TRANSACTIONS OF THE INSTITUTE OF AVIATION
No. 3(240), pp. 32-48, Warsaw 2015
DOI: 10.5604/05096669.1194965

ISSN 0509-6669
eISSN 2300-5408

INFRARED BUILDING INSPECTION WITH UNMANNED AERIAL VEHICLES

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Abstract

Article discusses the subject of energy efficiency in the construction and building sector and the use of unmanned aerial vehicles in order to study energy consumption in buildings. At the beginning, the concept of energy efficiency in buildings is presented, its importance and impact on the environment. Then, the article discusses the current situation, the trends in Europe and the potentials of this sector together with the most important legal issues related to the topic of energy efficiency. The next section explores the effects of buildings on the environment, in particular, through heat loss. The article also outlines the importance of research methods and thermal imaging. Specifically developed unmanned aircraft classification is adapted for the use in thermal studies. The topic is discussed in terms of both the characteristics and structure, as well as the advantages and disadvantages of the use of such solutions. Possible paths of development in this subject are presented, as well as problems and concerns. The last part focuses on the example of the use of unmanned platform to study thermal imaging of a residential building. This is a case study carried out in December 2014.

Keywords: energy efficiency, unmanned aerial vehicles, energy modeling, heat losses, thermal imaging, sustainable energy development, final energy consumption, building sector.

1. ENERGY EFFICIENCY

1.1. Importance of Reducing Energy Consumption

Experts point out the increasing importance of reducing energy consumption in energy systems. Currently, the greatest energy consumption can be observed in the building sector, transport and industry. The greatest potential for reducing energy consumption is in those sectors. Over the period from 1990 to 2008, the total Gross Domestic Product in EU-27 increased by an average of 2.1% per year but the final energy consumption, in turn, only 0.5%. Consequently, the energy consumption decreased by 1.6%. During the past 20 years, energy efficiency in the EU-27 increased by 19%, with an average annual value of 1.1%. Energy consumption in the building sector increased by about 13%, with an annual average of 0.7%. In the industrial sector in the EU-27 energy consumption decreased by 30% over the last two decades, with an annual average of 1.9%. The transport sector improved energy efficiency by about 15% over the past 20 years, averaging 0.9% per year [1].

Carbon dioxide price increased from the beginning of the year 2013 by 40%, to about 6.9 Euro per tonne, and since April 2012, the cost of its purchase went up by as much as 140%. Industry generators draw attention to the growing problem of reducing the free emission, which in a few years will force them to drastically raise energy prices. With the continuing increase of emissions prices, in a few years, energy prices can be up to 50% higher than today. Abatement options are few. The use of renewable energy and energy efficiency are considered the basis for sustainable energy development, but recently more and more often, experts point out the increasing importance of reducing energy consumption in energy systems. While renewable energy sources such as biomass, wind or hydro, begin to arise more and more controversy and doubt about the absolutely positive impact on the environment, saving energy is the cleanest way of reducing gas emissions. Its potentials is huge and much bigger than the possibility of alternative sources of energy, including renewable energy sources and existing nuclear power technologies [2], [3].

Investments in energy efficiency improve the image of the country and cause an increase in the competitiveness of the economy in the world. At the same time, this type of initiative stimulates an internal development and promotes technological growth, providing new jobs and increasing the value of the sector. A very important, if not the most important issue for the countries at the stage of catching up with the most developed economies, is the fact that improving energy efficiency is the cheapest and most cost-effective way to achieve sustainable energy development [4].

2.1. Current Situation and Reduction Potential in the Construction and Building Sector

Over the last two decades energy consumption in EU has decreased by around 1.6%. The levels are very different for the individual countries. In Estonia, energy consumption decreased by 8%, Slovakia and Lithuania by 5%, while in Portugal and Spain consumption has increased in the last 20 years [5]. That has an impact on both the change in the structure of the economy, such as the development of the service sector in relation to the industry, as well as efforts to improve energy efficiency. It is worth mentioning, at this point that, the technological development of the country concerned is correlated with highly energy-intensive infrastructure development such as roads, grids, etc. The energy consumption in the building sector is affected by a number of opposing factors. On one hand, it improves the quality of the materials used, the energy saving and energy efficiency of household appliances and lighting, on the other hand, it increases the surface area and the number of units built and operated using the equipment in them. For the past 20 years, energy efficiency in the EU-27 has increased by 19%, with an average annual value of 1.1%. In the same period, energy consumption in the construction sector has increased by about 13%, with an annual average of 0.7% (approx. 0.4% per person). In 2006, emissions of the residential sector accounted for 10% of total greenhouse gas emissions of the European Union [6].

In the industrial sector, over the past two decades, in the EU-27, energy consumption has been reduced by 30%, with an annual average of 1.9%. Differentiation between countries is quite large. Reducing the consumption was observed in almost all industries, with the exception of the textile. Three of the most energy-intensive industries, responsible for 50% of total consumption, is the steel industry, paper and chemicals, reduced energy consumption by 53%, 27% and 11%.

Over the years in the building sector can be observed a significant improvement in terms of energy consumption. This is due to both the development of construction technologies, as well as raising standards of heating. Observing this data, one can estimate the potential of energy efficiency improvements associated with the modernization of the building at certain period.

1.3. Legal Basis to Improve Energy Efficiency

Each new solution, even the most accurate and cost-effective, can have huge problems in the implementation if there are no pre-relevant regulations and provisions facilitating and enhancing its application. The aim is to improve both supervision and regulations, as well as the promotion and support of research and development. The idea of improving energy efficiency has been adopted by the European Parliament through the preparation of a package of measures on energy and climate change, known colloquially as "three times twenty plus 10". Key assumptions include the achievement of this package 2020 [7] by the countries of the Union with a number of objectives:

- Increase of renewable energy share in overall energy consumption by 20%;
- Reduction of greenhouse gas emissions (compared to the base year 1990 and 1989 for some countries) by 20%;
- Reduction of primary energy consumption by 20% as compared to 2006;
- Increase of biofuels share in overall production by 10%.

