FACULTY OF CIVIL
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OF TECHNOLOGY

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INNOVATIONS – SUSTAINABILITY – MODERNITY – OPENNESS
ENERGY

edited by
Dorota Anna Krawczyk
Iwona Skoczko
Ewa Szatyłowicz

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Dorota Anna Krawczyk
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Faculty of Civil and Environmental Engineering
Bialystok University of Technology
45E, Wiejska Street
15-351 Bialystok
www.wb.pb.edu.pl

Association of Sanitary Engineers
and Technicians in Bialystok
2, M. C. Skłodowskiej Street
15-950 Bialystok
www.pzits.bialystok.pl

Contents

Jakub Frankowski

Poznan University of Life Sciences, Faculty of Agronomy and Bioengineerring
Institute of Biosystems Engineering
jakub.frankowski@up.poznan.pl

ASSESSMENT METHODS OF HEMP BIOMASS TO SOLID BIOFUELS PRODUCTION

keywords: bioenergy, renewable energy source, waste management, cannabis sativa

Abstract:

Hemp (Cannabis sativa L.) was one of the first species used by mankind for economic purposes, mainly in the textile industry. Currently, its biomass is increasingly being used as raw material for the production of bioenergy. The aim of the study was to describe methods of production of solid biofuels from hemp as well as the procedure for assessing their quality through the analysis of their physical and chemical properties. The biomass of Henola (the newest Polish hemp variety) constituted the substrate for the research presented in this study. The following analyses of the chemical composition of the raw material were determined: the content of cellulose, holocellulose, lignin, pentosanes, minerals, nitrogen, carbon, hydrogen, sulfur and chlorine. The heat of combustion and heating value were checked additionally. The data demonstrated higher content of cellulose and hollocelulose complexes, compared to other annual plants. In addition, the percentage of sulfur and chlorine was low, which is very important in case of using biomass for heating. Moreover, the heating value was 17.100 $kJ \cdot kg^{-1}$ with a substrate moisture content of 8.5%. The obtained results indicate that the biomass of hemp is a good substrate for the production of solid biofuels.

Introduction

According to the assumptions approved by the Council of the European Union, Poland should achieve a fifteen-percent share of energy from renewable sources by 2020 in the total balance of gross final production [1]. Thus, the main pillar of increasing the share of energy production from renewable sources in Poland should be biomass, mainly of plant origin [2]. There is a large spectrum of possibilities for its use for energy purposes [3, 4, 5, 6].

One of the species whose biomass is suitable for versatile use for the production of various types of biofuels are hemp [7, 8]. Cannabis (*Cannabis sativa* L.) is a species that has been cultivated since antiquity in Asia and the Middle East. Over the centuries, they have spread to Europe and other continents. The old tradition of cultivation and processing of this species is also witnessed in Poland. The first scientific research related to the development of agrotechnology, harvesting and using hemp as a raw material for fiber production was carried out in Poland in the interwar period [9, 10, 11]. After the Second World War, especially in the 1960s and the 70's of the 20th century, the area of their cultivation in Poland was the largest in the history of our country and each year it reached approximately 30.000 hectares. Later, it dropped significantly due to the growing popularity of cotton clothing. After years of marginalization, revitalization and a renewed increase in their significance, it is currently regaining its position in Polish economy [12, 13].

However, according to the legal provisions, hemp cannot be currently cultivated strictly for energetic purposes in Poland. Nevertheless, it is possible to use waste biomass from its processing or cultivation for seeds as a raw material for energy production. As a result of breeding work, as well as through the improvement of technological processes, there is an increase in both efficiency as well as profitability of the cultivation and conversion of the energy contained in hemp biomass [14, 15, 16]. Waste biomass of hemp can be used for the production of solid biofuels [7], biogas [8] or bioethanol [17, 18], which can be added to conventional liquid fuels [19]. However, the production of briquettes and pellets is the easiest way to effectively manage the hemp straw and farmers can do it themselves.

The aim of the study was to describe the methods of production of solid biofuels from the chosen variety of hemp as well as the procedure for assessing their quality through the analysis of their physical and chemical properties [20]. Also, the energy efficiency of the raw material was determined based on the results of laboratory analyses.

Material and methods

Typical varieties of hemp give low yield of seeds (approximately 8-12 $dt \cdot ha^{-1}$), which are mainly used as seed for further reproduction or for the production of nutritious edible oil [21, 22]. Due to the consumers' growing interest in hemp products, other than fiber, work on the creative breeding of new varieties has been intensified in recent years [23, 24]. In 2007, the researchers from the Institute of Natural Fibers and Medicinal Plants (INF&MP) decided to start a breeding program. The aim of the process was to obtain a new form of oilseed hemp, which would be different from the typical representatives of hemp grown mainly for fiber. After years of intensive work and selection of plants, interesting breeding lines were obtained. In 2014 the best of them was submitted for registration tests at the Research Centre for Cultivar Testing (COBORU) [25]. By the decision of this organization the cultivar IWN-P/08N was added to the national register under number R 2908 as a variety called Henola. In addition, in the same year INF&MP was granted the exclusive right to breed this variety by national plant breeders' rights [12].

Compared to a typical fiber hemp varieties, such as Białobrzeskie or Tygra, Henola's growing season is about 3 weeks shorter. It is also two times lower in height and has significantly larger inflorescences in the same soil and climate conditions (Fig. 1.) [12, 25]. The biomass of Henola from vegetation period of 2018 constituted the substrate for the research presented in this study.

Fig. 1. Comparison of a typical variety of fiber hemp Białobrzeskie with Henola
Source: own picture.

The hemp straw remaining after harvesting seeds can be used in various branches of the economy, including for the production of biocomposites [26] but it can be also used for energetic purposes. The large proportion of oil in Henola seeds makes it ideal for downstream operators interested in edible and technical oil. Henola can produce up to 3,000 pounds of grain per hectare, more than double the amount of traditional hemp varieties [12]. The rest of the biomass is a waste which should be managed.

The following analyses of the chemical composition of the Henola's straw as a raw material were determined: the content of cellulose, holocellulose, lignin, pentosanes, minerals, nitrogen, carbon, hydrogen, sulfur and chlorine. The heat of combustion and heating value were checked additionally.

Analyses of the chemical composition of the raw material were performed according to the PN-92/P-50092 standard for plant material [20, 27]. The following parameters were determined:

- moisture content using the over-dry (gravimetric) method;
- content of cellulose according to Seifert using a mixture of acetylacetone and dioxane;
- content of lignin according to Tappi using concentrated sulfuric acid;
- content of holocellulose using sodium chlorite;
- amount of substances soluble in organic solvents according to Soxhlet;
- pentosanes using the trihydroxybenzene method;
- substances soluble in 1% NaOH.

