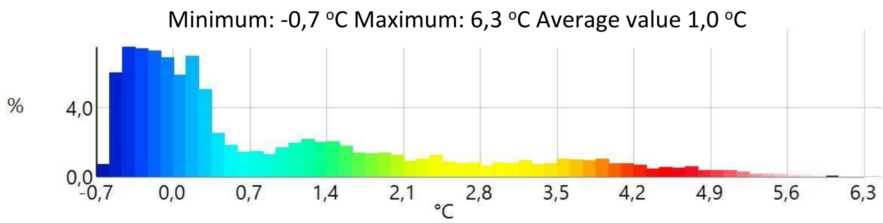


Image parameters:
Emissivity coefficient: 0.93
Displayed temp. [°C]: 0

Measured objects	Surface temperature, ºC	Emissivity coefficient	Ambient temperature, ºC
Point 1	4,0	0,93	0,0
Point 2	2,4	0,93	0,0
Point 3	1,4	0,93	0,0
Point 4	0,9	0,93	0,0
Point 5	-0,9	0,93	0,0
Point 6	0,9	0,93	0,0
The warmest point 1	6,3	0,93	0,0



Notes:	The window is in satisfactory condition.

Table 5.6 (part 4)

File: IV_00135.BMT Data: 05.12.2023 Time 12:22:15			

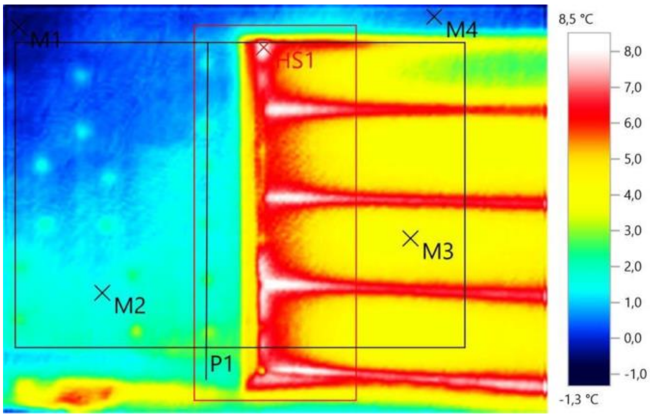



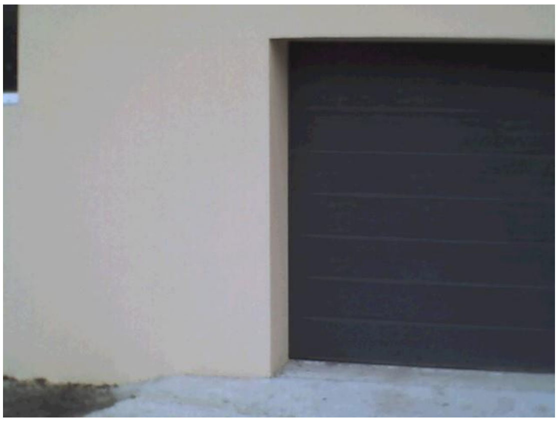
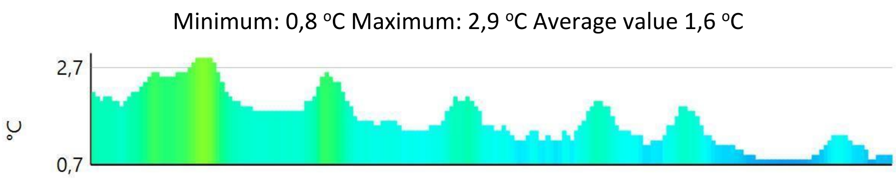
Image parameters: Emissivity coefficient: 0.93 Displayed temp. [°C]: 0			
Measured objects	**Surface temperature, ºC**	**Emissivity coefficient**	**Ambient temperature, ºC**
Point 1	-0,4	0,93	0,0
Point 2	1,5	0,93	0,0
Point 3	4,0	0,93	0,0
Point 4	0,5	0,93	0,0
The warmest point 1	8,5	0,93	0,0
			
Notes:	Heat losses through gates		

Table 5.6 (part5)

File: IV_00087.BMT
Date: 05.12.2023 Time 11:34:42

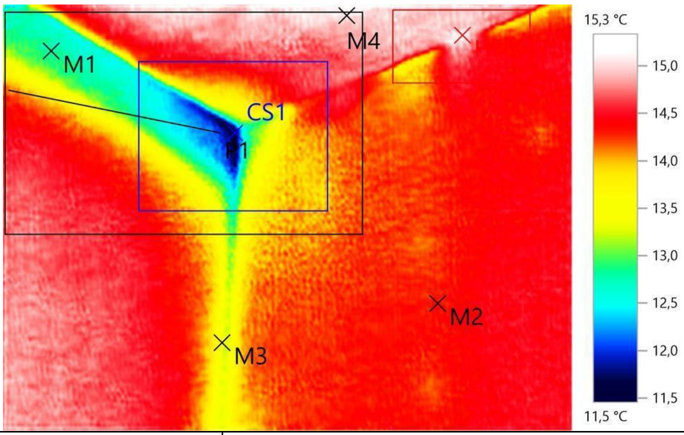
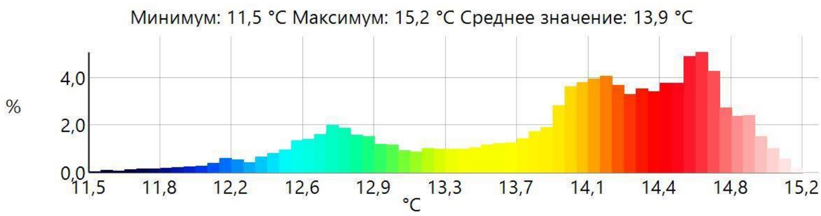


Image parameters:
Emissivity coefficient: 0.93
Displayed temp. [°C]: 0

Measured objects	Surface temperature, ºC	Emissivity coefficient	Ambient temperature, ºC
Point 1	12,8	0,93	20,0
Point 2	14,3	0,93	20,0
Point 3	13,4	0,93	20,0
Point 4	15,1	0,93	20,0
The coldest point 1	11,5	0,93	20,0
The warmest point 1	15,2	0,93	20,0



Notes: The corner in the middle of the room was found wet. The reason is high humidity level in the room due to painting works.

Table 5.6 (part 6)

File: IV_00124.BMT
Date: 05.12.2023 Time: 11:57:44

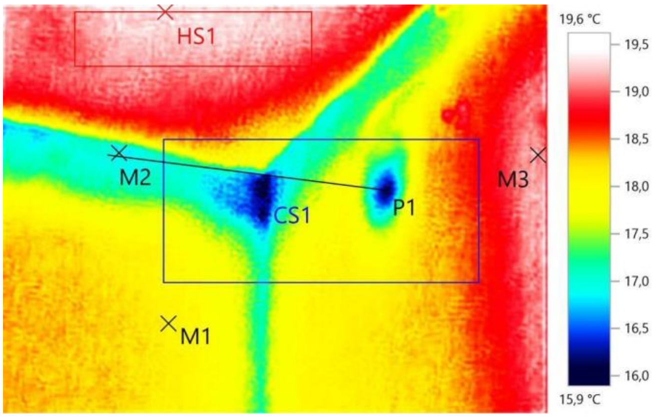
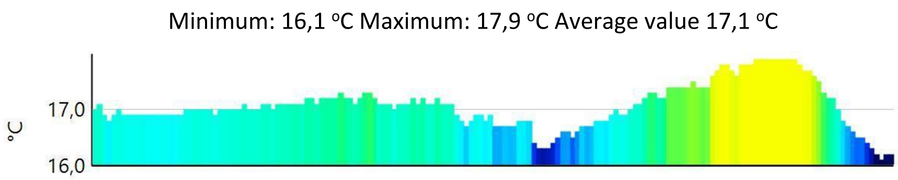


Image parameters:
Emissivity coefficient: 0.93
Ambient temperature, [°C]: 20

Measured objects	**Surface temperature, °C**	**Emissivity coefficient**	**Ambient temperature, °C**
Point 1	18,1	0,93	20,0
Point 2	16,9	0,93	20,0
Point 3	19,1	0,93	20,0
The coldest point 1	15,9	0,93	20,0
The warmest point 1	19,5	0,93	20,0



Notes:

The corner was found wet in the middle of the room/ The reason is high humidity level of 80% on the 2nd floor in the room due to painting works.

The temperature of the wall corner (CS1) is below the dew point temperature.

Thermal imaging of the office and warehouse building revealed no deficiencies in the thermal protection of the building envelope.

The results of the instrumental control (thermal imaging) showed that the building»s premises have an increased moisture content in the air due to the painting works in the building.

Places with slightly excessive normative temperature difference on the inner surface of the envelope and the indoor temperature were found in accordance with (DBN B.2.6-31:2021- Table 3). [2]

CHAPTER 6. BLOWER DOOR TEST

6.1 KEY CONCEPTS AND DEFINITIONS

6.1.1 INTRODUCTION

This chapter of the study guide describes the instrumental inspection and the methodology for assessing air permeability of building enclosures. This method allows you to measure actual energy efficiency of a building by means of instruments. It is particularly relevant for buildings with a large heated volume, where large heat losses may occur. If the building enclosure is not sufficiently airtight, heating costs can be enormous. In such cases, it is necessary to carry out quality control of the construction and installation works to ensure the airtightness and energy efficiency of the building. Building air permeability test should be mandatory for buildings with a heated volume of more than 1000 m^3. Specialists in air permeability testing of buildings are already in demand.

Air permeability is one of the most important parameters of the building enclosure, which determines the airtightness and energy efficiency of a building. A building is more energy-efficientid if its air permeability is lower. It means that the building enclosure does not have significant defects through which air passes and, accordingly, heat losses occur [33].

A pressure drop of 50 Pa is created artificially using special BLOWER DOOR TEST equipment to simulate the effects of a strong wind. The test is carried out in two modes. In the first mode, the fan blows air into the building, the air flows under pressure through the gaps in the building enclosure, and the value of the air flow in m^3 that has passed through the area of the external enclosure in m^2 is recorded. In the second mode, the fan thins the air by blowing it out of the room. The value of the air flow in m^3 that passed through the area in m^2 is also recorded. Read more about the test procedure in Section 6.3. Video instructions for the air permeability test can be found at [35]:

https://drive.google.com/drive/folders/1qWTgvNuBKk3dK-A8_wib5bThOa1r_s-q?usp=sharing

Air permeability is expressed as the amount of air leakage in cubic metres per hour per square metre of a building enclosure when the building is exposed to an internal air pressure drop of 50 Pa ($m^3/(h*m^2)$.

In such conditions of artificially created strong wind, it is especially effective to conduct a thermal imaging inspection of a building, which can identify leaks that are not visible to a thermal imaging camera under normal conditions.

Thus, with the help of instrumental inspection of the air permeability of buildings, it is possible to determine the actual air permeability, which is denoted as q50 ($m^3/(h*m^2)$. In contrast to the calculation method, which takes into account only the design data of the building enclosure, the instrumental method takes into account the quality of construction and installation works performed and assesses the actual condition of building enclosure and energy efficiency class.

6.1.2 Regulatory references

The guide provides references to the following regulations and normative documents:

1. ISO 9972:2015 Thermal performance of buildings — Determination of air permeability of buildings — Fan pressurization method, UK Standard, 2015. 38p.

This standard specifies a method for the instrumental testing of air permeability of buildings using BLOWER DOOR TEST equipment. [33].

2. DSTU EN ISO 9972:2022. Characteristics of heat engineering buildings. Determination of air permeability of buildings. Test pressure method [34].

This standard is used to measure air permeability of buildings. It specifies a test pressure method that provides a method for measuring the resulting air flow rate as a function of pressure differences inside and outside the building.

In the regulatory documents of most European Union countries, such as Estonia, Finland, Germany, Great Britain, Ireland, air permeability parameter q_{50} ($m^3/(h*m^2)$) is approved for determining energy efficiency. Ukrainian and Lithuanian standards use air exchange rate parameter n_{50} (h^{-1}). It is recommended to use air permeability parameter q_{50} to determine the energy efficiency of buildings.