One of the first regulations dealing with energy efficiency is the EU directive 2006/32/EC called ESD (EU Directive on Energy End-Use Efficiency and Energy Services) [8]. Its provisions came into force on 1 January 2008 and assume that the EU Member States achieve energy reduction relative to baseline by 9% for a period of nine years (2008 - 2016). This means that the average efficiency is to be improved by about 1%. The Directive requires that the decrease should be the result of deliberate actions taken by the governments of the member states.

In June 2008, the Project began conducting the Common Shares on the implementation of Directive 2012/27/EC on energy end-use efficiency and energy services. Currently, under the name of the CA ESD II (the project has been extended) is performed corrugated structure for the information exchange among the countries of the European Union, creation of sponse opportunity to share and experience as well as to enable discussion and application of optimal solutions for the provisions of Directive 2006/32/EC implementation.

Requirements of the Directive imposes an obligation to develop and prepare national plans to achieve the objectives, the so-called Energy Efficiency Action Plans (EEAP). These documents must be based on the assumptions of the energy policy of the European Union.

2. THERMAL ANALYSIS OF BUILDINGS WITH UNMANNED AERIAL VEHICLES

2.1. Heat Loss

The energy performance of a building is a complex and dynamic phenomenon influenced by many different parameters such as external temperature, solar radiation, U-Values of the walls, thermal mass of the building, ventilation rate and activities inside the building. The optimum design of the building is highly dependent on the climate and the topological environment, in which the building is situated. The energy use of buildings can be substantially reduced by an improved design of the building components and control of the systems. Table 1 shows how different type of buildings, varied by the year of construction, differs in terms of energy need for heating.

Table 1. Annual energy need for heating [kWh/m^2] [9]

Building Date	Detached House	Terraced House	Multi-Detached House	Apartment Building
1917	365.9	459.4	326.9	326.9
1918	365.9	459.4	326.9	326.9
1945	352.2	297.2	202.1	202.1
1971	208.6	188	190.4	190.4
1979	209.3	187.4	154.5	154.5
1989	131.4	172.4	81.2	81.2
2003	90.4	79.3	72.4	72.4

Heat loss from the interior of the building, the two major ways: transfer through the materials that make up the the outer envelope of the building (measured the U-Value) or by the exchange of air between its interior and the external environment, that is ventilation.

It is estimated that typical heat losses from a building are as follows [10]:

- Walls – 35%;
- Roofs – 25%;
- Floors – 15%;
- Draughts – 15%;
- Windows – 10%.

The rate at which heat is transferred by the outer envelope of the building is expressed as U-Value. Heat always warms region of the cold area and each constituent material of the outer building envelope transfers heat at different rates. Low U-Values are given to those materials whose the heat transfer is slow and therefore are good as heat insulators. The lower the U-value is, the lower the amount of heat loss, and the better insulating properties.

For each considered construction, irrespective of the U-Value, the heat loss is directly related to the temperature difference from the outside and the inside, and, to a lesser degree, color and texture of the exterior walls. Moisture reduces the isolation performance of materials, because wet material has increased conductivity. Even moderate changes of moisture can significantly increase the element U-Value, reducing its insulating properties. Common causes include moisture penetration in the walls due to damaged or deleted render leaks gutters and poorly fitted window frames. Therefore, it is important to ensure that buildings are well maintained and waterproof, in order to keep the U-Value at a low level [10].

The thermal bridge occurs at the site where the outer part of the wall, roof or floor removes heat from the interior of the building faster than the material surrounding it. Properly installed insulation provides consistent thermal protection and can reduce thermal bridging. It should be noted that the increased insulation performance can cause problems of thermal bridges, allowing condensation and enhancing effects.

2.2. Thermal Imaging

There are many techniques for investigating the energy efficiency of the building, which does not interfere with its structure. These are simple techniques, such as measuring equipment for testing the moisture. But, they are also more complicated and expensive, for example

thermography. In any case, it is important to make an expertise selection of appropriate methods of measurement and an interpretation of results.
Infrared (IR) is invisible radiant energy that is emitted by every object with the temperature above absolute zero. Infrared or thermal imaging can be used in various applications including detecting and assessing heat losses in insulated systems, observing changing flow in the pipe networks or detecting overheating of electrical apparatus. Thermal imaging can be successfully used in construction and building sector, mostly for detection of defects in insulation layers, thermal bridges and defects in heating network.

Thermography, or thermal imaging, is photography using a camera that captures infra-red (IR) light rather than the visible light captured by a standard camera. IR rays are outside the visible spectrum, and are invisible to the naked eye. All objects that are warmer than absolute zero (-273°C) emit infrared light. The warmer an object is, the more infrared light it emits. IR cameras record the amount of infrared light and transfer it into temperature, which is indicated by the scale bar or thermogram.

As the buildings are typically large constructions, it is convenient to perform thermal imaging inspections keeping the proper distance from the object. A perfect solution is the usage of remotely operated Unmanned Aerial Vehicles (UAVs) equipped with IR cameras. An advantage of this solution also gives a possibility to inspect roof or other tall constructions that cannot be easily accessed by a man.

Thermal imaging cameras are able to capture even very small differences in temperature at 0.1°C. The image presented by means of a thermal imaging camera is multicolored, where each color represents a different temperature. Different scales may be used depending on the presented objects. Thermal Imaging studies have many uses in many fields, and can thus be a useful diagnostic tool in the analysis of the state of the building. Particularly the issue of non-invasiveness of research is very important, eg. in historic buildings.