Contents of minerals were determined according to the DIN 51731 standards.

Experimental material was cut into smaller pieces using a power saw and next comminuted manually and ground in a Pulverisette 15 laboratory mill, with the analytical fraction of 0.4 – 0.1 mm being separated on sieves. The obtained results are means of three measurements and were calculated in relation to the dry matter of the material.

The gross calorific value (or: heating value) was determined by means of a ZKL-4 calorimeter according to PN-81/G-04513, which is designed to measure the gross calorific value of solid fuels. For the purpose of the analysis, wood material was prepared in the form of compressed tablets. Analytical samples of 1 g material were completely combusted in the atmosphere of oxygen at 3 MPa.

The analysis consisted of the measurement of complete combustion of the sample in an oxygen atmosphere placed in a combustion bomb which was immersed in water as well as the measurement of the rise of water temperature [28]. The values were calculated according to the formula:

$$Q_s^a = \frac{C(D_t - k) - c}{m} \text{ [kJ·kg}^{-1}\text{]} \quad (1)$$

where:

C – heat capacity of the calorimeter of 12 783.69 [J·g^{-1}],

D_t – temperature rise of the main period [K],

k – correction for heat exchange with the surroundings [K],

c – sum of corrections for additional thermal effects like heat correction emitted during wire burning [J],

m – mass of the solid fuel sample [g].

For a more complete characterization of the analyzed raw material, also its net calorific value (or: fuel value) that is the gross calorific value decreased by the heat of vaporization of water separated from the fuel during combustion was determined. These values were calculated according to the following formula:

$$Q_i^a = Q_s^a - 24.42(\mathrm{Wa}-8.94\mathrm{Ha})\ [\mathrm{kJ{\cdot}kg^{-1}}] \qquad (2)$$

where:

Qs – average gross calorific value of solid fuel in the analytical state [$J \cdot g^{-1}$],
24.42 – heat of vaporization of water at 25°C corresponding to 1% of water in the fuel,
Wa – moisture content in the analytical fuel sample [%],
8.94 – analytical factor for conversion of hydrogen content into water content,
Ha – hydrogen content in the analytical fuel sample of fuel.

In the sample of hemp straw, the content of carbon, hydrogen and nitrogen was also determined using procedures compliant with the requirements of the following standards: PN-EN 15104: 2011 and PN-EN 15289: 2011.

Results and discussion

In the table below (Tab. 1.), the obtained results of analyzes of physical and chemical properties of hemp straw have been summarized.

Tab. 1. Average results of analyzes of physical and chemical properties of hemp straw

Analyzed parameter	Content (% of dry matter)
Celullulose	46.63
Lignin	15.36
Hemicelluloses	30.63
Holocellulose	81.82
Pentosanes	19.12
substances soluble in cold water	7.83
substances soluble in hot water	8.63
soluble substances in 1% NaOH	29.59
mineral substances (ash)	5.07
extractive substances	4.22
Nitrogen	1.66 ± 0.07
Hydrogen	5.68 ± 0.02
Carbon	42.69 ± 0.79
moisture content	8.5
heat of combustion	18 300 $kJ \cdot kg^{-1}$
calorific value	17 100 $kJ \cdot kg^{-1}$

Source: own study.

The results enable the evaluation of hemp straw of Henola cultivar for the possibility of its use as a substrate for the production of solid biofuels. First of all, it has a high content of cellulose (over 45%), and hemicellulose (over 30%) and similar content of lignin (approx. 15%) to another annual plants [29, 30].

In addition, analyzing the obtained results, it can be stated that its calorific value of hemp straw is only slightly lower than other waste commonly regarded as a valuable substrate for the production of solid biofuels, e.g. in comparison with meadow hay (18 640 $kJ \cdot kg^{-1}$) or beech sawdust (18 790 $kJ \cdot kg^{-1}$) [31, 32]. However, by comparing the obtained results with other substrates of vegetable origin, such as particle boards (19 850 $kJ \cdot kg^{-1}$) or fibreboard (20 100 $kJ \cdot kg^{-1}$) [33] lower calorific value was achieved for the analyzed substrate.

These differences stem from diversity of hemp morphology and physico-chemical properties in compared materials [34]. In addition, all tested substrates have a lower calorific value than hard coal, for which it amounts to approximately 31 000 kJ·kg-1 and is higher than for every kind of straw [35, 36]. However, compared to other organic waste, the heat of combustion obtained is relatively high, especially in comparison with other energy plants. It is higher than the heat of combustion of kenaf biomass (15 800 $kJ \cdot kg^{-1}$), virginia mallow (17 200 $kJ \cdot kg^{-1}$), miscanthus (17 900 $kJ \cdot kg^{-1}$), or corn straw (18 100 $kJ \cdot kg^{-1}$) and rape straw (18 100 $kJ \cdot kg^{-1}$). However, the obtained value of this parameter is lower than in the case of hemp panicle (19 800 $kJ \cdot kg^{-1}$) [37], but it is not a common source to produce biofuel.

The energy efficiency of Henola's straw was determined based on the calorific value of the raw material and the three-years average yield of dry mass of straw [12]. The results were summarized in Tab. 2.

Tab. 2. Energy efficiency of hemp straw per the unit of the cultivation area

Straw yield [$Mg\ DM \cdot ha^{-1}$]	Calorific value [$GJ \cdot Mg^{-1}$]	Energy efficiency [$GJ \cdot ha^{-1}$]
4.1	17.1	70.1

Source: own study.

The energy efficiency of Henola's straw per hectare is lower than the results estimated for fiber varieties of hemp. This is due to the lower height of Henola. It is recommended to use the straw for energy purposes as waste remaining after the cultivation for seeds.

Summary

The data demonstrated higher content of cellulose and hollocelulose complexes compared to other annual plants, which is a very important parameter to determine the possibility of using biomass for energy purposes. The content of lignin was similar to other varieties of hemp and also other species. Also the heat of combustion and heating value of hemp straw were higher than those of other common energy crops. It was shown that the ash content was approx. 5%. Moreover, the heat of combustion was 18 300 kJ·kg^{-1} and heating value was 17 100 kJ·kg^{-1}, while moisture content was 8.5%.

The obtained results indicate that the biomass of Henola gives comparable results with the parameters characteristic for the typical fibrous hemp biomass. To sum up, it is a good substrate for the production of solid biofuels.