Normative values of air permeability in EU countries are given in Table 6.1

Table 6.1

Normative values of air permeability in EU countries

Country	Standard	q50	n50
Latvia	LBN002-15	<1,5	
Lithuania	STR 2.01.02:2016		<1,0
Estonia	RKAS	<1,0	
Poland	Building Codes2014		<1,5
	EnEv	<2,5	
Czech Republic	with mechanical ventilation	<1,5	
	with recuperation	<1,0	
Germany	DGNB(Target)	<2,5	
Great Britain	BREEAM ATTMA	<2,5	
Ukraine	DBN V.2.6-31: 2021		<2,0 (C)
Passive houses		<0,6	

6.1.3 Terms and definitions

Building envelope are surfaces separating the interior of a building or its adjacent parts. According to [34].

Air change rate is the ratio of air flow through the building envelope enclosure to the internal volume. According to [34].

Air permeability is the ratio of air flow through the enclosing structures to the area of envelopes. According to [34].

Specific leakage rate - air flow through the building envelope per unit area of the envelope. According to [2].

Effective leakage area - is the area of air flow through the building envelope calculated during the test. According to [34].

Specific effective leakage area is the ratio of the area of air flow through the building envelope to the area of the building envelope during the pressure drop test. According to [34].

Closed opening is an opening that a device has for closing and does not require additional sealing for closure. According to [34].

Opening sealing is a sealing of an opening with the help of auxiliary means. According to [34].

6.1.4 Designations

Table 6.2

Designations

Designations	meaning	Unit of measurement
A_E	area of the enclosing structure	m^2
A_F	floor area	m^2
ELA_{pr}	effective air flow area during the test pressure drop	m^2
ELA_{Epr}	specific effective air flow area (enclosing structure) during the test pressure drop	m^2/ m^2
ELA_{Fpr}	specific effective air flow area (floor) during the test pressure drop	m^2/ m^2
C_{env}	коефіцієнт витрати повітря - air leakage rate	$m^3/(hour *Pa^n)$
C_{λ}	коефіцієнт потоку повітря air flow rate	$m^3/(hour *Pa^n)$
n_{pr}	air exchange rate during the test pressure drop	$hour^{-1}$
ρ	pressure	Pa
ρ_{bar}	uncorrected atmospheric pressure	Pa
P_v	water vapour partial pressure	Pa

P_{vs}	saturated water vapour pressure	Pa
q_{50}	air flow at a pressure drop of 50 Pa	m^3/hour
q_{Epr}	specific air flow per unit area of the building envelope during the test pressure drop	$m^3/(hour*m^2)$

Table 6.2 (part 2)

q_{Fpr}	specific air flow per unit floor area during the test pressure drop	$m^3/(hour*m^2)$
q_m	measured volumetric air flow rate	m^3/h
q_{pr}	volumetric air flow rate during the test pressure drop	m^3/h
q_r	readings of air flow measurement instruments	m^3/h
V	internal volume	m^3
Δ_p	pressure drop	Pa
Δ_{po}	pressure drop (average) at zero air flow	Pa
Δ_{po1} Δ_{po2}	pressure drop at zero air flow before and after the test (the opening of the air pressure generating equipment is closed)	Pa
Δ_{po+} Δ_{po-}	average value of positive and negative pressure drop at zero air flow (+ and - mean positive and negative pressure drop through the enclosing structures, respectively)	Pa
Δ_{pm}	measured pressure drop	Pa
Δ_{pr}	test pressure drop	Pa
φ	relative air humidity	-
T_0	absolute temperature under standard conditions	К
T_e	absolute outdoor temperature	К
T_{int}	absolute indoor temperature	К
θ	temperature in °C	°C

Table 6.2(part 3)

ρ	air density	kg/m^3
ρ_0	air density under standard conditions	kg/m^3
ρ_e	outdoor air density	kg/m^3
ρ_{int}	indoor air density	kg/m^3

Designations are given according to DSTU EN ISO 9972:2022

6.2 Equipment for the instrumental testing of air permeability

6.2.1 BLOWER DOOR TEST. RETROTECEU 6110 system (flow 14000m^3/h)

(Fig. 6.1):

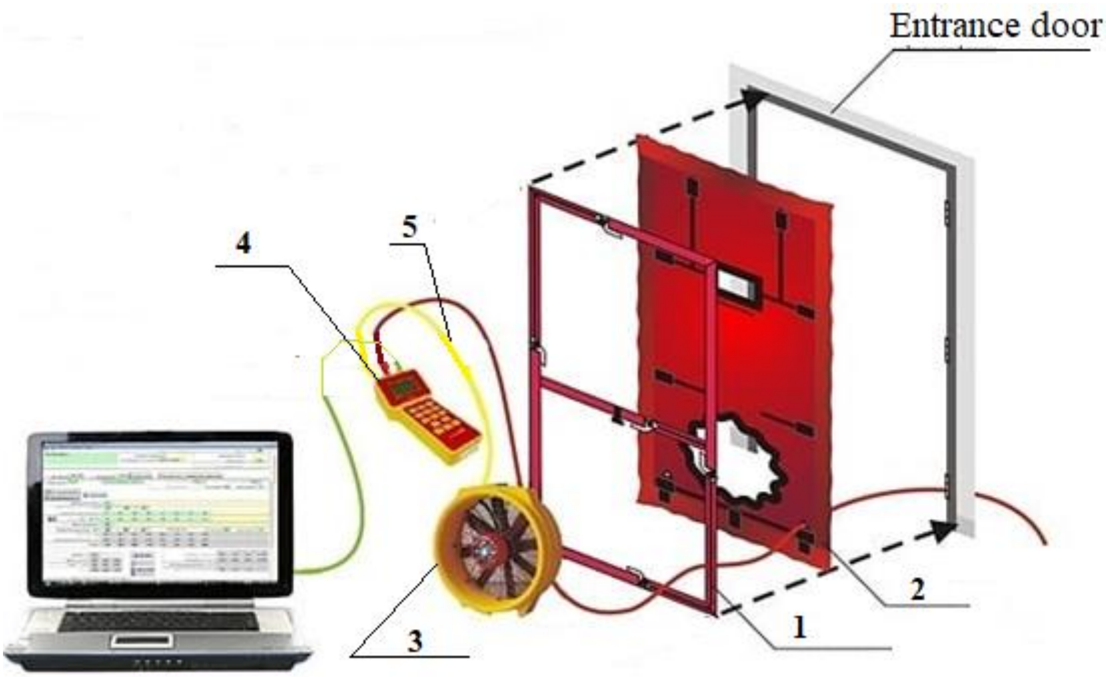


Fig. 6.1 RETROTEC EU 6110 system

1 - metal frame, which is shaped to the size of a doorway; 2 - awning fabric ;
3 - calibration fan; 4 - differential pressure gauge;
5 - connection cables

6.2.2 Software. Data recording and further calculations are performed using a software package «MultiFanTestic» v.5.11.29.73.

6.2.3 Auxiliary equipment.

➢ Thermal imaging camera - to obtain a thermogram of thermal radiation (Fig. 6.2). For more information, see the link: [36] https://www.Testo.kiev.ua/docs/docs_new/Testo-868_Man_UA.pdf

With the help of thermal imaging inspection, which is carried out at a guaranteed pressure drop, it is possible:

- to exclude the influence of factors that reduce the probability of defect detection;
- to identify the place of infiltration at low temperature differences;
- to find the places of infiltration when measuring air permeability of enclosing structure.

The combined use of two technologies improves the quality of thermal imaging inspection.

The air permeability test provides information about the real value of this parameter.

Conducting a comprehensive survey before putting a building into operation helps minimise losses.

➢ Thermometer - for recording the temperature ºC outside and inside.

➢ Anemometer – for measuring air velocity m/s in the room (Fig. 3).

Fig. 2 Thermal imaging camera Testo 868

Fig. 3 Anemometer

➢ Rangefinder - for measuring linear dimensions.

➢ Theatrical smoke is used to visually identify defects in the building»s external structures.

Fig. 6.4 Theatrical smoke

6.3 Regulations for the air permeability test

6.3.1 Test methods

Air permeability of a building is the feature of building envelopes to let the air pass through under the influence of pressure differences.

Each method requires individual preparation:

Method 1 – testing a building in operating conditions, when openings for natural ventilation are closed and openings for mechanical ventilation or air conditioning of the entire building are sealed.

Method 2 – testing a separate part of the building enclosure, in which all openings for natural ventilation are sealed and doors, windows and hatches are closed.

Method 3 –testing of a building in which certain openings are sealed or some openings can remain open in accordance with current standards or regulations at the national level. For more information on test methods, see [34].

6.3.2 Site visit preparation

It is necessary to collect necessary information about the facility (object) before going to the site:

- basic drawings of the building (plans, sections, facades with actual dimensions);
- address where the object is located;
- is the building put into operation or not;
- type of ventilation and heating is in the building;
- height of the building above the sea level in metres (can be found by the address at the link [37]: https://uff.pp.ua/vysota.html);

It is also necessary to check probable temperature and weather conditions in advance: the test should be carried out when the temperature difference between indoor and outdoor temperature is at least Δt 15°C, the weather should not be sunny, it is better to carry out the test in the second half of autumn, winter or early spring. For more information on test conditions, see [34].

The next step is to determine geometric parameters of the building, such as conditioned area m^2, conditioned volume m^3, and area of enclosure m^2.

Let»s determine the air-conditioned area of the building:

$$A_f = (b * l) * N^{st}, \text{ m}^2 \quad (6.1)$$

where A_f - conditioned area

N^{sr} – number of storeys,

l – length of a building (inner dimensions),

b– width of a building (inner dimensions).

Conditioned volume:

$$V_f = (b * l) * H, \text{m}^3 \quad (6.2)$$

where V_f - conditioned volume of a building

H– height of a building, m.

l – length of a building,

b– width of a building

Total area of the translucent part:

$$F_t = (b_{dr} * h_{dr}) + (b_{w1} * h_{w1}) + (b_{w2} * h_{w2}),\ \mathrm{m}^2 \qquad (6.3)$$

where b_{dr}- width of a door, m;

h_{dr}- height of a door, m;

$b_{w\,i}$- width of a window, m;

$h_{w\,i}$- height of a window, m.

Total area of the opaque part:

$$A_{uo} = L * H - F_{op},\ \mathrm{m}^2 \qquad (6.4)$$

where F_{op} –total area of the opaque part;

L - unit length, m;

H – floor height, m.

If the insulation is through the ceiling, the area of the ceiling is taken into account when calculating the area of external enclosure; if the insulation is through the roof, the area of the roof is taken into account.

Floor slab area

$$A_{fs} = (b * l),\ \mathrm{m}^2 \qquad (6.5)$$

l – length of a building (inner dimensions),

b– width of a building (inner dimensions),

Roof area:

$$A_{roof} = (l_{sl} * b_{sl}) * n_{sl},\ \mathrm{m}^2 \qquad (6.6)$$

l_{sl} – length of a roof slope,

b_{sl} – width of a roof slope,

n_{sl} - number of roof slopes.

Total area of external enclosing structures:

$$A_{tot} = A_t + A_{op} + A_{roof},\ \mathrm{m}^2 \qquad (6.7)$$

for buildings with roof insulation

where A_e - total area of external enclosing structures, m^2;

A_t - total area of the translucent part, m^2;

A_{op} - total area of the opaque part, m^2;

A_r - roof area, m^2

$$A_{tot} = A_t + A_{op} + A_{fs}, \ m^2 \quad (6.8)$$

where A_{rc} – area of roof covering, m^2.

It is also necessary to check the condition of the equipment: operability, battery charge.

6.3.3 Site preparations

Before the start, it is necessary to measure the actual dimensions of the building: width, length and height, if they do not match the data in the drawings, it is necessary to recalculate the geometric parameters of the building, such as: conditioned area m^2, conditioned volume m^3, area of external enclosing structures m^2.

The next step is to record temperature values outdoors and indoors. The initial data is entered into the FanTestic software (Fig. 6.5):

- building height above sea level (1);
- building height above ground level (2);
- heated volume of the building (3);
- area of external enclosure (4);
- heated area of the building (5).