Current solutions for infrared inspections are combination of hardware (camera, lens, detectors, etc.) and software. Smart using of the advanced software can give information about quantity of the energy loss, the risk of appearance of dew point and other valuable data.

Thermal Imaging studies can identify problems with the building surface. Thermal imaging may be used to identify and locate areas of moisture thinner wall elements, cracks and cavities. Specialization is required not only in making decisions about how to take pictures, but also later in their interpretation. Unfortunately objects that have high or low emissivity, such as, for example metal, do not provide accurate temperature measurement. Also, elements such as weather conditions, orientation and time of day, is the flow of the results. Information collected from thermal images can be properly evaluated only in conjunction with the data collected in the framework of a comprehensive study of the state.

2.3. Classification of Unmanned Aerial Vehicles

UAVs (unmanned aerial vehicles) or drones are such aircrafts that can fly without an on-board human operator [11]. An unmanned aircraft system (UAS) is the entire system, which consists of main components: the unmanned aircraft (UAV), communication data link, the ground control station (GCS) and the operator. UAV can be either ground or remote controlled, partially of fully autonomous [12].

A wide range of UAV types can be classified according to their operational range, weight, missions, performance, configuration, complexity or altitude. Unfortunately, currently there is no widely used, universal and common UAV classification. The categories are classified according to the range: long, short and close, altitude: high, medium, low and very low, and based on the purpose of UAV: target and decoy, reconnaissance, combat, research and development, civil and commercial [12], [13], [14].

According to [12] the UAV classification can also be distinguish depending on the application: dull, dirty and dangerous missions. The main civilian application are: border security, environmental monitoring and agriculture, remote sensing, aerial mapping and meteorology.

Based on the characteristic the following classification, which can vary with national legal restrictions, can be taken into account when selecting the UAV for thermal imaging:

- NAV (Nano Air Vehicles): usually used in swarms of UAVs for radar confusion for ultra-short range surveillance. Due to very small dimensions all sensors including cameras, propulsion system and control subsystems need to be made small enough [15];
- Micro UAVs (Unmanned Micro Aerial Vehicle): have a close range, are portable, hand launched, and fly at very low altitude. Payload weight is less than 2 kg. Take-off weight is less than 5 kg. Total power is lower than 100 W. Total time less than 1 hour [16];
- Mini UAVs (Unmanned Aerial Vehicle Mini): have a close range and fly at low altitudes. Payload weight is about 1 ÷ 3 kg. Take-off weight is less than 20 kg. Total power is less than 10 kW. Total time is shorter than 2 hours [16];
- Regular/Small UAVs: medium range, medium altitude. They include launch systems. Payload weight is less than 150 kg. Take-off weight is lower than 400 kg. Total power 10 ÷ 50 kW. Total time less than 6 hours;
- MALE UAVs (Medium Altitude Long Endurance): they perform long flights at medium altitudes [16];
- HALE UAVs (High Altitude Long Endurance): they perform long flights at high altitudes. Total flight time is about 24 ÷ 48 hours [16].

A lot of research and work have been done in UAV technology in order to increase the flight endurance and payload. According to [12] different UAV aerodynamic configurations and sizes with variety of capabilities, endurance and flight levels were developed and classified as follows:

- Fixed-wing UAVs – in general a runway to takeoff and land or catapult launching system is required. Fixed – wing UAV can provide a long endurance and high cruising speed;
- Rotary-wing UA (rotorcraft, vertical takeoff and landing VTOL) – they may be in different configurations like: helicopters, coaxial, tandem and multi-rotors. Their main advantages are high maneuverability and hovering ability in order to enable operation in closed spaces [17];
- Blimps – usually balloons and airships. They are lighter than air, but with large sizes, have long endurance and fly at low speeds [12];
- Flapping-wing UA – which have flexible and/or morphing small wings inspired by birds and flying insects [12];
- There are also some other hybrid or convertible configurations [12] like: convertible rotor aircraft, tilt-wing-body aircraft, ducted fan aircraft, jet-life aircraft [15].

2.4. Advantages of Unmanned Aerial Vehicles for Thermal Imaging

A number of applications are directly related to a thermal imaging issue like the buildings thermal diagnosis, inspection of industrial facilities, such as chimneys, cooling towers, water towers, tanks and pipelines, detection of water deficit in agriculture, the temperature measurements for production lines and industrial facilities monitoring, locating people during search and rescue missions, monitoring areas after fires or other natural or industrial disaster and many others.

Depending on characteristics and performance of UAVs, it is possible to use them to perform all sorts of tasks that require special sensors. Well designed and equipped UAVs can be used for buildings thermal inspections. Aerial thermal imaging performed by UAVs can be very advantageous in the building sector in order to identify the thermal losses and bridges, construction defaults, detect defects, lack of insulation or air leakage, control energy losses and provide monitoring.

The (UAV) unmanned aerial vehicle application in thermal imaging is very beneficial for a number of technical and economic reasons, the most important are as follows: an ability to take pictures for small, difficult areas, relatively no time and space constraints, low operating costs resulting in getting a view of a wide area in a minimum time and cost, an ability to support digital processing of aerial and satellite images, environmentally friendly application, a relative independence from aviation weather conditions.

For civil and for a specific application of thermal imaging the main advantages of UAVs are:

- Increased capabilities like endurance, real-time deployment and full spectrum coverage compared to satellite-based remote sensing applications and manned aircraft;
- Advantage of investment and operation costs;
- Technology maturation due to military applications.

On the other hand, there are significant challenges associated with the development of UAVs, both technical and regulatory ones.