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Paulina Roszkowska, Marta Magnuszewska, Dorota Anna Krawczyk[1)]

Bialystok University of Technology
Faculty of Civil and Environmental Engineering
Department of HVAC Engineering
[1)] d.krawczyk@pb.edu.pl

VIRTUAL LABORATORIES IN ENGINEERING ANALYSIS

Abstract:

In this article we would like to show how important and necessary it is to introduce new forms of teaching among students of technical universities. One of these forms is e-laboratory. This paper shows two selected e-laboratories developed under VIPSKILLS Erasmus+ project. First one allows to analyze heating system with underfloor heating, whereas second e-lab concerns radiators. In both cases potential of usage e-laboratories in didactic and scientific analysis was shown.

Introduction

VIPSKILLS it is a virtual and intensive course developing the practical skills of a future engineer [1]. The aim of the project was to expand practical skills, which focused on the cooperation in international groups and creative thinking on many levels. The participants of the project had the opportunity to exchange the necessary information to help in the selection of the most beneficial solutions in the field of construction, environmental engineering and power engineering. One of the forms of teaching-learning were e-laboratories, which allowed for quick comparative analyses, with the introduction of several basic parameters, eliminating time-consuming measurements. Using a virtual laboratory, each participant of the course had the opportunity to recreate and practice the experiments at any time and place [3]. The laboratories included the themes of RE (renewable energy) and HVAC (heating, ventilation and air-conditioning) as well as indoor air quality (IAQ) systems [2].

Examples of e-laboratories developed

Under VIPSKILLS project 6 e-labs were developed. All of them are available on the project webpage [1]

One of the laboratories concerns a low-temperature heating system such as underfloor heating. It is characterized by a low temperature of medium in the power supply, so we are able to provide maximum thermal comfort while maintaining low operating costs. Thanks to this e-laboratory we can observe changes in the heat output of the floor radiator, total heat losses and the flow rate of the heating medium depending on the type and size of the pipes used. The following parameters were assumed for calculations:

- Temperature of the medium in the supply = 50˚C
- Refrigerant cooling temperature = 10 ˚C
- Temperature in the heated room = 20 ˚C
- Heated room area = 10m^2

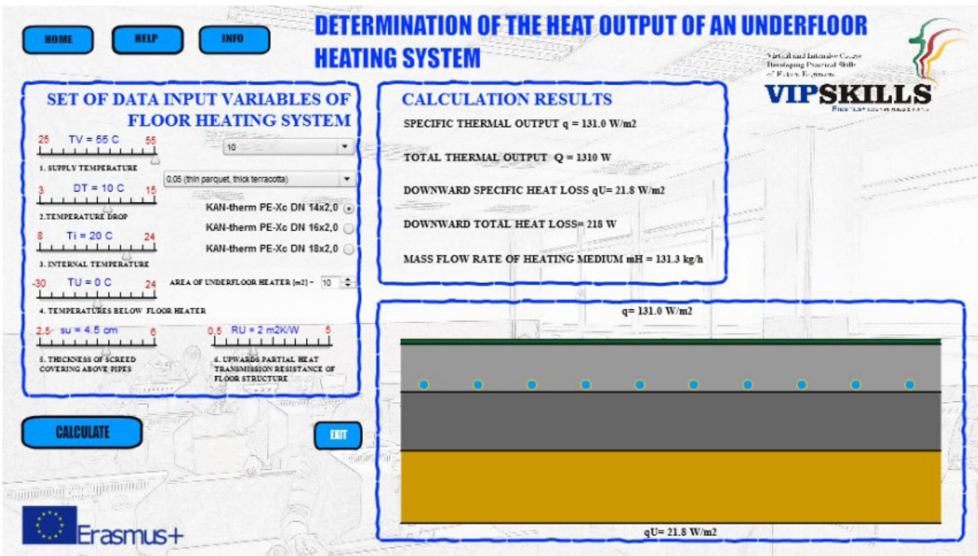

Fig. 1. Example 1.1 – Results of selection of a floor radiator made of Kan-Therm Pe-Xc DN 14x2.0 with a spacing of 10 cm

In the example 1.1 and 1.2 (Fig. 1-2) we can see results of selection of floor radiator. In example 1.1, installation was made of pipes with a diameter DN 14x2,0 and in example 1.2 installation was made of pipes with a diameter DN 16x2,0. After the analysis we can see that with the increase in the diameter of pipes there is an increase in the heat output of the radiator, as well as a minimal increase in total heat losses and the size of the factor flow. In addition, the spacing of pipes is also important for the selection of pipes. E-laboratory allows you to observe changes in the efficiency of a floor radiator made of one type of pipes, but with a completely different spacing of wires.

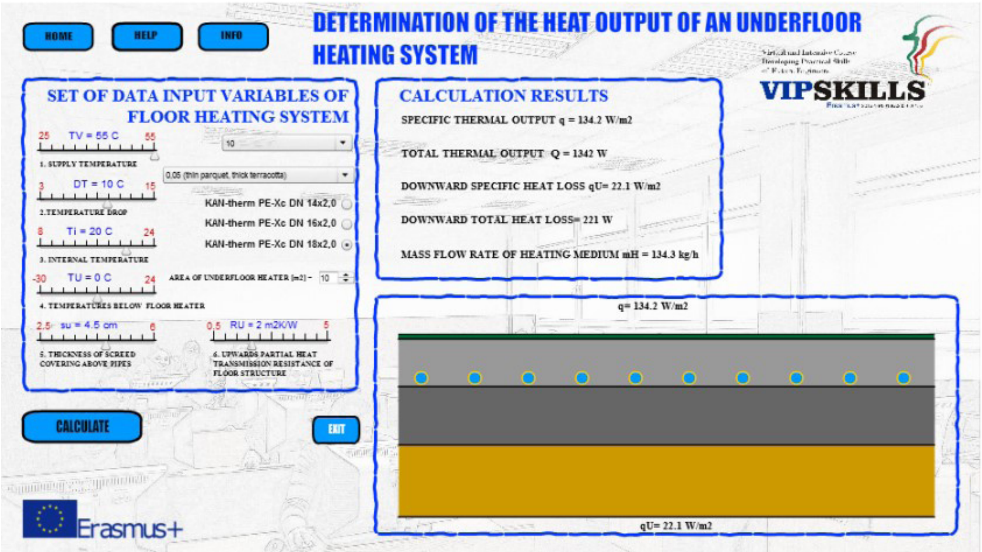

Fig. 2. Example 1.2 – Results of selection of a floor radiator made of Kan-Therm Pe-Xc DN 16x2.0 with a spacing of 10 cm