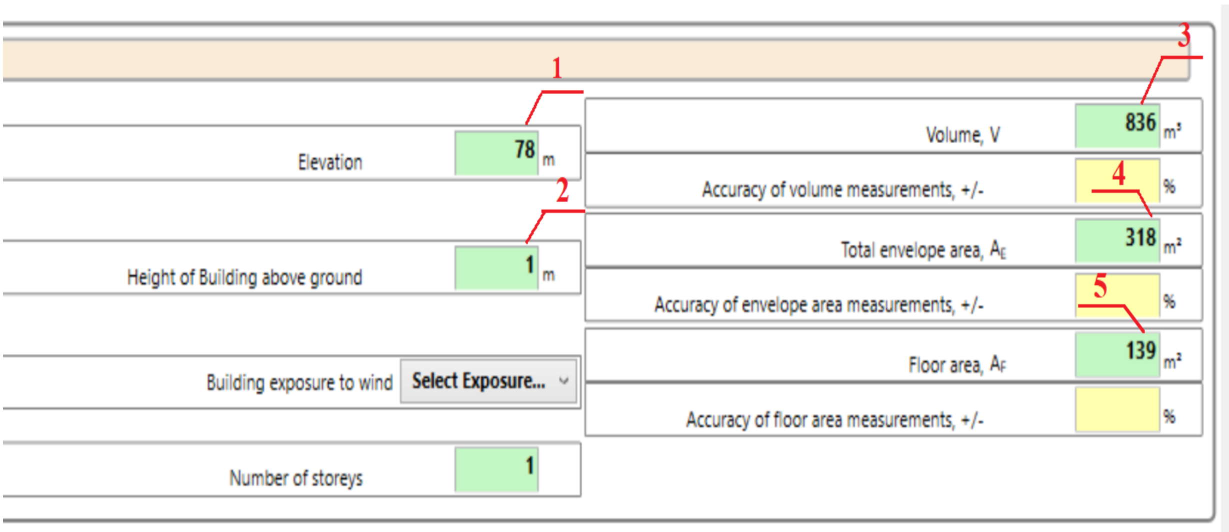


Fig.6.5 Entering data into the FanTestic programme

The next step is to record the temperature values outside and inside (Fig. 6.6):

- indoor temperature (1);
- outdoor temperature (2).

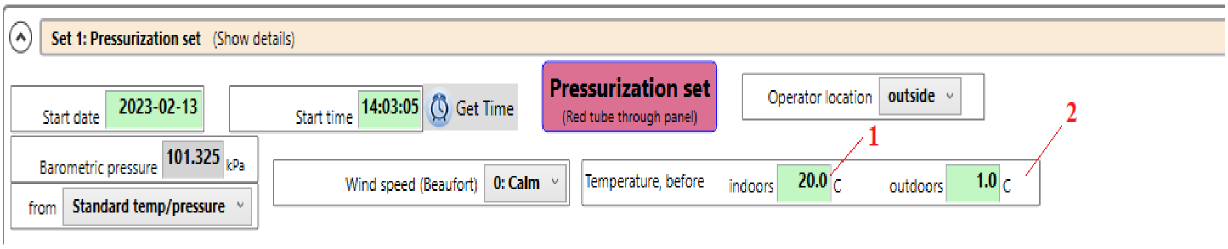


Fig.6.6 Entering initial temperature data into FanTestic

The date and time of the test are automatically recorded in the software.

The next step is to seal all openings in the building with aluminium adhesive tape, such as ventilation, exhaust hoods, water pipes (if the water supply is not yet in use) and other openings (Fig. 6.7).

Fig.6.7 Ventilation sealing

During the test, all external doors and windows should be closed and internal doors should be open. The external door is open to install the airlock in it.

Fuel combustion equipment, exhaust fans and air conditioners, as well as radiators and thermostats are switched off during the test.

6.3.4 Equipment calibration and connection

Take out the air door frame rails, adjust two long ones to the height of the outer doorway (Fig. 6.9), and three short ones to the width of the opening using cams (Fig. 6.8).

The lock (lever below the cam) is in position (Fig. 6.8).

Fig. 6.8 Position of the cam

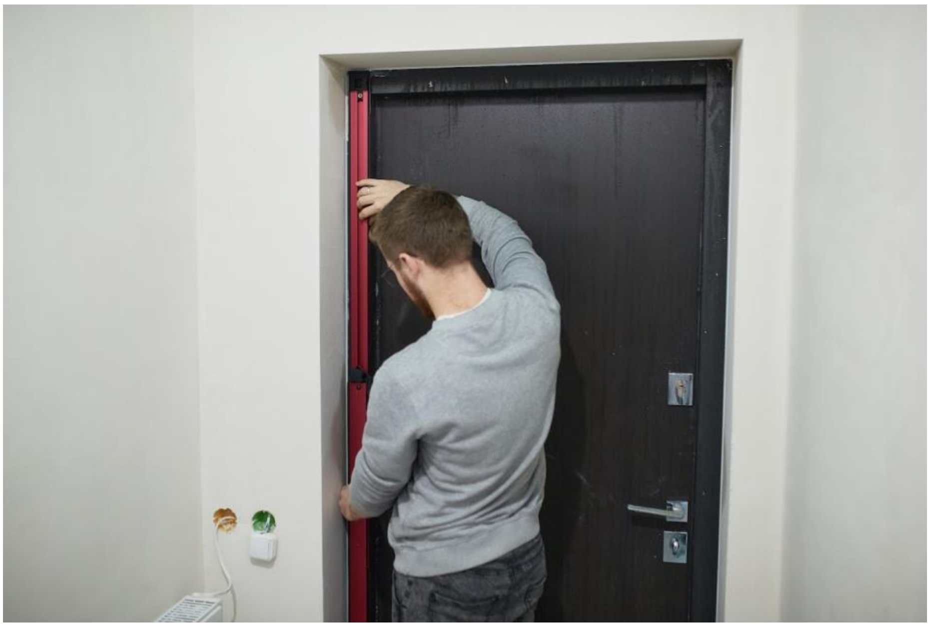


Fig. 6.9 Adjusting the height of the door frame

First, lay out the airlock frame on the floor so that all the grooves match the numbers (Fig. 6.10).

Fig.6.10 Assembling the air door

Connect the frame by inserting it into the slots until it clicks (Fig. 6.11).

Fig.6.11 Connecting the air door grooves, number to number

Put the assembled frame aside, lay the canvas face up in its place, so that the fan hole is located at the bottom (Fig. 6.12).

Place the frame on the canvas and fasten the canvas tightly to the frame with the connecting adhesive flaps.

Fig. 6.12 Attaching the air door leaf to the frame

Lift the assembled frame with the leaf (canvas) and insert it into the opening of the external entrance door. Adjust the frame to the opening with the cams, bringing the frame into close contact with the wall of the doorway, and then press the frame tightly against the slopes of the opening with the clamps. It is necessary to rotate the clamp to tight the air door frame. When the clamps are clamped, there should be a characteristic creak, which means that the door is tightly and hermetically inserted into the opening (Fig. 6.13).

Fig. 6.13 Installation of the air door in the entrance door opening

The fan is inserted into the opening in the canvas with the rotor outwards and the bushings inwards. The fan is attached to the middle horizontal rail with connecting adhesive valves (Fig. 6.14).

Fig.6.14 Fan installation

Connect the block to the fan (Fig. 6.15, Fig. 6.16). The red cable No. 1 (1) from the connector block, see Fig. 15, has an elastic connector to connect the cable (2) at one end (see Fig. 6.15) and a yellow elastic cable (5) at the other end. There is also a cable with a plug to connect to the fan (4). Screw the red cable (4) with the plug into the hole on the top of the fan, and insert the yellow elastic cable (5) into the yellow hole on the fan (Fig. 6.17).

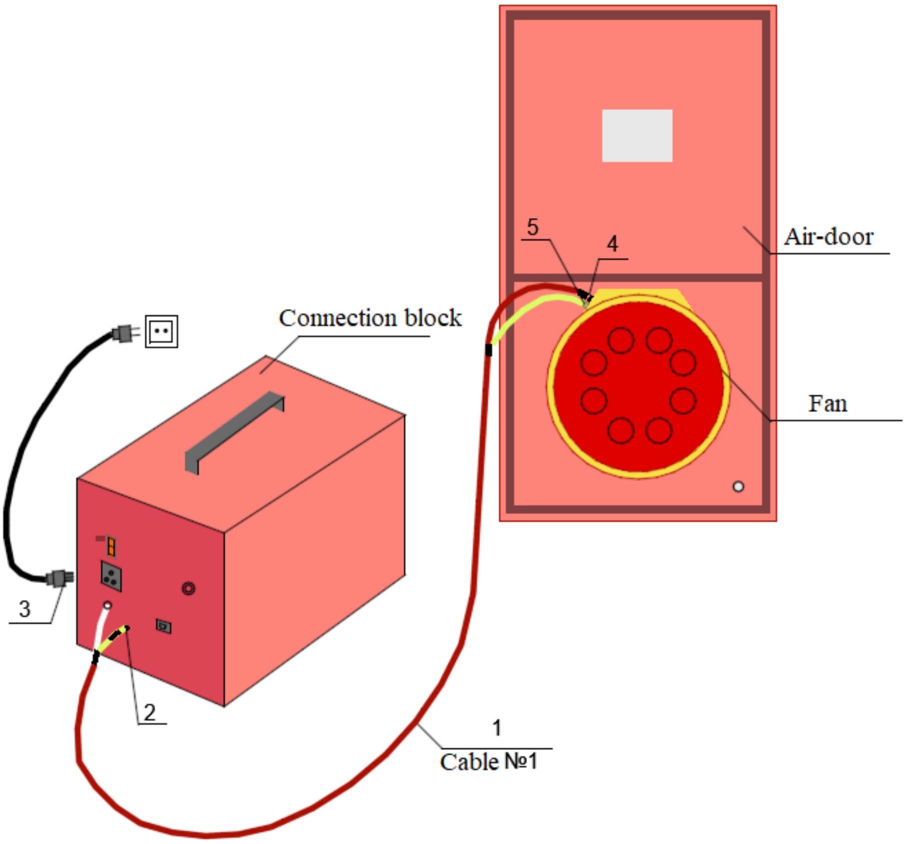


Fig.6.15 Scheme to connect the fan

1 – cable No. 1; 2 - elastic connector to connect cable No. 2; 3 - power supply cable; 4 - cable with the plug to connect to the fan; 5 - elastic yellow cable to connect to the fan

Fig. 6.16 Connection of the fan system

Fig. 17 Installation of the yellow cable in the fan opening

Connect the block with the connection cable (3) to the power supply in the socket (Fig. 6.15.)

Connect the manometer to the connector block. Take out a separate red cable (12), see Fig. 6.18. It has a long red cable at one end (8), a short yellow cable (7) and a yellow plug (6).

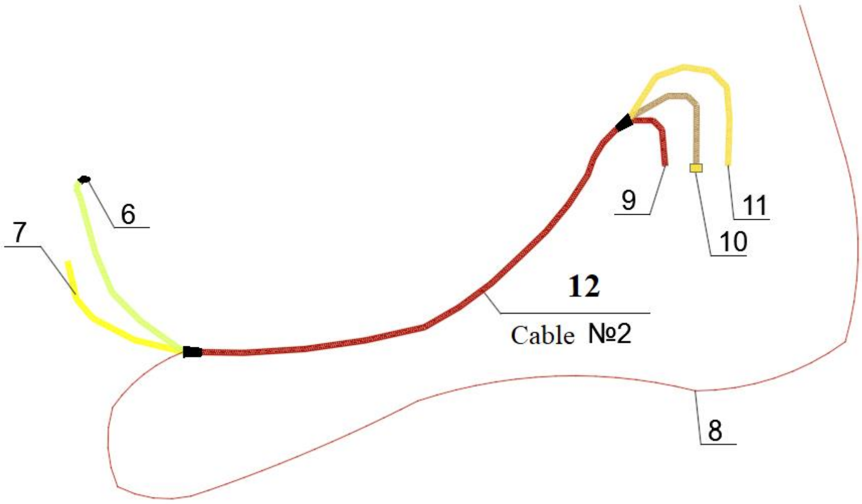


Fig. 6.18 Cable scheme No. 2

6 - yellow plug; 7 - short yellow cable; 8 - long red cable; 9 - red cable for connecting to the manometer; 10 - yellow plug for connecting to the manometer; 11 - yellow cable for connecting to the manometer; 12 - separate cable No. 2