The greatest potential for thermal imaging application have rotary-wing (multi-rotors) and fixed-wing structures, which can be assimilated to a group of Mini UAV (Unmanned Aerial Vehicle Mini). This is due to relatively low manufacturing, investment and operation costs of UAV platform and an on-board equipment, which consists of a control system, navigation and registration data. In addition to the cost important factors are: critical technical parameters of the UAV like altitude, range, flight time, payload, take-off weight and external dimensions, portable, automatic and autonomous control and navigation, and different applicability [18], [19]. UAVs allow fast, relatively cheap high resolution data and images acquisition of any orientation [14].

Valuable advantage of UAVs of using vertical take-off rotorcraft is a careful examination of all the elements such as vertical walls buildings and ability to accurately diagnose roofs and facades of buildings without the need to expose people to work at heights. This method provides fast and precise control of both the entire roof surface and the side surfaces, which is not only the most accurate, but also very economical. UAV thermal imaging is very essential because most of heat loss from a building refers to the roof, walls and windows and technical details are necessary for modernization, technical and economic improvement of the energy performance of a building. Regular monitoring can lead to significant cost savings and defects removal at an early stage.

In some cases of buildings, apart from individual evaluation of their energy performance and roof inspection, the availability of thermal imaging information allows taking into account the spatial circumstances and location of the buildings themselves and the general study of the surrounding area for the global performance measurement [20].

Properly used thermal imaging cameras can give a fast and reliable control of the amount of heat loss in the building as a result of leaks and defects. The use of appropriate sensors and computer systems will provide automatic and precise location of any faults, fast acquisition time of thermal imaging data, high ground resolution image data, high accuracy positioning, the ability to perform multiple and repetitive data aqusition at the time of registration.

2.5. Challenges of Unmanned Aerial Vehicles for Thermal Imaging

UAVs are modern devices that combine cutting edge technology in the field of control, electric propulsion, GPS and aviation. Currently they are made of extremely lightweight materials, advanced BLDC motors and can be vertical take-off (multi-rotors).

The current research problems, which are associated with the development of UAVs relate mainly to a new construction, design and implementation of autonomous flight, real time communication, integration of multiple sensors UAV platform and automation of data acquisition [14]. Regarding the current trends of UAV miniaturization, and also payloads, there is a need for smaller and more compact equipment. According to [21] the growth of thermal imaging sensors miniaturization and lowering weight can be seen in the past few years. Some existing very light and small thermal sensor models are suitable for light UAS: FLIR with 0.07 kg of weight and 7.5 - 13.5 μm of spectral range and Themoteknix Systems Ltd with 0.105 kg of weight and 8 - 15 μm of spectral range.

The scope of the future work includes research and development focused on the following specific topics [14], [15], [22], [23], [24], [25], [26]:

- the lack of prescriptive standards, legislation and regulation for development and operation in civilian airspace system;
- regulations for the certification of UAS operations and maintenance activities including automated separation for safe operation of UAS in high-density operating environment;
- political and social acceptance of UAS application in the civilian area;
- civil law regulation for cameras usage and privacy rights;
- safety of the technology and its potential for accidents;
- “Sense and Avoid” systems development, certification and integration into controlled airspace;
- ability to operate in different weather conditions and high turbulence;
- development of new low cost UAV platforms and innovative UAS design;
- on-line and real-time, near (quasi) real-time UAS design;
- design of mission techniques for thermal imaging at low flight levels;
- development of autonomous on-board flight management systems;
- planning and implementation of autonomous UAV flight;
- optical sensor calibration procedure;
- different sensors and multispectral cameras integration and usage on board an UAV;
- process automation of sensors orientation;
- georeferencing tools of aerial images at low-level flights;
- UAV data integration with data from ground-based measurements;
- combining data obtained from different sensors: video, RGB, IR, NIR, CIR, laser scanning;
- on-line digital data transmission and methods of compression;
- data processing automation: point cloud processing, generating of digital elevation model, digital surface model (DEM/DSM) and 3D models with georeferencing data;
- 3D mapping and GIS development;
- UAV flexibility for different application.

3. CASE STUDY – DETACHED HOUSE

During the winter season in 2014 an UAV with IR camera was used for inspection of a detached house located in Warsaw, Poland.

UAV used for this operation was a multirotor hexacopter with the maximum payload of around 7 kg, and flight time around 20 minutes. Hexacopter allows for optimum performance,

stability and precise operation which is important in maneuvering in urban areas. The model of UAV used was equipped with all the necessary systems including downlink for video preview, gimbal for controlling the view from camera and GPS.
IR camera used was designed for mobile and aerial operations. It has a resolution of 320 x 280 pixels and accuracy of ±2°C. The camera operates in the spectrum of 7.5 - 13 µm, which allows to measure temperature in the most common applications. The camera allows for the real-time view for the operator, and attached software allows for performing different analysis. The output data could be a film with the temperature data or single photos made in a time lapse.

The inspected building was quite new, built in modern technology and no defects or thermal bridges were expected. However, with the use of IR camera, two of them were found.

The inspection was performed during a winter day with the temperature of -8°C. It was partially cloudy with some occasional direct sunlight. The outcome of the inspection is presented below.