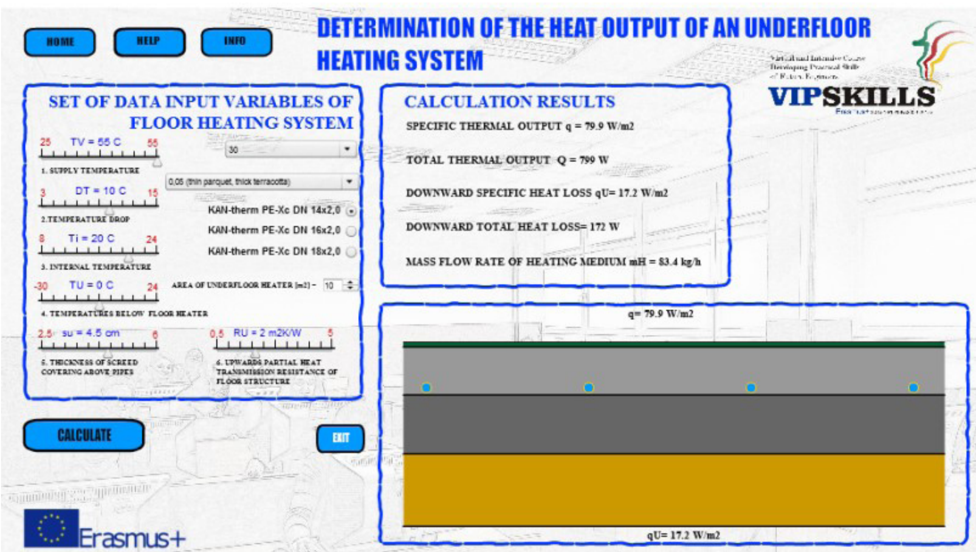

Fig. 3. Example 1.3 – Results of selection of a floor radiator made of Kan-Therm Pe-Xc DN 14x2.0 with a spacing of 30 cm

Comparing example 1.1 in which the pipe spacing of 10 cm was assumed, with example 1.3 in which the pipe spacing of 30 cm was assumed, we can see that the thermal efficiency of a radiator made of Kan-therm Pe-Xc DN 14x2,0 pipes decreases with the increase in the pipe spacing. Denser pipe-laying will make the floor more even. The value of the spacing is determined by the designer taking into account the heat demand of the room [4].

In another e-laboratory we can compare the influence of water system parameters on the heating efficiency of a radiator. On the basis of these data, such as flow temperature, temperature difference between flow and return temperatures and the target room temperature, we are able to obtain the actual heat output of the radiator and the logarithmic temperature difference for specific installation parameters.

For example, the PURMO steel panel radiator type C11 with dimensions L=1200mm, H=500mm, and the catalogue heat output of Qn=1042 W was taken. High-parameter 80/60/20 installation was compared with low-parameter 55/45/20 installation, assuming that the demand for heat in the room is 1000 W. With the help of the e-laboratory, we can quickly compare the influence of the water temperature in the installation by entering the above data. In a high-parameter system (Fig. 4, example 2.1), in order to satisfy a given heat demand, we need one heater, because the calculated efficiency of one heater was 1028 W.

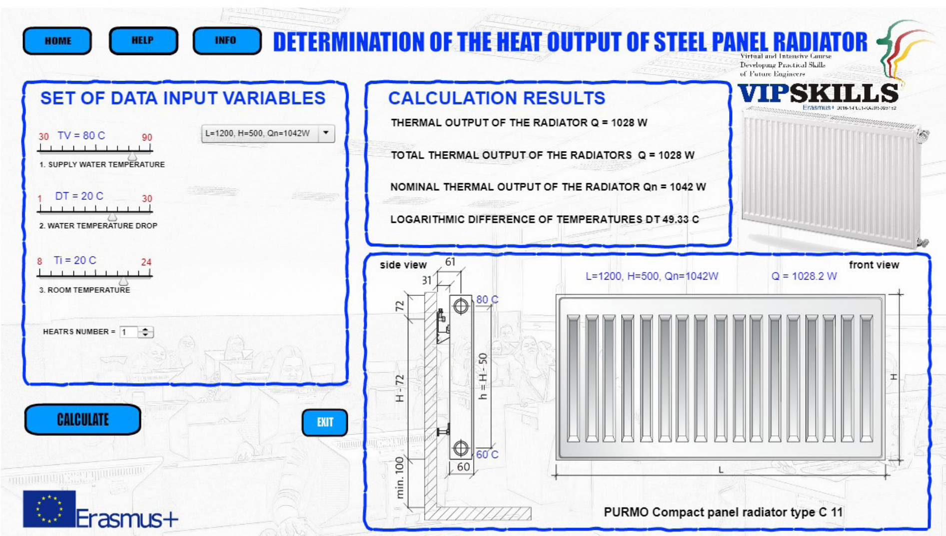

Fig. 4. Example 2.1 – High-parameter water system 80/60/20

In example 2.2 (Fig. 5), the efficiency of one radiator of the same size is equal to 530 W, which means that in order to ensure the heat demand in the room it is necessary to install 2 radiators.

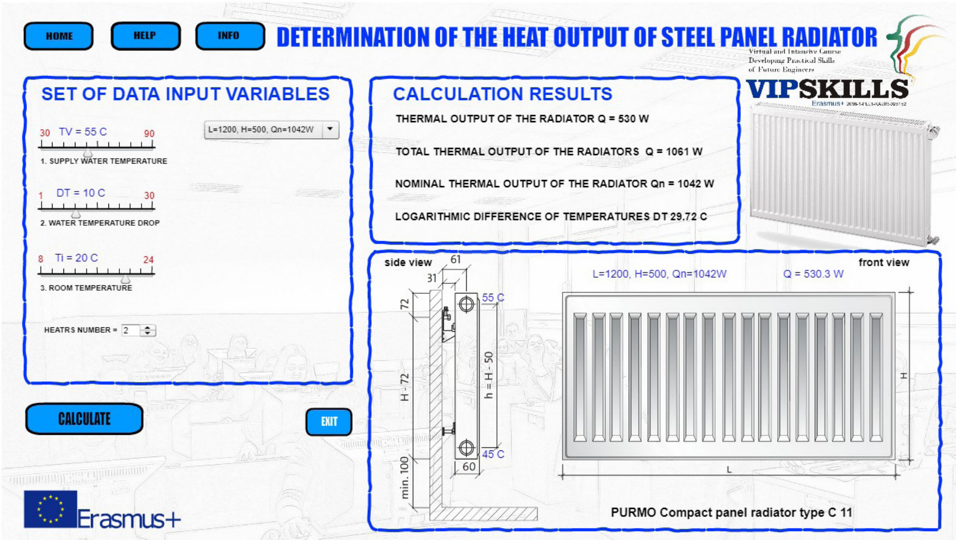

Fig. 5. Example 2.2 – Low-parameter water system 55/45/20

As a result, we can decide which installation is more comfortable for the individual needs of the user and more beneficial in terms of operation. Choosing a high-parameter installation, the radiators will be cheaper, because they need to be installed less. By choosing a low-parameter installation that will be powered by e. g. heat pumps or solar collectors, the cost of radiators will be higher, due to the need to install more devices and pipes, but the conditions at home will be more comfortable, because the air will not be too dry [5].