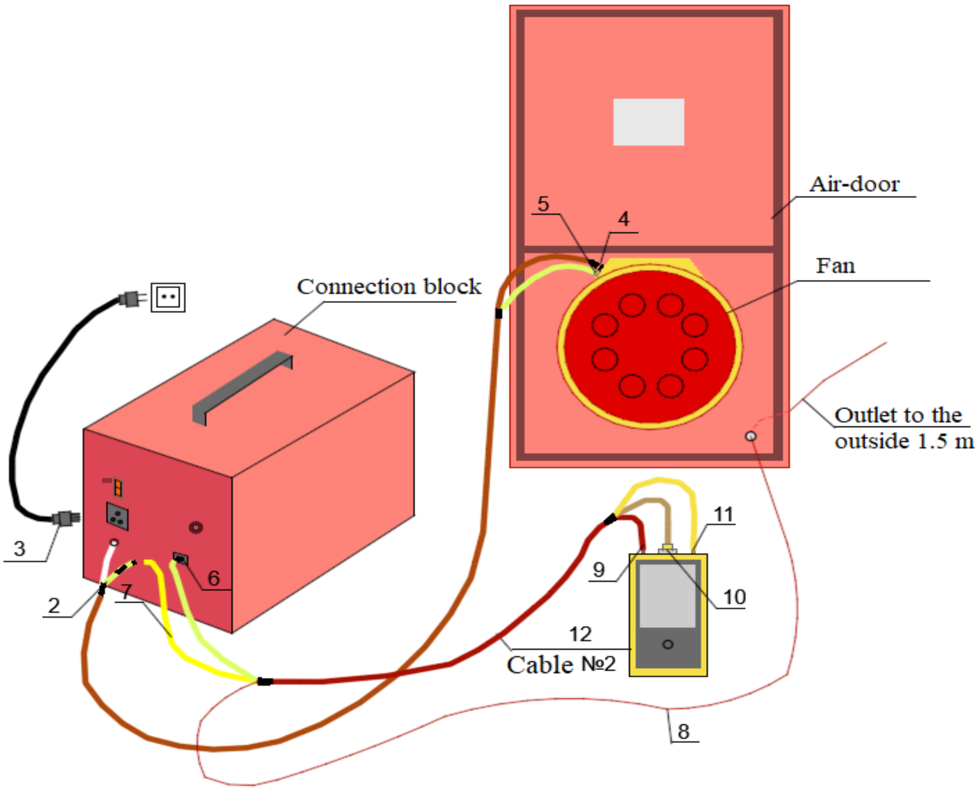


Fig. 6.19 Equipment connection scheme

1 - cable No. 1; 2 - elastic connector for connecting cable No. 2; 3 - power supply cable; 4 – cable with plug for connecting to the fan; 5 - elastic yellow cable for connecting to the fan; 6 - yellow plug; 7 - short yellow cable; 8 - long red cable; 9 - red cable for connection to the manometer; 10 - yellow plug for connection to the manometer; 11 - yellow cable for connection to the manometer; 12 - separate cable No. 2

The long red cable (8), see Fig. 6.19, is inserted into the small hole in the airlock leaf (canvas) on the right, which goes outside 1.5-2m (Fig. 6.20). The yellow short cable is inserted into the yellow hole in the unit (Fig. 6.21). The yellow plug (6), see Fig. 18 is inserted into the «IN» socket of the block (Fig. 6.21).

On the other end of the separate cable No. 12 (12), see Fig. 6.18, there is a red short cable (9), a yellow short cable (11) and a yellow plug (10). Insert the red short cable into the red hole on the top of the manometer, the yellow cable into the yellow hole, and the yellow plug into the upper connector of the manometer (Figures 6.19, 6.22).

Fig.6.20 External cable

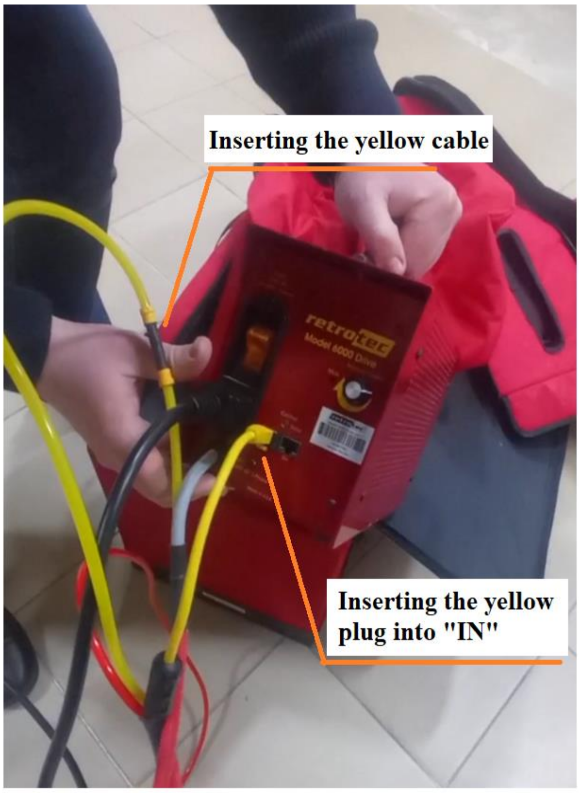


Fig.6.21 Cable connection

Puc.6.22 External cable

Switch on the manometer by pressing the touch button.

Press the «ON» button on the connector block.

How to set up a manometer

Select the fan opening mode. In the main menu of the manometer, click on the fan icon and select the number of open plugs (Fig. 6.23). You can determine how many plugs to open only in a practical way. If the conditioned volume of the building is less than 1000 m^3, choose the type with two open plugs.

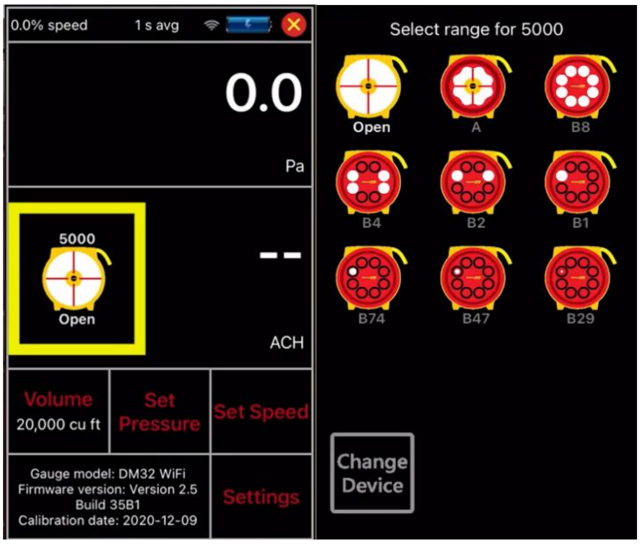


Fig.6.23 Fan mode selection

Set the conditioned area and the conditioned volume of the building. Set the units of measurement: pressure Pa, area m^2, volume m^3 (Fig. 6.24).

Fig. 6.24 Manometer settings

6.3.5 Testing

The test is conducted in two modes:

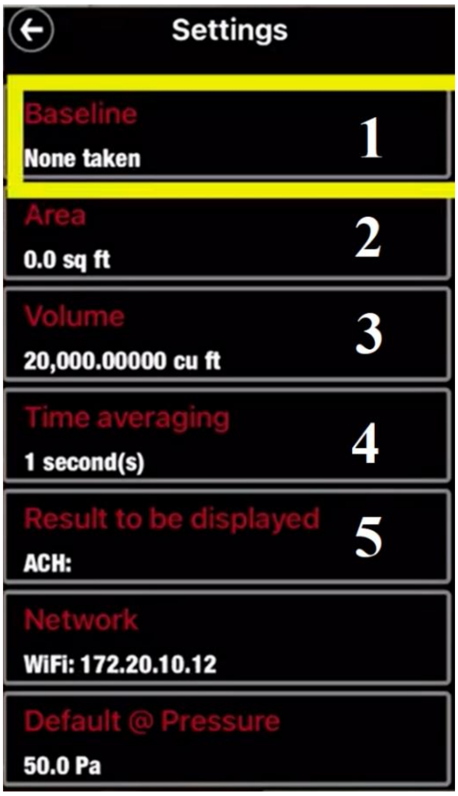
1. In the mode of pressurize test, the fan blows air into the room. In this case, the fan is installed with the outward rotor and the inward plugs. All values of the pressure difference should be with a «-» sign according to [34]. During the test, thermal imaging is carried out outside the building, theatre smoke is used inside the building, and the most defective places where smoke leaks are visible from the outside.

2. In the mode of depressurize test, the fan blows the air from inside to outside. In this case, the fan is installed with inward rotor and outward plugs. All values of the pressure difference must have a «+» sign. According to [34].

6.3.6 Pressurize testing

Identify the baseline. Close all fan plugs and cover the fan.

Go to «Settings» (Fig. 6.25), click on Baseline. After the baseline countdown begins, wait for 20 seconds, then fix the value, for example, 0.7 Pa. Be sure to resert the baseline value, as the manometer automatically takes this value into account. After determining the baseline, remove the cover from fan and open the fan plugs (Fig. 6.26).



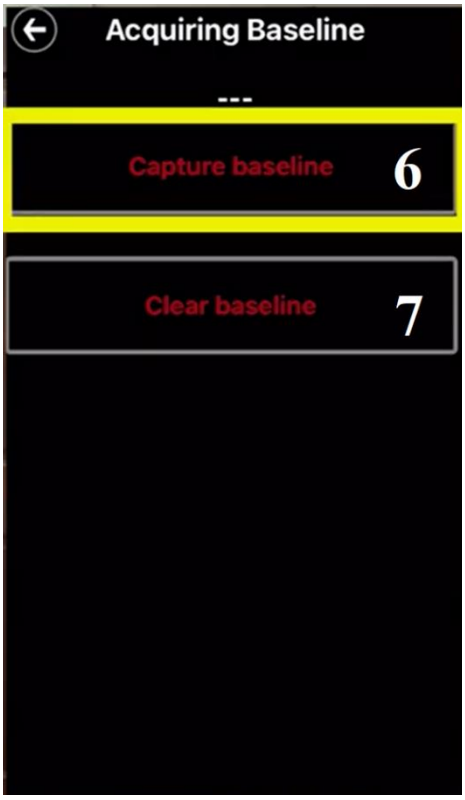


Fig. *6.55 Entering parameters* *Fig. 6.26 Launching baseline*

1 - baseline, 2- area parameter, $м^2$, 3- volume parameter $м^3$, 4- average time for fixing the differential pressure indicator, 5- measutrement unit, 6- entering baseline, 7- resert of baseline

Calculating the initial pressure. The value of the baseline is multiplied by a constant of 5, for example, 0.7*5= 3.5 Pa, according to [34]. But the minimum value of the initial pressure should be 10 Pa, according to DSTU EN ISO 9972:2022. So in this case, we take 10. If the baseline was b-3, then the initial pressure would be 15. Enter the value of the baseline into the FanTestic software.

Open all plugs.

Use the arrow to enter the main menu. Enter the initial pressure using the Set Pressure command, enter the initial pressure, press set, and the fan automatically starts working (Fig. 6.28).

In the programme, specify the type of fan opening (Fig. 6.27).

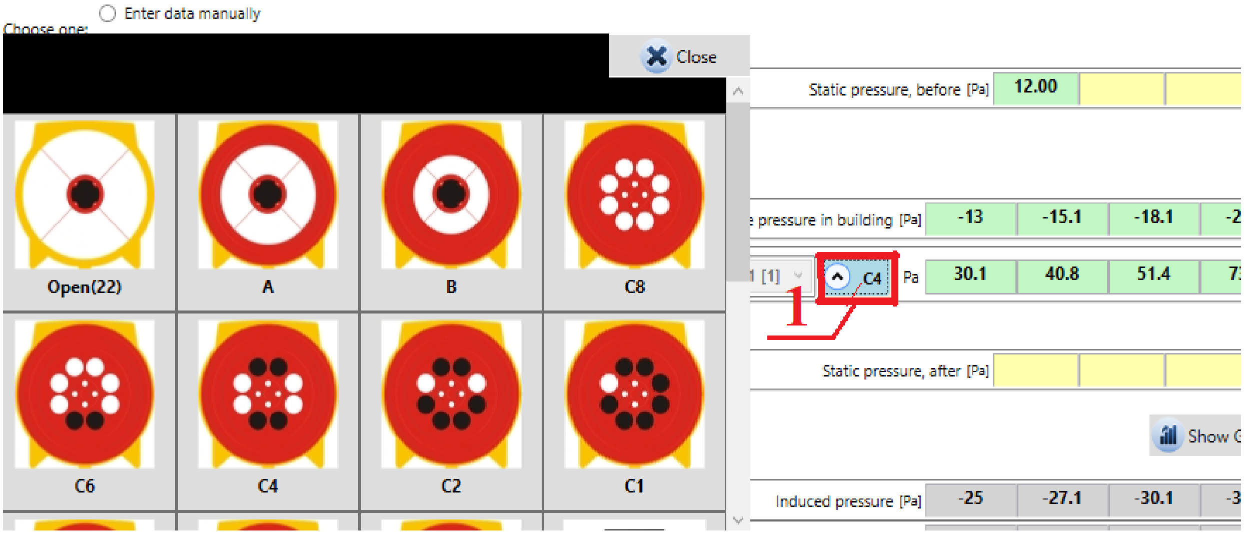


Fig. 6.27 Type of fan opening

1- Button for selecting the type of fan opening

Fig. 6.28 Entering initial pressure

After starting the fan, monitor the pressure on the fan below and the pressure difference above on the display, when the indicator stops for a few seconds, record the pressure value, write it down in FanTestic, and increase the pressure by +5 Pa. This way mark 10 points, record the pressure drop in the upper line, and record the pressure on the fan in the lower line (Fig. 6.29).