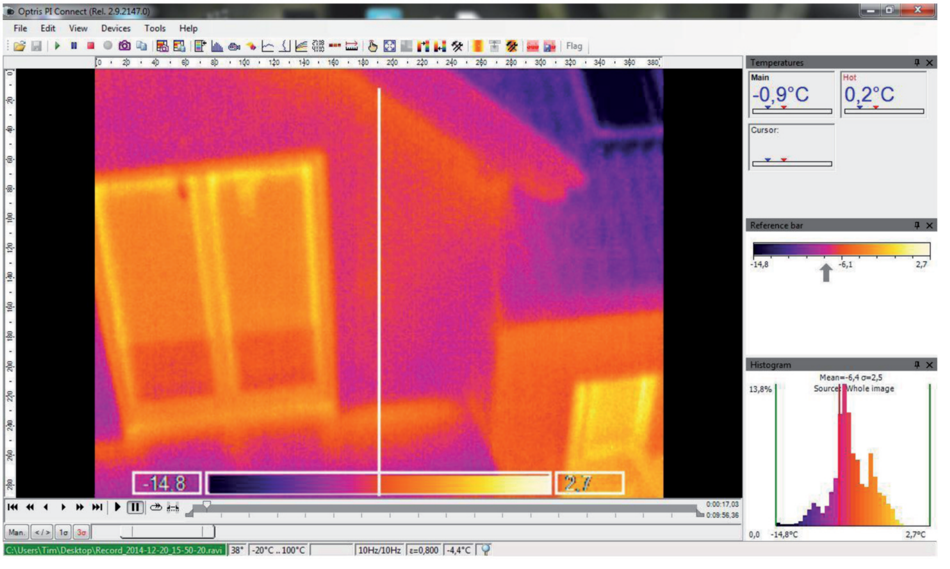

Figure 1. Picture of the facade from the west. Level +1. Visible thermal bridge on the connection of the balcony slab with the building construction. The white line presents temperature profile [zdj. T. Sasin, 2014]

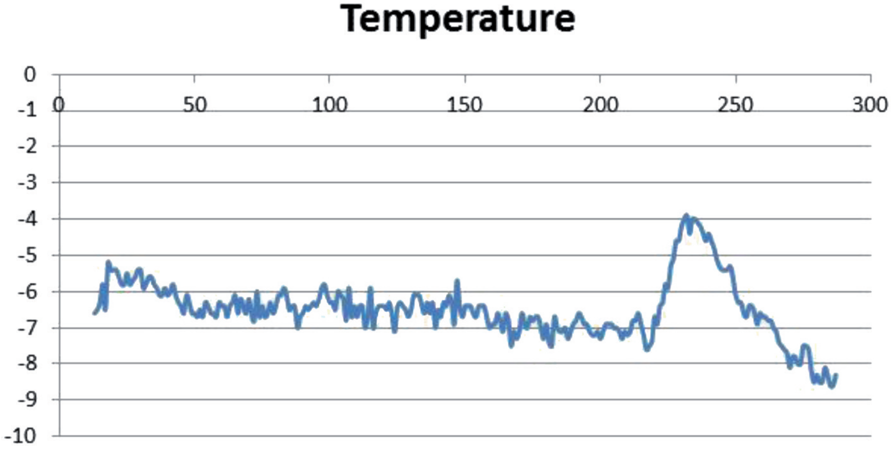

Figure 2. Temperature profile (white line). Visible temperature increase on thermal bridge

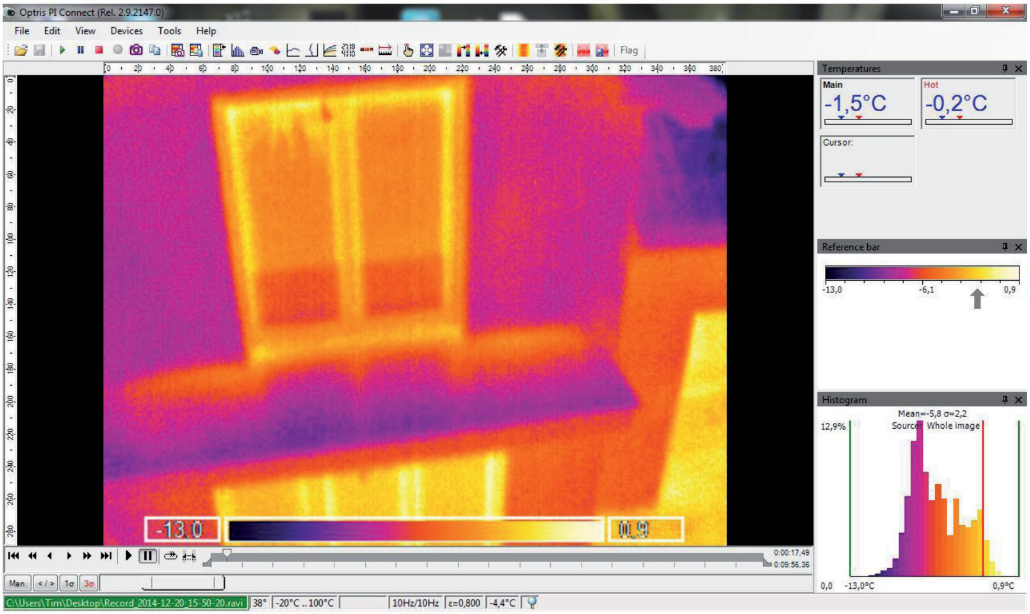

Figure 3. Picture of the facade from the west. Level +1. Visible thermal bridge on the connection of the balcony slab with the building construction [zdj. T. Sasin, 2014]