Summarizing

As shown in examples, e-laboratories can be successfully used for estimation of heating system parameters etc. They can be useful in both didactic work and scientific analysis. It is an ideal solution in many aspects. One of the advantages is the speed and ease with which many analyses can be carried out. Thanks to this solution we are able to transfer many variants without leaving home and without time-consuming measurements. Another advantage is the possibility to use them at any time in your life, no matter where you are, it is enough to have with you devices that will allow you to open an e-laboratory and access the Internet. To sum up, e-laboratories can be a future for future engineers.

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Joanna Borowska

Bialystok University of Technology
Faculty of Civil and Environmental Engineering
Department of Spatial Economy and Energy Building
e-mail: j.borowska@doktoranci.pb.edu.pl

WINDOW CONSTRUCTION AND ITS MAIN FEATURES

keywords: window, glass, frame, diffusers, spacers, sun visors

Abstract:

The windows are located in every residential building and fulfill very important tasks responsible for its proper functioning. Their most important features are thermal and acoustic insulation, tightness, and daylight permeability. This article will describe the main structural elements of the window, as well as the materials from which they are most often made and their thermal properties. Specialized coatings produced on glass and additional elements that will improve the thermal insulation of the window will also be characterized.

Introduction

The main function of window in residential buildings is to ensure the supply of solar energy to the interior of the rooms, as well as to reduce the energy needed to heat the building. Referring to the regulations in force in Poland [9], from January 1, 2017, the maximum permissible heat transfer coefficient for windows – U_{max} is 1.10 W/(m^{2}K) and will continue to decrease with subsequent years. Therefore, when choosing the type, size and dimensions of windows, remember that their thermal parameters meet the above restrictions.

According to [2], the window should provide adequate thermal and acoustic insulation, proper tightness of the window opening, adequate amount of daylight and the right amount of air necessary for correct ventilation operation, adequate level of life, health and property protection as well as an appropriate level of load transfer coming from forces acting on the window and the construction of the building.

Each window, regardless of the material, consists of the same elements. Usually, only two main ones are mentioned - the frame and the pane. However, there are many more. Even in the simplest single-wing window, you can distinguish up to 8 different construction elements. It is worth mentioning that the standard [2] described and named as many as 13 different elements of a window made of PVC. In the figure 1 they will be presented and named according to the standard [6].

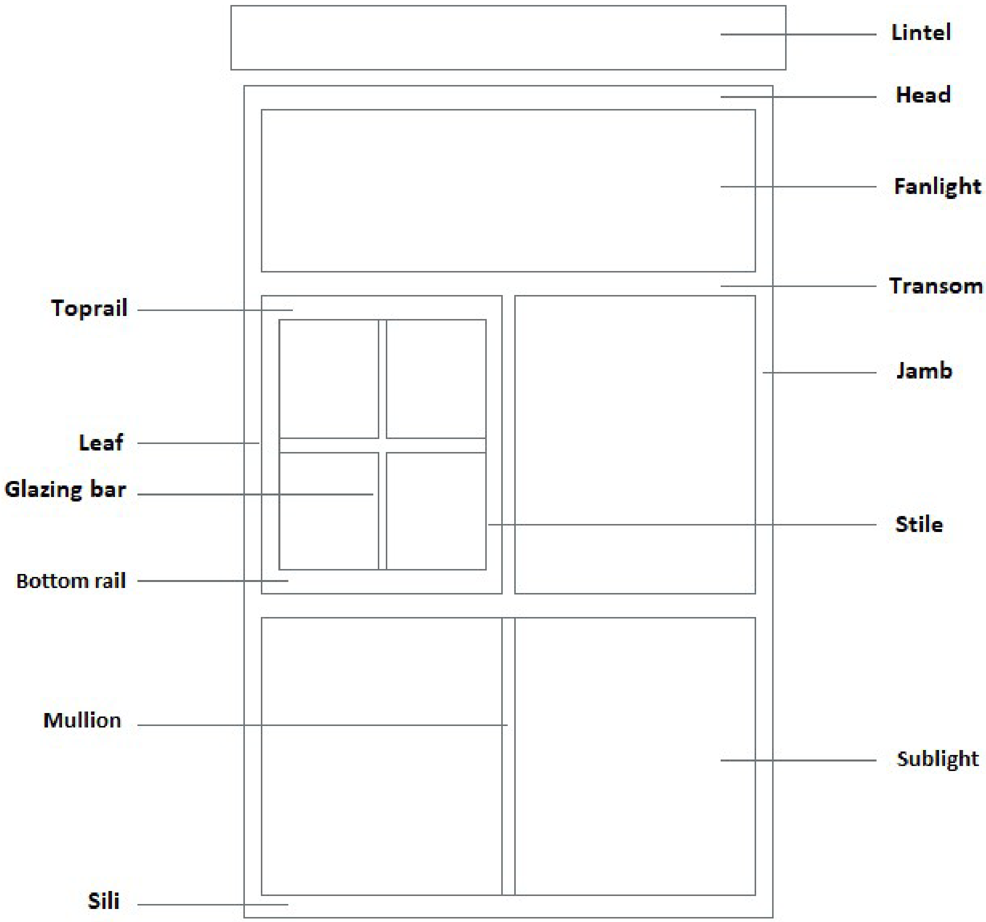

Fig. 1. Window construction elements, from the top: lintel, head, fanlight, toprail, transom, jamb, leaf, glazing bar, stile, bottom rail, mullion, sublight, sili

Source: [2].

The article presents various materials from which a window frame can be made, currently used glass packages and coatings on glass, as well as the possibility of using innovative elements that improve both the thermal insulation of windows and its deterioration at the expense of, for example, more efficient ventilation of rooms.

Window frames

Window frames can be made of various types of material profiles depending on their type, insulation parameters, price, as well as the purpose of the building. The Polish construction market offers such material profiles as [7]:

- „wooden profiles uniform and homogeneous on a combination of the finger-like composite structures and sliding in height: Wz-2000, Anderson;
- glued laminated wooden profiles (for single-family structures): fakro, okpol;
- profiles made of polyester-glass fiber (small-sized): fiberglass inline 700,
- window used for production on sliding sash;
- PVC profiles: two-, three-, five-, six-, seven-chamber (over 70 profiles), used for the production of window frames, shop windows, glass extensions (winter gardens);
- aluminium profiles: with a thermal bridge (so-called cold), with a thermal screw fastening, with a thermal break made of rigid plastic, used for window production, shop windows, glass extensions (winter gardens) and curtain walls (glass facades);
- profile mixed profiles (so-called compact) – wood + plastic + aluminium or wood + aluminium, used for the production of window frames."