At the top, write down the value of the pressure difference (it should be with a «-» sign, because the air is pumped into the building), at the bottom, write down the pressure on the fan.

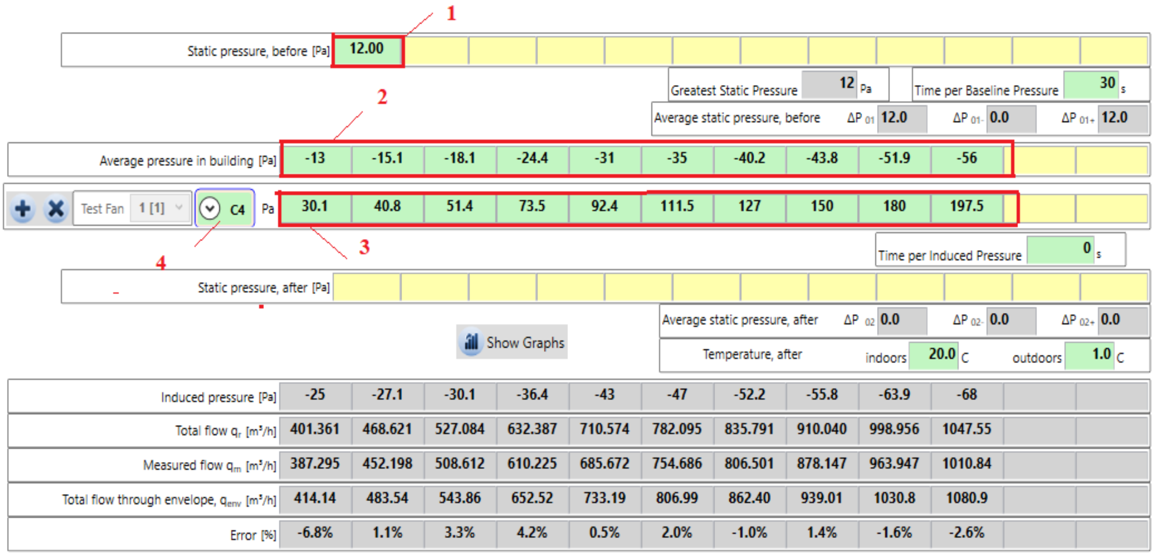


Fig. 6.29 Entering initial pressure, differential pressure and fan pressure

1 - initial pressure value, 2 - differential pressure value, Pa, 3 - fan pressure value, Pa, 4 - button for selecting the fan opening type

Watch the fan power in the upper left corner, the power should not exceed 80% (Fig. 6.30). If the power exceeds 80%, stop the test, open more plugs and run the test again from the baseline.

If, after starting the fan, the manometer shows a dash instead of a value, the fan power is insufficient, stop the test, close the plug and run the test again from the baseline.

Fig. 6.30 Recording pressure

1 - fan power; 2 - value of pressure difference, Pa; 3 - value of pressure on the fan, Pa; 4 - button for increasing the pressure by 5 Pa

After determining the 10 points (the differential pressure values, i.e. the upper pressure, should be at intervals of approximately 5 Pa, and the last point should be approximately 50 Pa), stop the fan operation by pressing the Stop button.

Identify the baseline. Remember to close the fan before identifying the baseline. The value of the baseline is recorded in the FanTestic software.

6.3.7 Depressurize testing

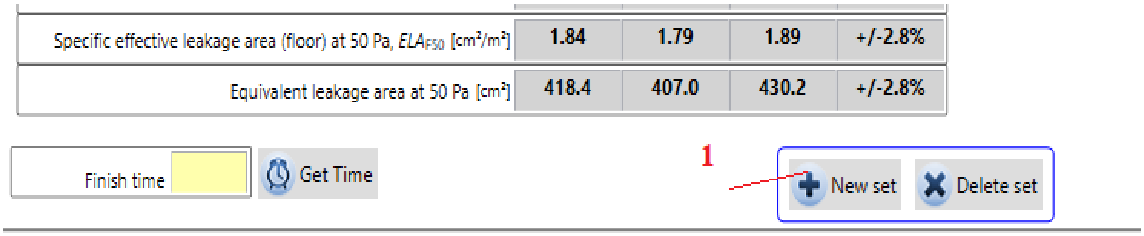
Remove and turn the fan over with the rotor inside and the plugs outside. It is necessary to have someone outside to change the number of plugs. Close it and cover it.

Identify the baseline again, and record the value of the baseline in FanTestic.

Open the fan plugs.

Create a new unit in FanTestic, (Fig. 6.31).

Take the temperature and pressure outside and inside, and record them in the new unit in FanTestic.



Specific effective leakage area (floor) at 50 Pa, ELA_{F50} [cm²/m²]	1.84	1.79	1.89	+/-2.8%
Equivalent leakage area at 50 Pa [cm²]	418.4	407.0	430.2	+/-2.8%

Fig. 6.31 Entering initial pressure

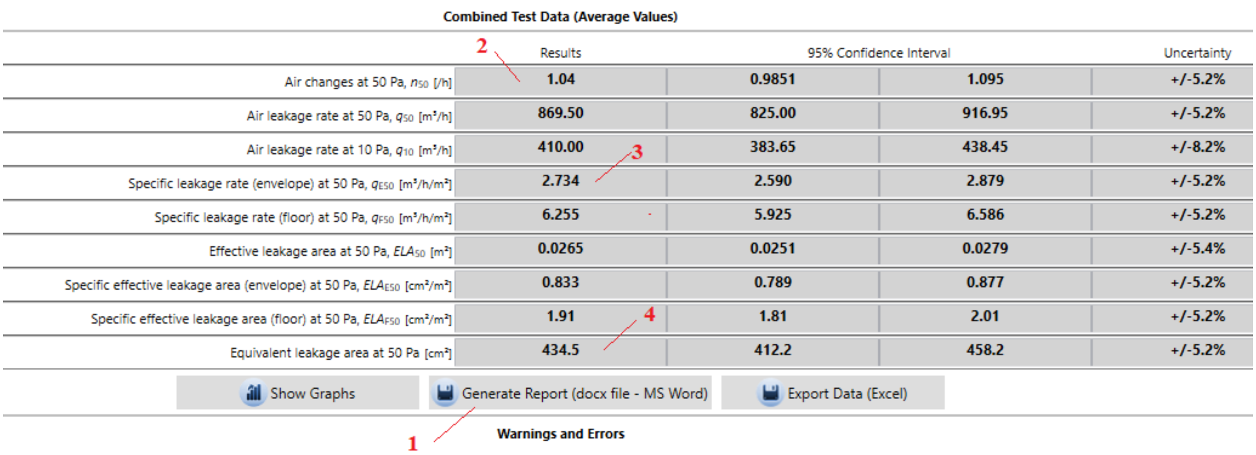
Determine and set the initial pressure from the baseline.

Conduct the test in the same way as the test in the pressurize/depressurize test mode. We record 10 points. But it is important to record the value of the pressure difference (it should be with a «+» sign, because the air is liquefied inside a building). Write down the values of the pressure difference and the pressure on the fan in the FanTestic software. Stop the fan by pressing the Stop button.

Identify the baseline. Do not forget to close all fan plugs before identifying the baseline. The value of the baseline is recorded in the FanTestic software.

Generate an automatic report in the program (Fig. 6.32).

6.3.8 Results analysis



Combined Test Data (Average Values)

	Results	95% Confidence Interval		Uncertainty
Air changes at 50 Pa, n_{50} [/h]	1.04	0.9851	1.095	+/-5.2%
Air leakage rate at 50 Pa, q_{50} [m³/h]	869.50	825.00	916.95	+/-5.2%
Air leakage rate at 10 Pa, q_{10} [m³/h]	410.00	383.65	438.45	+/-8.2%
Specific leakage rate (envelope) at 50 Pa, q_{E50} [m³/h/m²]	2.734	2.590	2.879	+/-5.2%
Specific leakage rate (floor) at 50 Pa, q_{F50} [m³/h/m²]	6.255	5.925	6.586	+/-5.2%
Effective leakage area at 50 Pa, ELA_{50} [m²]	0.0265	0.0251	0.0279	+/-5.4%
Specific effective leakage area (envelope) at 50 Pa, ELA_{E50} [cm²/m²]	0.833	0.789	0.877	+/-5.2%
Specific effective leakage area (floor) at 50 Pa, ELA_{F50} [cm²/m²]	1.91	1.81	2.01	+/-5.2%
Equivalent leakage area at 50 Pa [cm²]	434.5	412.2	458.2	+/-5.2%

Fig. 6.32 Generated report

1. Generating an automatic report in Word; 2- parameter of air exchange rate n50 (h^{-1}); 3- parameter of air permeability q50 ($m^3/h/m^2$).;

4- equivalent leakage area at 50 Pa, (cm^2)

After an automatic report is generated in Word, you need to fill in the data obtained in the report template provided in Appendix A.

According to the results of the test in a two-storey residential building, it was found out:

- parameter of the air exchange rate at a pressure drop of 50 Pa (n50 air changes at 50 Pa) is 1.04 (h-1) (Fig. 6.32).

- specific leakage area through the building envelope at 50 Pa, i.e. the air permeability q50 is 2.734 ($m^3/h/m^2$) (Fig. 6.32);

- equivalent leackage area at 50 Pa is 434,5 (cm^2). (Fig. 32). This indicator is the diameter of the opening in the wall, which includes the areas of all defects and gaps in the external building envelope. FanTestic calculates these values automatically. For more details on the methodology to measure air permeability, see DSTU EN ISO 9972:2022 [34].

These indicators can be used to assess the condition of the building envelope. In this case, the building is energy efficient in terms of air permeability. The building corresponds to energy efficiency class B.

6.3.9 Thermal imaging in air permeability test conditions

During the air permeability test, which typically takes 30 minutes, the defective areas are cooled or heated by the air flow passing through them and the temperature reaches the required difference for be detected by a thermal imaging camera (see Figure 6.33). On the left, the thermography was taken in the building before the test using a differential pressure of $\Delta P = -/+50$Pa, on the right, the thermography was taken during the test using a differential pressure.

We can see on the right that even minor airtightness defects in a building can be identified much more clearly.