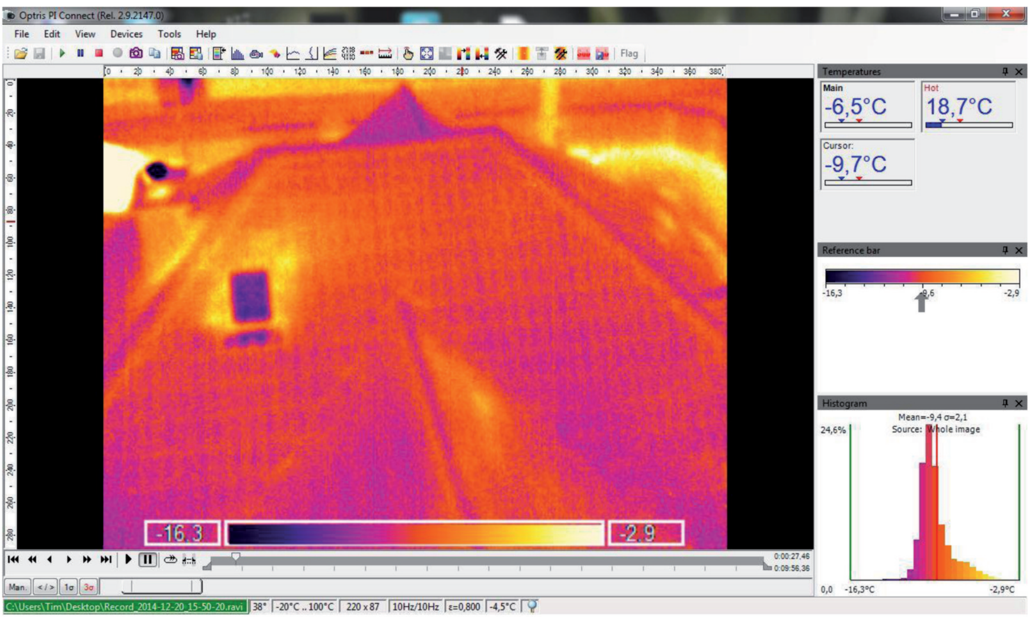

Figure 4. Picture of roof window, shoot from the west. Visible heat losses around the window [zdj. T. Sasin, 2014]

Figure 5. Picture of roof window, shoot from the west. Visible heat losses around the window [zdj. T. Sasin, 2014]

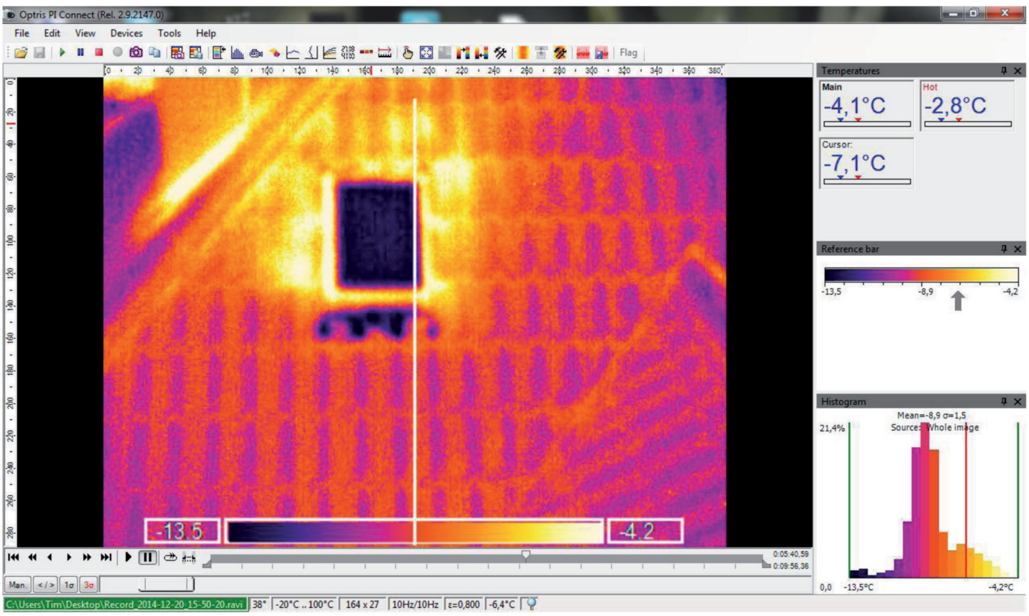

Figure 6. Picture of roof window, shoot from the west. Visible heat losses around the window. The white line presents temperature profile. Visible vent exhaust in left upper corner [zdj. T. Sasin, 2014]

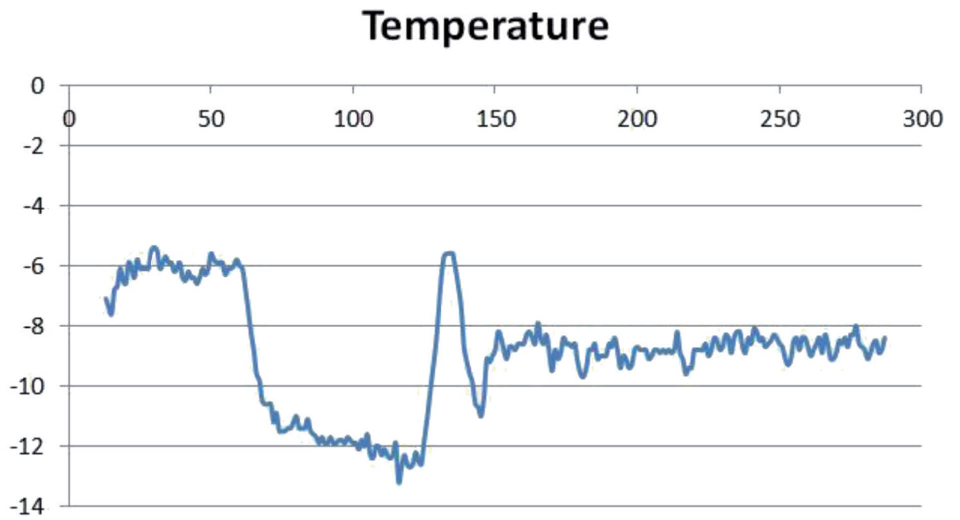

Figure 7. Temperature profile (white line). Visible decrease of the temperature is the reflection of the sky in the glass

The figure 7 shows the difference between the temperature above the window (around -6°C, first part of the chart) and the temperature below the window (around -9°C, second part of the chart).