Depending on the material from which the window is made, its thermal insulation properties are different (Tab.1) [1] It can be noticed that the heat transfer coefficient for the frame made of aluminium is almost twice as high as for a frame made of PVC with a three-chamber profile. Even a frame with a regular profile made of PVC is characterized by a U_f coefficient lower than the aluminium frame.

Tab. 1. Frame heat transfer coefficient for various materials

Frame type and material	U_f
PVC (three-chamber profile)	1.50 – 1.65
Wood (single-chamber profile glued)	1.90 – 2.00
PVC (regular profile)	2.15 – 2.30
Aluminium (with a thermal profile)	2.60 – 3.10

Source: [1].

Depending on the material of the window frame, the parameter y describing the linear heat transfer coefficient of the thermal bridge on the frame-glass side is shaped differently. The data presented below (Tab.2) show that fluctuations of this coefficient can have a large range. And the higher the value of the y coefficient, the worse the thermal insulation of the window.

Tab. 2. Linear heat transfer coefficient y on the frame-glass interface for different frame types

Type of frame	Linear heat transfer coefficient y	
	Double or triple glazing, uncoated glass filled with air or gas	Double or triple glazing, low-energy glass filled with air or gas
Wooden or PCV	0.06	0.08
Metal with thermal break	0.08	0.11
Metal without thermal break	0.02	0.05

Source: [M].

When analysing table 2, it is worth noting that by using different types of distance frames the thermal bridge at the frame-glass interface will never be removed. However, using different distance frames, it can be reduced to the minimum values that have little effect on the final result of the heat transfer coefficient of the comprehensive window.

Window glass and functional coatings

It is extremely difficult to imagine a window without any glass in a technically functional building. Depending on the type of window construction, the glazed area can be from 95% of the total area in the case of permanent glazing up to 45% for a small basement window. The large share of glazed surfaces in the entire surface of the structure makes the properties of insulating glass significantly affect and shape the level of performance and usability of each window, and the skill of their proper selection contributes directly to the product's compliance with both the basic and specific requirements set out in the regulations construction law, technical and construction regulations and provisions of technical specifications [2].

Glass is a transparent, inorganic, non-crystallized substance, obtained as a result of melting at a temperature between 1300ºC and 1500ºC, followed by cooling of glass raw materials, where the glass mass changes its liquid state into a supercooled liquid with high viscosity, i.e. solid state with an amorphous structure [5].

The most commonly used glass in the construction used for window frames is soda-lime-silicate glass called ordinary glass. The raw materials used for the production of building glass are: [5]:

- SiO_2 silica – forming a vitreous body,
- $CaCO_3$ calcium carbonate – an ingredient that stabilizes and hardens glass, increases chemical resistance and gives gloss,
- Na_2CO_3 soda – used to lower the temperature of the glass mass to about 1400ºC,
- magnesium and aluminium – used for hot working, affect the chemical resistance and strength of the glass;
- oxides of antimony, arsenic, fluoride compounds – these are glass clarifying admixtures,
- cullet – accelerating the melting of heated glass mass.

Float glass is the most popular type of construction glass. Its production consists in the continuous pouring and flow of molten glass melted on the surface of the tin (also molten), followed by cooling and cutting of the formed glass tape. They can be hardened and subjected to various modifications, thanks to which it combines many properties, e.g. optical, mechanical or thermal [G].

Currently available on the market glass packages divided into one, two or three chambers, depending on the amount of glass panes used to produce the so-called glazing unit package. Due to the fact that a lot of the properties of a double glazing depends on the place where some specific elements of its construction will be found, for example low-E coatings or foils, the following diagram also shows the correct way to determine and defining their position (Fig. 2) [2].

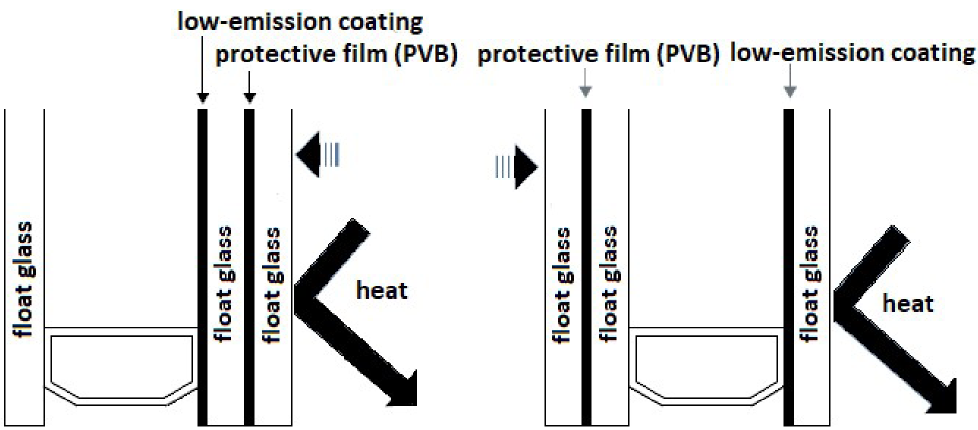

Fig. 2. The correct way to determine and define the position of the occurrence of coatings and foils on the glass

Source: [2].

Radiation and conduction are processes by which heat is lost through the glazing from the heated zone of the building. Solar-control coatings allow partial limitation of radiation losses. It should be noted that the amount of heat that will be radiated outside will depend mainly on the emission properties of the glass. Emission reduction is possible due to the glass coating with a material with the lowest possible emissivity. Such materials include, for example, aluminium or silver. The dielectric can be tin oxide, titanium, zinc. [4]

The emissivity of the glass is an important property that refers to the heat exchange by radiation of the glass surface in the part of the glazed window. Knowledge of glass emissivity is necessary to determine the coefficient of total solar energy transmittance "g" (solar factor) and the heat transfer coefficient U for the glass panel. The necessity of using low-emission glasses in windows is also connected with a new approach to the energy balance of buildings, introduced by Directive 2002/91 / EC implemented in Polish construction law on the energy performance of buildings [16], taking into account thermal insulation properties of window panes. [15]

Functional coatings for glass can be obtained by using titanium, silicon and aluminium nanoxides. Such coatings adhere exactly to the glass, so it is very difficult to damage them. This can happen only in the case of damage to the surface of the glass itself, including using sharp objects, abrasive cleaning agents or steel wool.