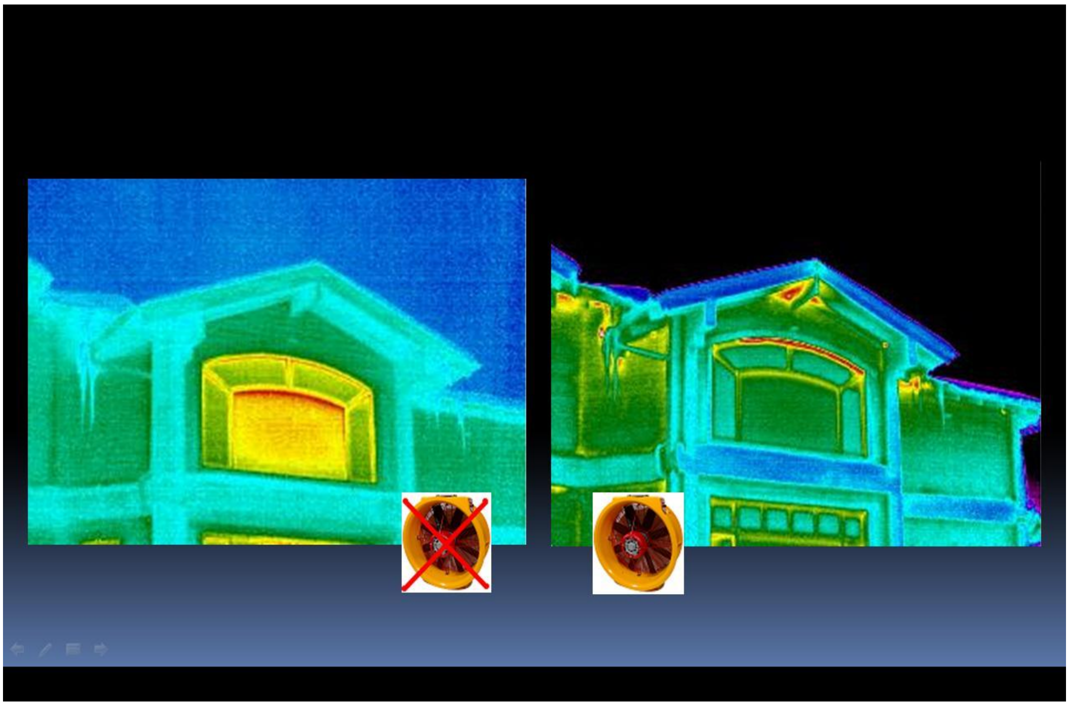


Fig. 6.33 Thermography of the house in normal conditions and during the air permeability test

6.3.10. Report

General information

Test date	24.02.2024
Customer	Konin
Performed by	Bondarenko
Property	two-storey residential building
Building Address	Dnipro, 4 Kryvorizhska St.
Year of construction	new
Floors	2
Area	154 m^2

Geometrical parameters

Building volume [m^3]:	**836**
Envelope area [m^2]:	**318,7**
Floor area [m^2]:	**138,8**
Building height (from ground to top) [m]:	**8,5**

Altitude [m]:	**78**
Number of building storeys	**2**
Accuracy of volume measurements:	**0,02**
Accuracy of envelope area measurements:	**0,02**
Accuracy of floor area measurements:	**0,01**

Note: the table is filled in according to MultiFanTestic (5.12.49.57)

Tesing method

Test method	**Pressurisation and depressurisation**
Terms and conditions	**Sealing of the building**

Architectural and structural scheme

Load bearing structures	**Internal and external walls**
Roof rype	**Gable roof**

External building structures

Walls	**400 mm gas block**
Floors	**Reinforced concrete slab insulated with 100 mm of expanded polystyrene**
Floor slabs	**220 mm hollow reinforced concrete slabs**
Roof	**Cold roof system**
Doors	**Metal and roller shutter garage doors**
Windows	**Double glazed windows**

Heating, air conditioning and ventilation system:

Heating system:	**Electric boiler**
Air conditioning and ventilation system	**Natural and mechanical**

Devices, equipment and software

Equipment	Description	Series number	Calibration end date
	Fan 6000	3PH602480 3PH602499	13.01.2024
	«MultiFanTestic» software v.5.11.29.73	License ===START_KEY===9:}hi% s`wvljk8»4+5»%`	
	Thermal imaging camera	TFA 12304910	

STAGE 1: Indoor air flow test

Environmental data

Environmental conditions		
Wind speed	7 m/s	
Initial Baseline Pressure	742 mmHg	
Final Baseline Pressure	742 mmHg	
Initial Temperature	1 °C	
Final Temperature	2 °C	

Note: the table is filled in according to MultiFanTestic (5.12.49.57)

Combined Test Data (Average Values)

	Results	95% confidence interval		Uncertainty
Air leakage rate at 50 Pa, [m³/h]	869,50	825,00	916,95	+/-5,2%
Air changes at 50 Pa, n50 [/h]	1,04	0,9851	1,095	+/-5,2%
Specific leakage rate (envelope) at 50 Pa, [m³/h/m²]	410,00	383,65	438,45	+/-8,2%
Specific leakage rate (floor) at 50 Pa, [m³/h/m²]	2,734	2,590	2,879	+/-5,2%
Effective leakage area at 50 Pa, [cm²].	6,255	5,925	6,586	+/-5,2%
Specific effective leakage area (envelope) at 50 Pa, [cm²/m²]	265,0	251,5	279,5	+/-5,4%
Specific effective leakage area (floor) at 50 Pa [cm²/m²].	0,8334 2	0,789	0,877	+/-5,2%

Note: the table is filled in according to MultiFanTestic (5.12.49.57)

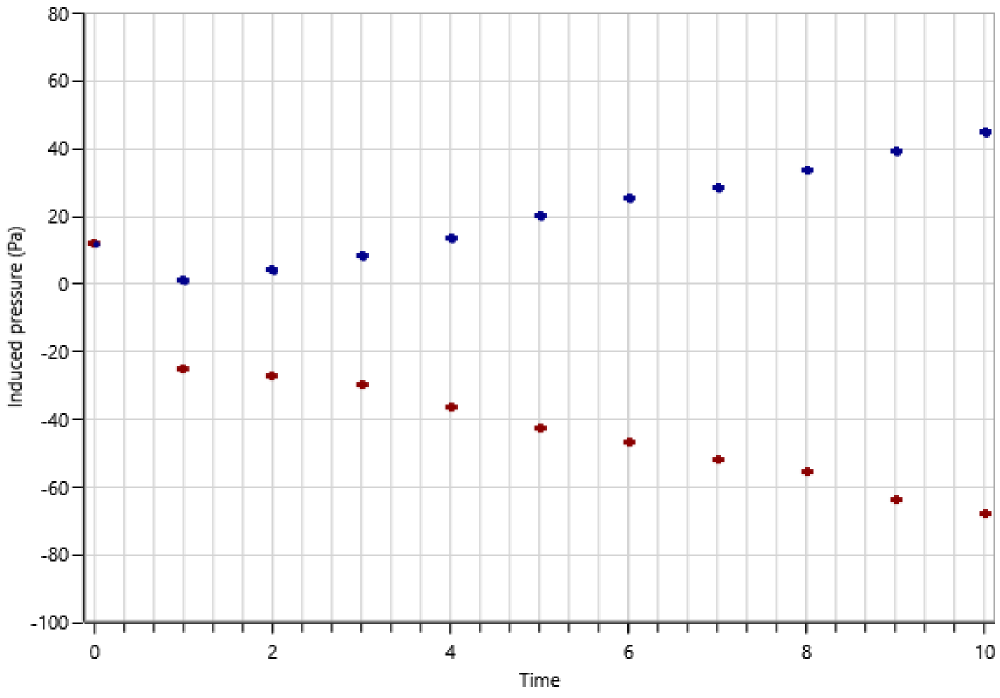


Fig. 6.34 Induced pressure graph

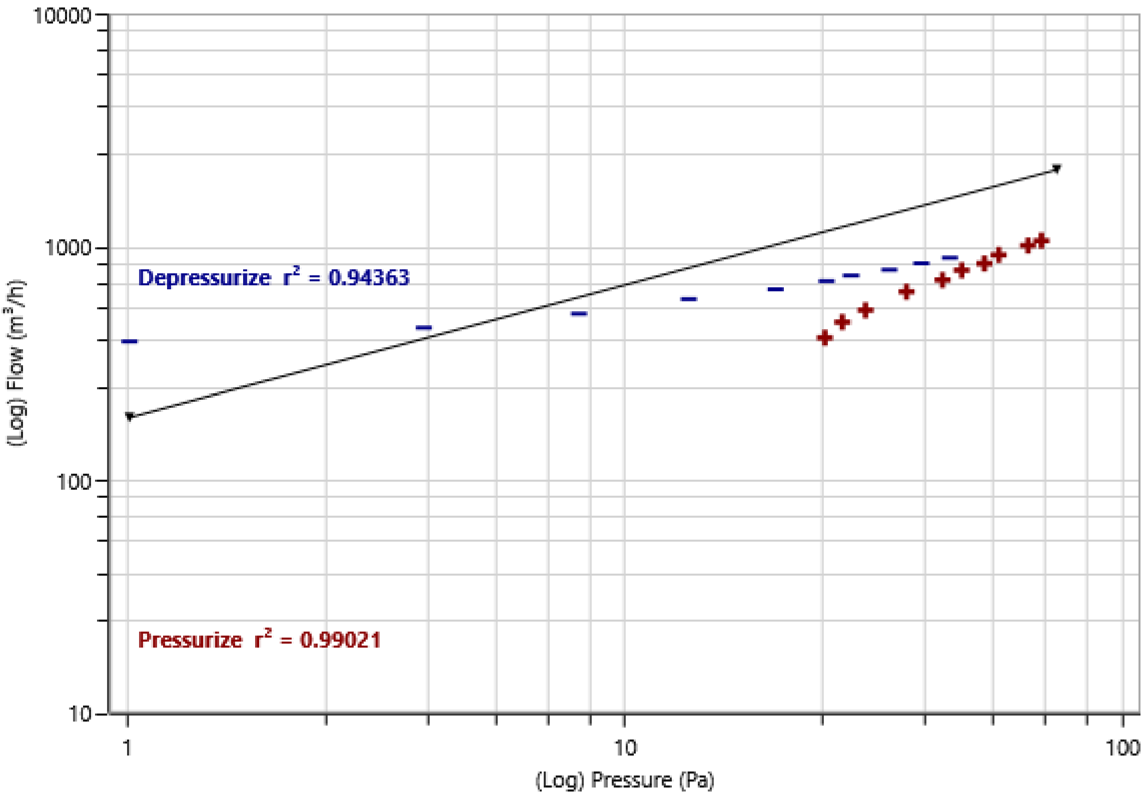


Fig. 6.35 Induced pressure graph

STAGE 2 Saturation test with indoor air flows

(After restarting the pressure reading in the dataset)

Environmental data

Environmental conditions		
Wind speed:	0,55 m/s	
Operator location:	indoors	
Greatest Baseline Pressure Point	12	
Initial Bias Pressure:	12,00 Pa	
Final Bias Pressure:	0,00 Pa	
Average Bias Pressure:	12 Pa	
Initial Temperature:	indoors: 20 °C	outdoors: 1 °C
Final Temperature:	indoors: 20 °C	outdoors: 1 °C
Barometric Pressure	101,325 kPa	from Standard temp/pressure

Note: the table is filled in according to MultiFanTestic (5.12.49.57)

Depressurize test analysis

Coefficient of determination, r^2	0.98333			
	mean	95% confidence limits		uncertainty
		lower	upper	
Slope, n:	0,225	0,18009	0,26973	
Air leakage coefficient, C_{env} [$m^3/h/Pa^n$]:	355,01	311,9	404,1	
Air leakage coefficient, C_L [$m^3/h/Pa^n$]:	374,01	328,6	425,7	
Air flow rate at 50 Pa, [m^3/h]				
Air changes at 50 Pa, n_{50} [/h]	901,57	835,5	972,8	+/-7,6%
Specific leakage rate (envelope) at 50 Pa, [$m^3/h/m^2$]	1,078	0,9963	1,161	+/-7,6%
Specific leakage rate	2,8351	2,619	3,051	+/-7,6%

(floor) at 50 Pa, [m³/h/m²]				
Effective leakage area at 50 Pa, [cm²].	6,4861	5,9923	6,9800	+/-7,6%
Specific effective leakage area (envelope) at 50 Pa, [cm²/m²]	274,8	254,7	296,5	+/-7,9%
Specific effective leakage area (floor) at 50 Pa, [cm²/m²]	0,86417	0,798	0,930	+/-7,6%

Note: the table is filled in according to MultiFanTestic (5.12.49.57)

Depressurize test analysis

Measured pressure [Pa]		13,0	15,9	20,0	25,3	31,9	37,2	40,2	45,6	51,0	56,5
Induced pressure [Pa]		1,0	3,9	8,0	13,3	19,9	25,2	28,2	33,6	39,0	44,5
№1, Range C4	Fan pressure [Pa]	46,4	59,5	77,3	101,5	124,0	145,0	160,5	180,0	203,5	226,0
Total flow rate, q_r [m³/h]	Flow [m³/h]	423,2	484,7	557,1	644,1	709,4	768,6	812,9	860,2	917,6	968,5
Measured flow, q_m[m³/h]	q_m [m³/h]	422,3	483,7	555,9	642,7	707,8	767,0	811,2	858,4	915,6	966,4
Depressurize test analysis (Continued table)											
Flow through envelope, q_{env} [m³/h]	q_{env} [m³/h]	395,0	452,3	519,8	601,1	662,0	717,3	758,6	802,7	856,3	903,8
Error [%]											
Measured pressure [Pa]	423,242	484,72	557,0	644,1	709,3	768,6	812,9	860,2	917,5	968,51	423,24
Induced pressure [Pa]	422,334	483,68	555,8	642,7	707,8	766,9	811,1	858,3	915,6	966,43	422,33
№1, Range C4	394,96	452,33	519,8	601,0	661,9	717,2	758,6	802,7	856,2	903,80	394,96
Total flow,q_r	11,3%	-6,2%	-8,3%	-5,4%	-4,8%	-2,2%	0,8%	2,6%	5,8%	8,4%	11,3