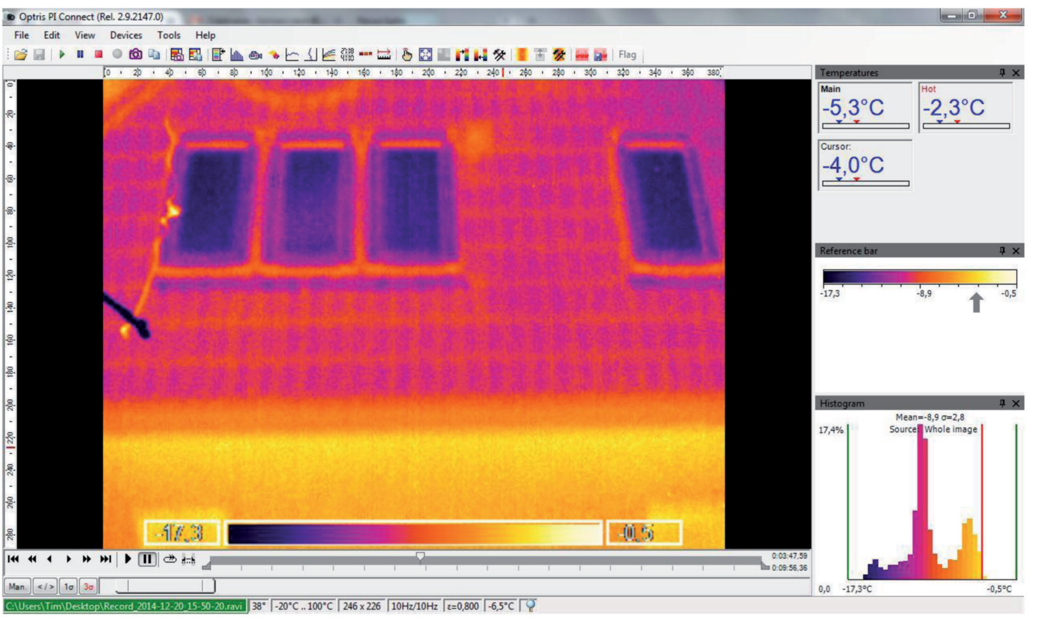

Figure 8. Roof windows, shoot from the north. Visible little thermal bridge close to the third window, in the right upper corner [zdj. T. Sasin, 2014]

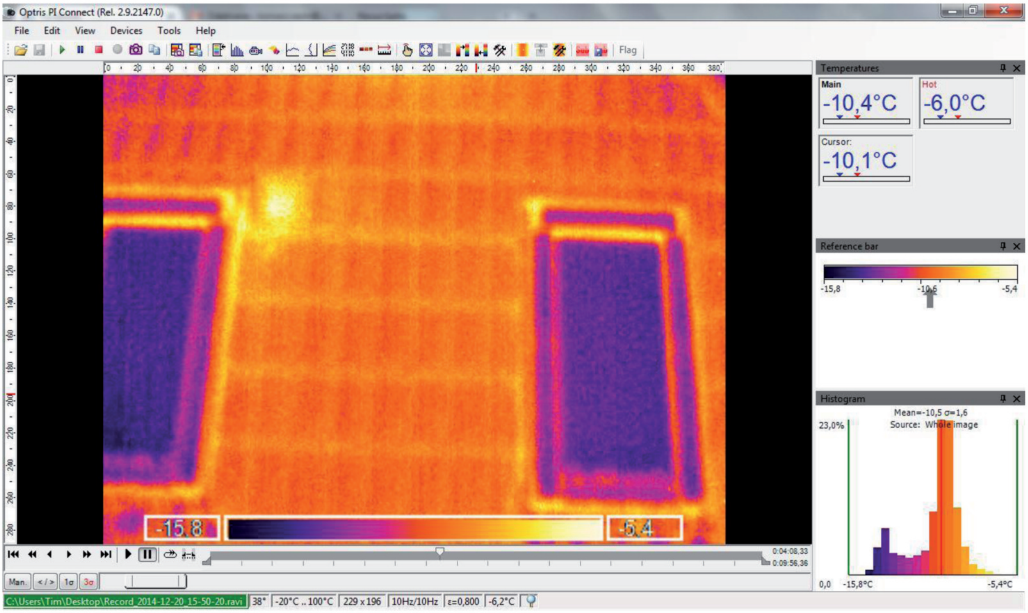

Figure 9. Roof windows, shot from the north. Visible little thermal bridge close to the third window, in the right upper corner [zdj. T. Sasin, 2014]

Figure 10. Roof windows, shot from the north. Visible little thermal bridge close to the third window, in the right upper corner − lack of snow [zdj. T. Sasin, 2014]