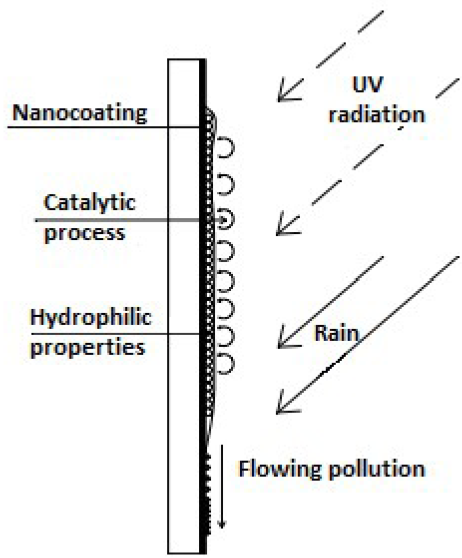

Fig. 3. Diagram of the operation of self-cleaning glass

Source: [8].

The main task of photocatalytic coatings is the decomposition of organic pollutants when reacting with solar radiation, and then the spontaneous flow of such dirt when rain or water hits the glass. [3] In the case of such coatings, the water, instead of drops, drips on the surface with an even layer and takes with it any impurities in its path. Compared with ordinary glass, it quickly becomes dry and the water does not leave unaesthetic stains [8]. The mechanism of operation of self-cleaning glass based on photocatalytic coatings is shown in the figure (Fig. 3).

Remember that the coating works even when the glass is very dirty. However, if the surface is so dirty that the light rays do not have access to the glass, the self-cleaning process will not take place. It is enough to clean the glass with a soft cloth with warm soapy water and the photocatalisation process will be activated again after a few days. A small beam of UV radiation is needed to activate the coating. The coating fulfills its task, therefore, also on cloudy days, and the effect of harmonious flow of water on the glass always stays under the influence of water [8].

However, many years of experience with self-cleaning glass used in construction show that residues in the form of dry drops unsightly looking on the glass are not negligible, sometimes even more visible than on glass without coating. Thus, scientists proposed that such glass be called easy-to-clean, which indicates the ease of removing dirt (if any). Nevertheless, glass with hydrophobic properties is widely used and very interesting for various applications. It supports the cleaning of shower cabins, it is also often used in car windows. Thanks to the latest solutions based on nanotechnology, glass bearing the self-cleaning titer is used in constructions with large glazing surfaces, such as in office buildings or shopping centers [8]. The advantages of self-cleaning glass can be included [11]:

- easier maintenance, because dirt adheres less to the surface to a lesser degree,
- better visibility through the windshield during rain,
- saving time and money,
- environmental protection thanks to reduced consumption of cleaning agents.

Additional elements affecting the improvement of window operation

Window diffusers are elements that through controlled air flow help to maintain the right amount of air in the rooms. These are devices that unfortunately reduce the thermal insulation of windows, but prevent the formation of mold and fungi in too moist areas. The amount of air flowing through the diffuser can be adjusted manually or automatically. Manual diffusers are devices in which the position of the diaphragm affects the amount of air supplied. The user of the diffuser adjusts its opening degree and thus determines the amount of air supplied, by manually changing the position of the device's throttle. Manually operated ventilators are used in places where the regulations do not allow using automatic ventilators, for example in the case of accommodation spaces with gas appliances: stoves, termites or heaters [10].

On the other hand, automatic diffusers, due to the method of air stream regulation, are divided as follows: pressure diffusers (react to the difference of external and internal pressure, allow the flow of constant air volume by changing the size of the supply opening), thermostatic diffusers (react to the external temperature, reduce air flow when the outdoor temperature decreases), humidity sensitive ventilators (react to indoor air humidity, regulate the air supply according to its humidity, the higher the humidity, the greater the inflow of air) [10].

Another element, this time improving the thermal insulation of windows, are distance frames. Distinguished are stainless steel spacers, standard aluminium frames and warm plastic frames or polymer foam. Frames can also be divided into two types: warm type (made of steel or composite insulating material), and also cold type (made of steel or aluminium) [7]. Manufacturers of distance frames declare very low values of the linear heat transfer coefficient Ψ thermal bridges at the window-frame interface in windows with their products. According to [9], the coefficient Ψ for PVC windows is proposed from 0.076 W/(m^2K) for the double glazing unit and aluminium frame, by 0.050 W/(m^2K) for the triple glazing unit and the stainless steel frame, up to 0.030 W/(m^2K) for warm frames of the latest generation.

Referring to the research of the Institute of Window Technology in Rosenheim [13], the value of the linear heat transfer coefficient Ψ at the glass-frame border in windows with glazing with one or two-chamber glazing using an aluminium frame is much higher than in the case of the same windows, but with glass panes with plastic or stainless steel spacers.

An important aspect influencing the thermal insulation of windows and degree of overheating of the rooms are sun visors. Typical sun visors include: blinds and blinds, lamellar walls, light breakers. Depending on what type of shield we are dealing with and from what material it is made, as well as what parameters of air permeability have, it is necessary to determine the heat transfer coefficient U_{ws}, which takes into account the influence of the applied sunscreen in the window [14].

The use of sun visors is particularly justified when we want to reduce unwanted (excessive) heat gains, and if we want to reduce heat losses. In the summer, their function is to limit the heating of buildings by the sun's rays, as well as to minimize the light reflexes that arise on sunny days. In the case of cloudy days, their task is to allow the maximum visible light to enter the interiors. It follows that covers should have variable parameters for different seasons, and this effect can be obtained when the covers are movable. [14]

Summary

The article presents various materials from which a window frame can be made, as well as widely used glazing packages and coatings placed on glass. In addition, the possibilities of using innovative elements influencing both the improvement of window thermal insulation and its deterioration at the expense of, for example, more effective room ventilation are described.

In modern windows, window frames made of wood, plastic, aluminium, compact, i.e. various combinations of materials, e.g. wood-aluminium, as well as composite frames, are widely used.

The number of glass packages in the window has a key impact on the thermal insulation of the entire window. The 1-, 2-, 3-chamber packages are currently being used on a large scale. Special coatings are applied to the glass, which give it the required features, eg low-emission coatings, reducing the transmittance of solar beams or nanocoatings, eg self-cleaning, which stay clean.

Window systems use various elements to support their operation, including window diffusers, which, although they slightly deteriorate the thermal insulation of the window, prevent the formation of fungi and mold in the rooms, improving their ventilation. Spacer frames are also widely used, which have a key impact on the reduction of the overall window penetration. In order to avoid overheating in the summer, sun visors are used.