[m³/h]											%

Note: the table is filled in according to MultiFanTestic (5.12.49.57)

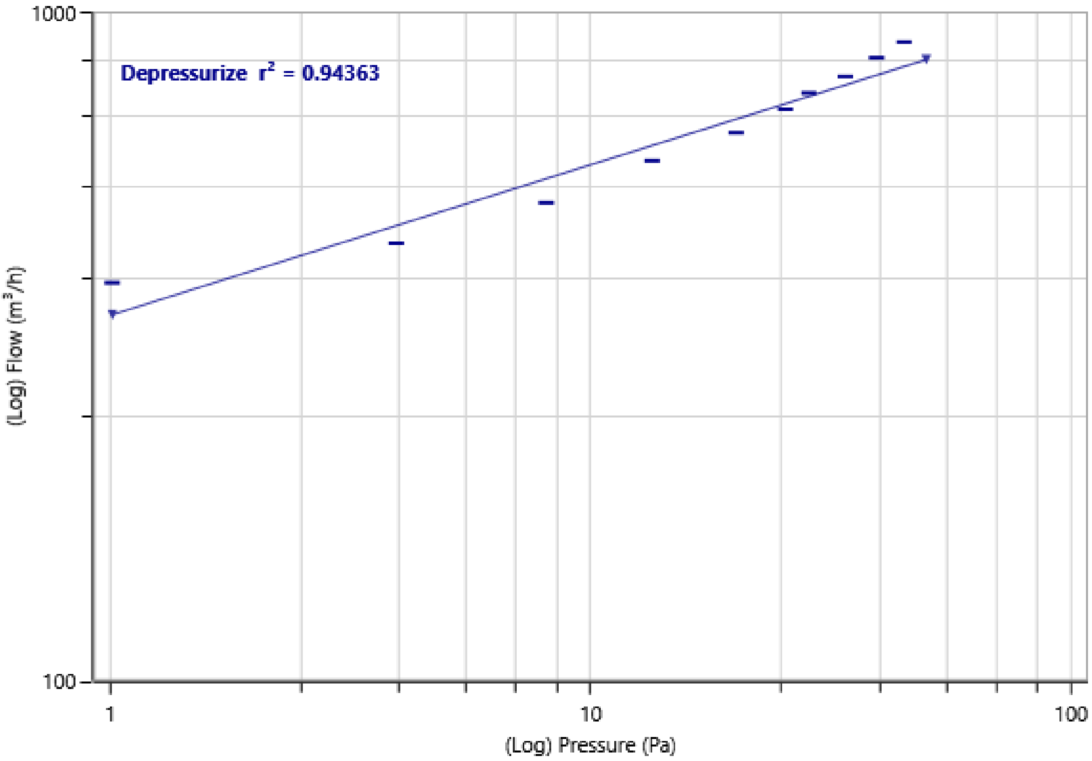


Fig. 6.36 Flow vs Induced Pressure (Depressurize Set)

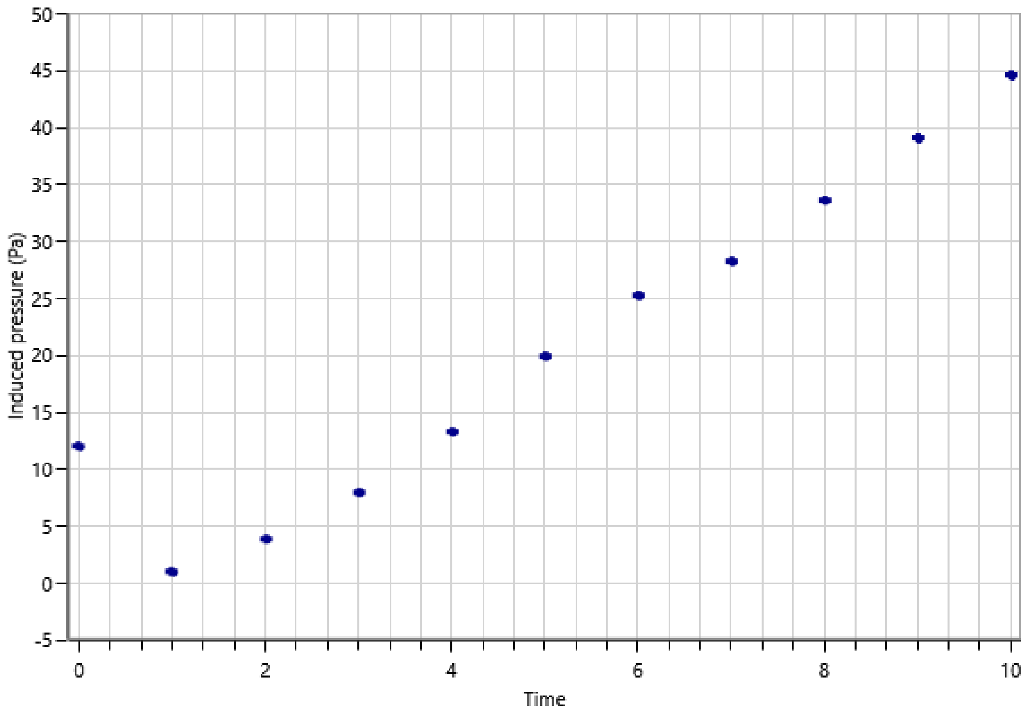


Fig. 6.37 Building gauge pressure (Depressurize Set)

General test result

Pressurize test analysis				
Coefficient of determination, r^2	0.99027			
	meab	95% confidence interval		Uncertainty
		lower	upper	
Slope, n:	0,914	0,84009	0,98831	
Air leakage coefficient, C_{env} [m³/h/Paⁿ]:	23,427	17,73	30,96	
Air leakage coefficient, C_L [m³/h/Paⁿ]:	23,428	17,73	30,96	
Air flow at 50 Pa, [m³/h]	837,40	814,4	861,0	+/-2,8%
Air changes at 50 Pa, n_{50} [/h]	1,002	0,9738	1,030	+/-2,8%
Specific leakage rate (envelope) at 50 Pa, [m³/h/m²]	2,6333	2,560	2,707	+/-2,8%
General test result (continued table)				
Specific leakage rate (floor) at 50 Pa, [m³/h/m²]	6,0245	5,8569	6,1921	+/-2,8%
Effective leakage area at 50 Pa, [cm²].	255,2	248,2	262,4	+/-2,8%
Specific effective leakage area (envelope) at 50 Pa, [cm²/m²]	0,80267	0,780	0,825	+/-2,8%
Specific effective leakage area (floor) at 50 Pa, [cm²/m²]	1,84	1,79	1,89	+/-2,8%

Note: the table is filled in according to MultiFanTestic (5.12.49.57)

Table of pressure drops and generated flows

Measured pressure [Pa]		-13,0	-15,1	-18,1	-24,4	-31,0	-35,0	-40,2	-43,8	-51,9	-56,0
Induced pressure [Pa].		-25,0	-27,1	-30,1	-36,4	-43,0	-47,0	-52,2	-55,8	-63,9	-68,0
№1, Range C4	Fan pressure	30,1	40,8	51,4	73,5	92,4	111,5	127,0	150,0	180,0	197,5

	[Pa]										
	Flow [m^3/h]	401,4	468,6	527,1	632,4	710,6	782,1	835,8	910,0	999,0	1048
	q_m [m^3/h]	387,3	452,2	508,6	610,2	685,7	754,7	811,2	878,1	963,9	1011
	q_{env} [m^3/h]	414,1	483,5	543,9	652,5	733,2	807,0	862,4	939,0	1031	1081
Total flow, q_r [m^3/h]		401,361	468,621	527,084	632,387	710,574	782,095	835,791	910,040	998,956	1047,55
Pressure drops and generated flows (continued table)											
Measured flow, q_m [m^3/h]		387,295	452,198	508,612	610,225	685,672	754,686	806,501	878,147	963,947	1010,84
Flow through envelope, q_{env} [m^3/h]		414,14	483,54	543,86	652,52	733,19	806,99	862,40	939,01	1030,8	1080,9
Error [%]		-1,8%	1,1%	1,3%	1,2%	0,5%	2,0%	-1,0%	1,4%	-1,6%	-1,6%

Note: the table is filled in according to MultiFanTestic (5.12.49.57)

Energy efficiency class of the building

The building corresponds to the energy efficiency class « B » according to the air exchange rate

6.3.11 Conclusions

Air permeability test allows assessing the condition of external envelope, the actual value of the air exchange rate n50 (h-1); air permeability q50 ($m^3/h/m^2$) and the value of the equivalent leakage area at 50 Pa, (cm^2). Air permeability test should become mandatory, especially for buildings with a conditioned area of more than 1000 m^3, to ensure quality control of construction and installation works as well as energy efficiency of the building.

APPENDIX A

Building airtightness report template

Prydniprovska State Academy of Civil Engineering and Architecture

REPORT
ON THE AIRTIGHTNESS OF THE BUILDING

____

(title of the object)

Customer: Full name

Contractor: Full name

Certificate №:

Tel.

Email.

2024р.

General information

Test date	
Customer	
Performed by	
Property	
Building address:	
Year of construction:	
Floors:	
Area:	

Geometrical parameters

Building volume [m³]:	
Envelope area [m²]:	
Floor area [m²]:	
Building height (from the ground to the top) [m]:	
Altitude [m]:	
Number of building storeys:	
Accuracy of volume measurements:	
Accuracy of envelope area measurements:	
Accuracy of floor area measurements:	

Note: the table is filled in according to MultiFanTestic (5.12.49.57)

Test method

Test method	
Terms and conditions	

Architectural and design scheme

Load-bearing structures	
Roof type	

External building structures

Walls	
Floor	
Floor slabs	
Roof	
Doors	
Windows	

Heating, air conditioning and ventilation system:

Heating system:	
air conditioning and ventilation system:	

Devices, equipment and software

Equipment	Description	Series number	Calibration end date

STAGE 1 Air flow test

Environmental data

Environmental conditions		
Wind speed		
Initial Baseline Pressure		
Final Baseline Pressure		
Initial Temperature		
Final Temperature		

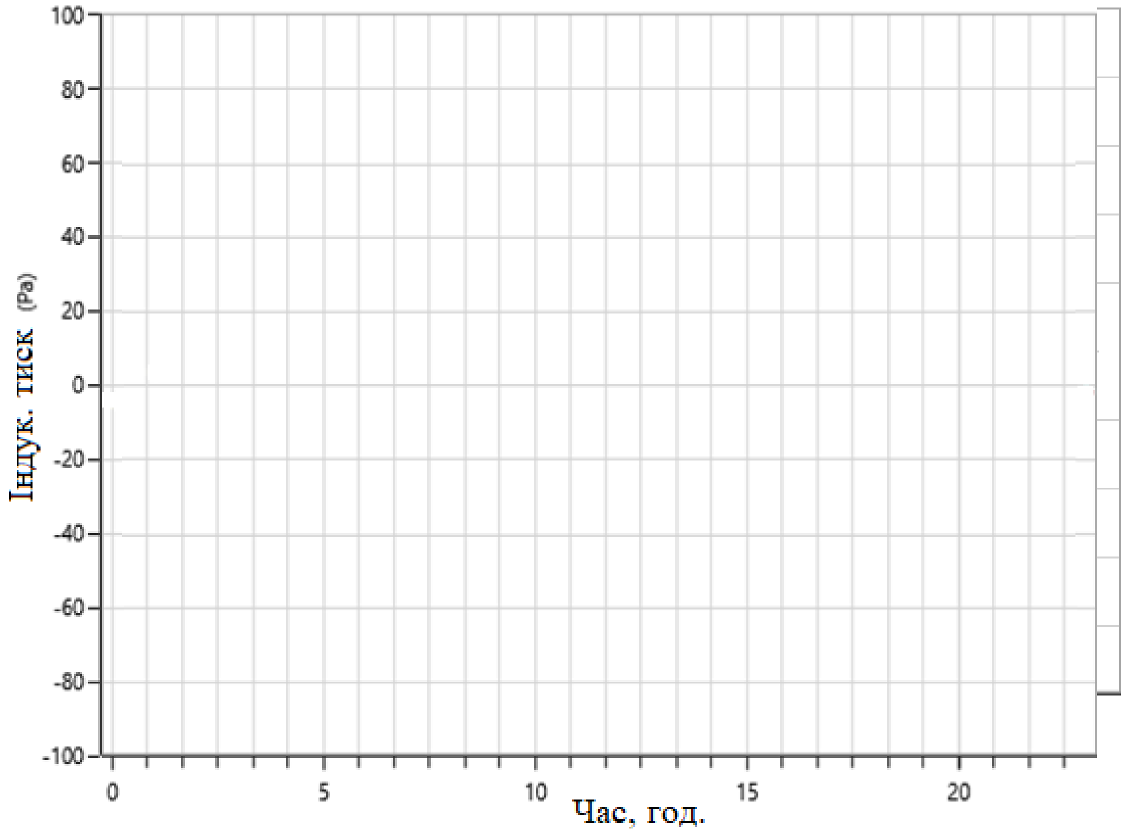
Note: the table is filled in according to MultiFanTestic (5.12.49.57)

Combined test data (average values)

	Results	95% confidence interval		Uncertainty
Air leakage rate at 50 Pa, [m³/h]				
Air changes at 50 Pa, n50 [/h]				
Specific leakage rate (envelope) at 50 Pa, [m³/h/m²]				
Specific leakage rate (floor) at 50 Pa, [m³/h/m²]				
Effective leakage area at 50 Pa, [cm²].				
Specific effective leakage area (envelope) at 50 Pa, [cm²/m²]				
Specific effective leakage area (floor) at 50 Pa [cm²/m²].				