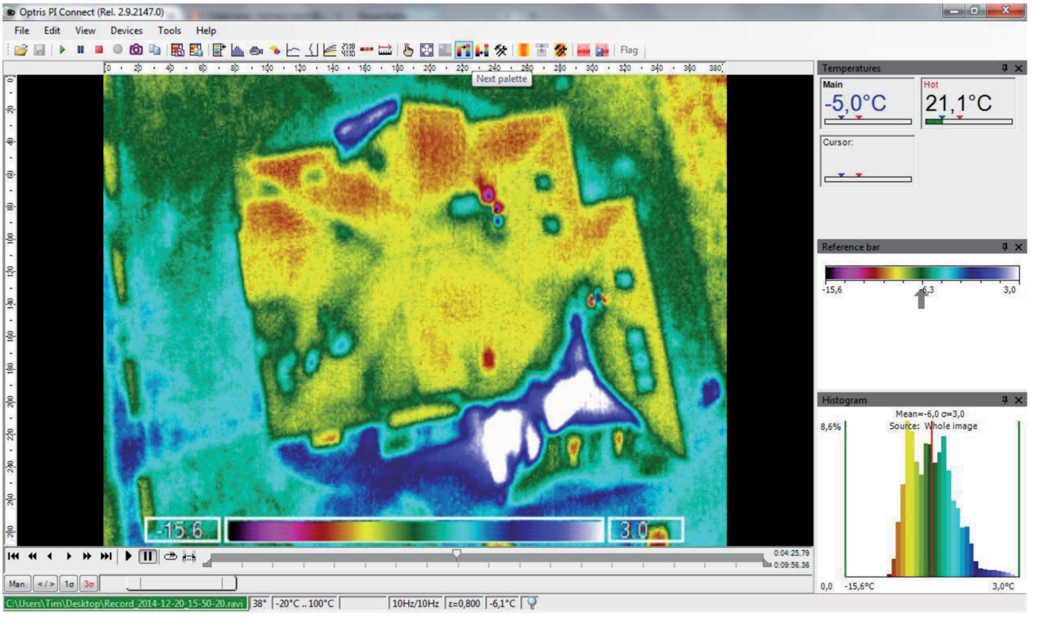

Figure 11. Picture of the whole building in reverse palette (red – cold, blue – warm). Visible warmer areas on the roof, caused by sun radiation [zdj. T. Sasin, 2014]


Figure 12. Picture taken from the east side. In the left, lower part visible vent exhaust [zdj. T. Sasin, 2014]

Figure 13. Picture of the whole building from the south side. Visible heat losses around roof window, placed on the west side [zdj. T. Sasin, 2014]

As shown on the pictures above, combination of an infrared technology and unmanned aerial vehicle is an optimum solution for inspections of buildings. Found defects in the roof would not be so easily discovered with the traditional method of inspection, moreover, using an UAV is much safer as there is no need to step out on the slippery surfaces by a man. This solution is also quicker, especially in parts with difficult access in the building, as an UAV needs less than 10 minutes to start and its flight speed is relatively fast.

Except detection of insulation layer defects, infrared technology can be used for calculation of heat transfer through the walls or particular elements of the building. In this particular case, infrared analysis can be used as a proof of incorrect execution of thermal insulation around two roof windows by the contractor and a basis for the compensation.

4. CONCLUSIONS

The rising costs of purchasing emission allowances and restricting access to free emission allowances will increase energy prices. It will have an impact on both domestic manufacturers who will have to bear additional costs in distribution, as well as the likely increase in energy imports from neighboring countries. Improving energy efficiency is the cheapest and most cost-effective way to reduce costs.

Thermal imaging can be successfully used in the construction and building sector in order to identify the thermal losses and bridges, construction defaults, detect defects, lack of insulation or air leakage and control energy losses.

Regular monitoring by thermal imaging techniques can lead to significant cost savings and defects removal at an early stage. Thermal imaging results will be necessary for modernization, technical and economic improvement of the building energy performance.

The results of the described case study conducted in December 2014 show that aerial thermal imaging performed by UAVs can be very advantageous in the building sector.

UAVs application can get a view of a wide area in a minimum time and cost, inspecting building elements, which can be hardly accessible by a man. UAVs application for thermal imaging can be a milestone in the energy research and development sector. The greatest potential for thermal imaging application have rotary-wing (multi-rotors) and fixed-wing structures, which can be assimilated to a group of Mini UAVs (Unmanned Aerial Vehicles Mini).

The current research problems associated with the development of UAVs for thermal imaging are mainly related to: legal constraints and standards regulations, safety, political and social acceptance, new UAVs and systems development, certification and integration, miniaturization of sensors, design and implementation of autonomous flight and new mission techniques, real time communication, integration of multiple sensors on UAV platform, automation of data acquisition and processing, UAV ability to operate in different weather conditions and high turbulence. The development of above mentioned topics can lead to an almost complete automation of buildings thermal testing.

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BADANIA TERMOWIZYJNE BUDYNKÓW Z WYKORZYSTANIEM BEZZAŁOGOWYCH STATKÓW LOTNICZYCH

Streszczenie

Artykuł omawia tematykę efektywności energetycznej w budownictwie oraz wykorzystanie bezzałogowych systemów latających do badania energochłonności budynków. Na początku przedstawione jest pojęcie efektywności energetycznej w budynkach, jej znaczenie oraz wpływ na środowisko. Następnie omówiona jest obecna sytuacja, trendy w Europie oraz potencjał jakim dysponuje ten sektor wraz z najistotniejszymi kwestiami prawnymi związanymi z tematyką efektywności energetycznej. Kolejny dział przybliża nam zagadnienia wpływu budynków na środowisko, w szczególności poprzez straty ciepła. Artykuł nakreśla również sposoby oraz znaczenie badań termowizyjnych. Szczegółowo opracowana jest klasyfikacja samolotów bezzałogowych przystosowanych do wykorzystania w badaniach termowizyjnych. Temat omówiony jest zarówno pod kątem charakterystyki i konstrukcji, jak również wad i zalet stosowania takich rozwiązań. Analizowane są również obecne ścieżki rozwoju w tej tematyce, problemy i wątpliwości. Ostatnia część skupia się na przykładzie wykorzystania platformy bezzałogowej do badania termowizyjnego budynku mieszkalnego. Jest to studium przypadku wykonane w Grudniu 2014 roku.

Słowa kluczowe: efektywność energetyczna, bezzałogowe systemy latające (BSL), modelowanie w energetyce, straty ciepła, badania termowizyjne, zrównoważony rozwój energetyczny, finalne zużycie energii, sektor budowlany.