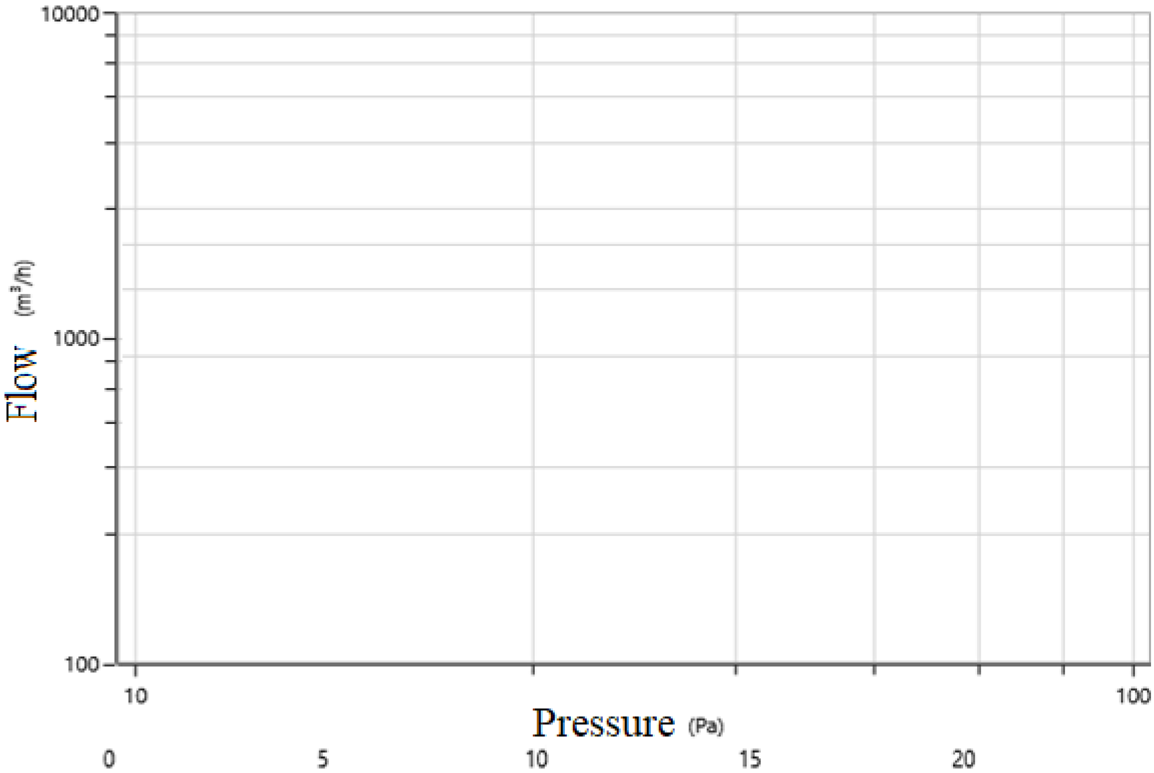
Note: the table is filled in according to MultiFanTestic (5.12.49.57)

Induced pressure



graph

Induced pressure graph



STAGE 2 Saturation with indoor air flows test

(After restarting the pressure reading in the dataset).

Environmental data

Environmental conditions		
Wind speed:		
Operator location:		
Greatest Baseline Pressure Point		
Initial Bias Pressure:		
Final Bias Pressure:		
Average Bias Pressure:		
Initial temperature:		
Final temperature:		
Barometric pressure:		

Note: the table is filled in according to MultiFanTestic (5.12.49.57)

Depressurize test analysis

Coefficient of determination, r^2	0.98333			
	mean	95% confidence limits		uncertainty
		lower	upper	
Slope, n:				
Air leakage coefficient, C_{env} [$m^3/h/Pa^n$]:				
Air leakage coefficient, C_L [$m^3/h/Pa^n$]:				
Air flow rate at 50 Pa, [m^3/h]				
Air changes at 50 Pa, n_{50} [/h]				
Specific leakage rate				

(envelope) at 50 Pa, $[m^3/h/m^2]$				
Specific leakage rate (floor) at 50 Pa, $[m^3/h/m^2]$				
Effective leakage area at 50 Pa, $[cm^2]$.				
Specific effective leakage area (envelope) at 50 Pa, $[cm^2/m^2]$				
Specific effective leakage area (floor) at 50 Pa, $[cm^2/m^2]$				

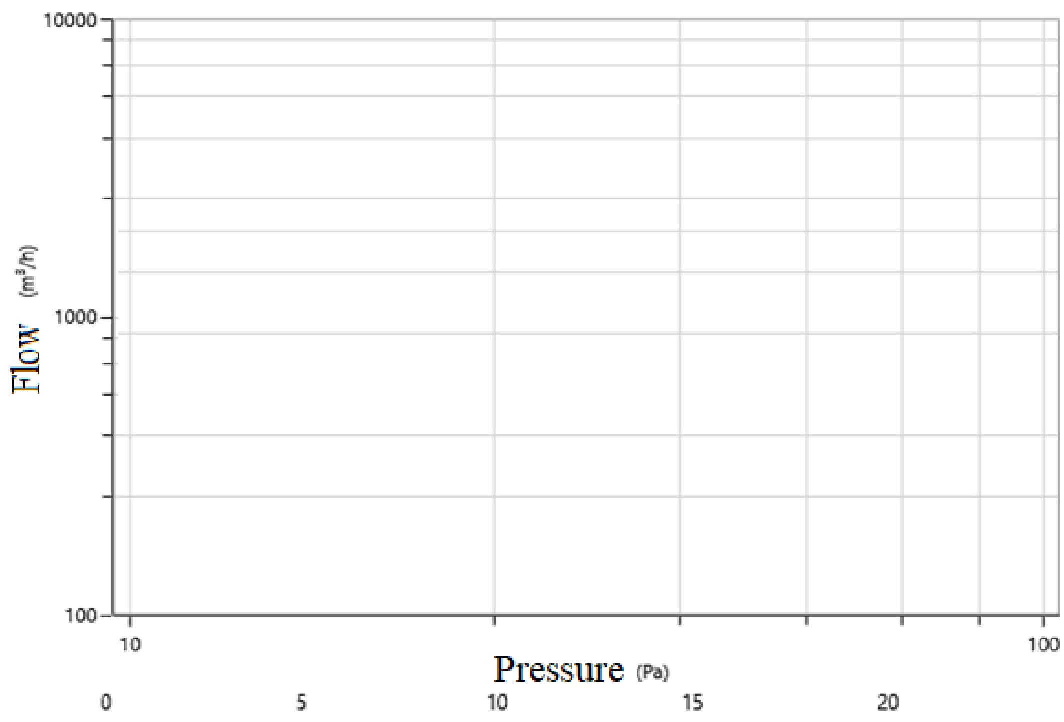
Note: the table is filled in according to MultiFanTestic (5.12.49.57)

Depressurize test analysis

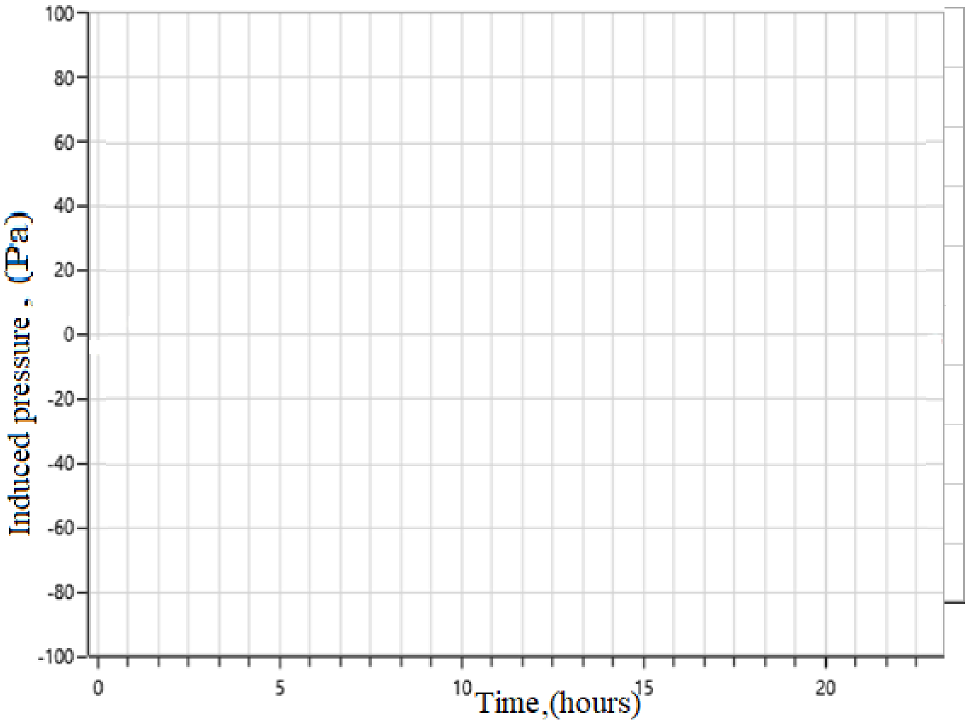
Measured pressure [Pa]											
Induced pressure [Pa]											
№1, Range C4	Fan pressure [Pa]										
Total flow rate, q_r $[m^3/h]$	Flow $[m^3/h]$										
Measured flow, $q_m [m^3/h]$	q_m $[m^3/h]$										
Flow through envelope, q_{env} $[m^3/h]$	q_{env} $[m^3/h]$										
Error [%]											
Measured pressure [Pa]											

Induced pressure [Pa]											
№1, Range C4											
Total flow, q_r [m³/h]											

Flow vs Induced Pressure (Depressurize Set)



Building gauge pressure (depressurize set)



General test result

Pressurize test analysis				
Coefficient of determination, r^2	0.99027			
	mean	95% confidence interval		uncertainty
		lower	upper	
Slope, n:				
Air leakage coefficient, C_{env} [$m^3/h/Pa^n$]:				
Air leakage coefficient, C_L [$m^3/h/Pa^n$]:				
Air flow at 50 Pa, [m^3/h]				
Air changes at 50 Pa, n_{50} [/h]				
Specific leakage rate (envelope) at 50 Pa, [$m^3/h/m^2$]				
Specific leakage rate (floor) at 50 Pa, [$m^3/h/m^2$]				
Effective leakage area at				

50 Pa, [cm²].				
Specific effective leakage area (envelope) at 50 Pa, [cm²/m²]				
Specific effective leakage area (floor) at 50 Pa, [cm²/m²]				

Note: the table is filled in according to MultiFanTestic (5.12.49.57)

Table of pressure drops and generated flows

Measured pressure [Pa]											
Induced pressure [Pa].											
№1, Range C4	Fan pressure [Pa]										
	Flow [m³/h]										
	q_m [m³/h]										
	q_{env} [m³/h]										
Total flow, q_r [m³/h]											
Measured flow, q_m [m³/h]											
Flow through envelope, q_{env} [m³/h]											

Note: the table is filled in according to MultiFanTestic (5.12.49.57)

Energy efficiency class of the building

The building corresponds to the energy efficiency class according to the air exchange rate

«_____»

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