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Andrzej Gajewski[1], Kacper Jermacz[2]

[1] Department of HVAC, Bialystok University of Technology,
45a, Wiejska Street, 15-351 Bialystok, Poland
a.gajewski@pb.edu.pl

[2] Students' Scientific Society "Heat Engineer" at Bialystok University of Technology,
45a, Wiejska Street, 15-351 Bialystok, Poland
k.jermacz@wp.pl, phone: +48 608 344 617

INDOOR AIR QUALITY IN AN AUTO REPAIR SHOP-CASE STUDY

keywords: Indoor Air Quality, IAQ, carbon monoxide concentration, carbon dioxide concentration, auto repair shop

Abstract:

The aim of the paper is indoor air quality (IAQ) assessment in an auto repair shop due to CO_2 and CO concentrations. Carbon monoxide and carbon dioxide concentration were being measured for a week. Two Testo 435-4 gauges were located at height of a head of an adult person (ca 170 cm above floor) in a room. CO_2 concentration was measured with IAQ probe which measures dew point temperature, psychrometer temperature and absolute pressure in indoor air. The second gauge was connected to CO probe. Measurements were done every 5 minutes and were averaged in an hour. Uncertainties were estimated using square-root combinations of fixed errors and random ones at 0.05 statistical significance. The measurements were done from 17th November to 23rd November 2018. The following graphs are plotted for carbon dioxide and carbon monoxide: hourly averaged concentration and 8-hour averaged concentration. The results are discussed and compared to Polish, foreign and international standards or recommendations. There were observed negligence of Polish law and nonfulfillment of healthy recommendations. An exhaust extraction system should be installed.

Introduction

Even hundreds persons in Europe per year are killed by carbon monoxide. CO is generated by malfunctioning boilers or it infiltrates from garages. In generally, it is a product of incomplete combustion [1]. Moreover, the problem also exists in the garages where CO presence should have been assumed. The CO mole fraction exceedance was measured in multi-car garage by Gładyszewska-Fiedoruk and Nieciecki [10], which inspired the paper authors to investigate the problem in other motorization area.

Carbon monoxide binds with haemoglobin to form carboxyhaemoglobin (COHb), which reduces oxygen's amount supplied by the blood. As a consequence, people suffer from tissue hypoxia at low exposure levels. At higher concentrations, the carbon monoxide significantly decreases oxygen consumption by the brain, the heart, exercising skeletal muscle and developing foetus (cf. WHO [2]). Non-smokers in certain jobs can have long-term COHb concentration up to 5%, while COHb content in heavy cigarette smokers can be up to 10%. Non-smokers, the foetuses of non-smoking pregnant women, people with coronary artery disease should be protected in such way that COHb level of 2.5% ought not to be exceeded (cf. WHO [2]). It will be met if CO concentration in respect of time is not exceeded, which is presented in **Table 1** in the rows with WHO data.

An analysis of **Table 1** leads to conclusion the WHO recommendations are not met in Poland, Germany and USA, and the value of discrepancy increases with the order in which the states are listed.

Tab. 1. Maximal acceptable CO concentration and in indoor air

Institution	Unit	Magnitude	Time of exposure
WHO [2]	[mg/m^3] ([ppm])	100 (90)	15 minutes
	[mg/m^3] ([ppm])	60 (50)	30 minutes
	[mg/m^3] ([ppm])	30 (25)	1 h
	[mg/m^3] ([ppm])	10 (10)	8 h
Regulation of MEL (Poland) [3]	[mg/m^3]	117	15 minutes
	[mg/m^3]	23	8 h
ASHRAE (USA) [4]	[ppm]	50	8 h
MAK (Germany) [5]	[ppm]	30	8 h

There is no WHO advice concerning carbon dioxide content. However, in the case, the standards in Poland, Germany and USA are similar, which is can be seen in **Table 2**.

Tab. 2. Maximal acce ptable CO_2 concentration and in indoor air

Institution	Unit	Magnitude	Time of exposure
Regulation of MLSP (Poland) [6]	[mg/m^3]	27000	15 minutes
	[mg/m^3]	9000	8 h
ASHRAE [4]	[ppm] ([mg/m^3])	5000 (9151)	8 h
MAK [5]	[ppm] ([mg/m^3])	5000 (9151)	8 h

Nieciecki and Fiedoruk [7] announce human body's reactions at particular CO_2 concentration values in the air. Here beneath, there are selected, from Nieciecki and Fiedoruk [7] paper, volume percents and human organism reactions that can appear in the job conditions:

- 0.15%-sense of unpure air and sense of stuffiness
- 0.2% weakened persons that are suffer from respiratory diseases can cough or sometimes can suffer from syncope
- 1% breath frequency is increased
- 1.5% mild metabolic stress appears after longer time of respiration, it is maximal tolerated concentration in the submarines or the space ships.

The volume percents of 0.15% means 0.0015 m^3 of CO_2 or 1.5 dm^3 in 1 m^3 of air.

European Garage Equipment Association (EGEA) gives a warning harmful exhaust are emitted from even modern combustion engines and it publishes general recommendations [8]:

- Exposure to vehicle exhaust emissions indoors should be avoided whenever possible
- If it cannot be guaranteed, the workspace should be equipped with an exhaust extraction system to protect the workers against hazardous substances,
- The exhaust emissions should be captured at source which means directly at the exhaust tailpipe. The exhaust nozzle or funnel should be designed so that 100% of the exhaust emissions can be captured
- Exhaust extraction systems should work at vacuum gage pressure
- The extraction volume should be at least 25% above the maximum emitted exhaust volume
- The extraction system specification should accommodate the largest engine in use at the workplace

EGEA [8] recommends extraction volume flow rates in dependence on engines' volume and kind of service:

- 450 m^3/h is needed for cars up to 4 litres engines which are serviced,
- 900 m^3/h is needed for cars up to 4 litres engines when exhaust tests are curried on,
- 1000 m^3/h is needed for trucks up to 16 litres engines which are serviced,

- 1800 m^3/h is needed for trucks up to 16 litres engines when exhaust tests are curried on.

Ventilating or air conditioning systems are controlled by the value of indoor temperature or relative humidity. Although carbon dioxide is though as a pollutant and its gains are taken in consideration in air balance, its concentration is not controlled in the ventilation systems (cf. e.g. [11]).

Carbon monoxide is much harmful substance by far. However, concentration of this poisonous substance is no desired value for the ventilation system controllers. The general aim of the paper is a change of an attitude to this issue so as carbon oxides concentration, especially carbon monoxide content, would be the desired values for the controllers of a ventilation system in any place where exhaust fumes are emitted. The particular goal is conviction of each auto repair shop owner to ventilation system installation.

The experiment

The measurements were conducted in three-place auto repair shop with four-person staff which floor plan is drawn in **Figure 1**.

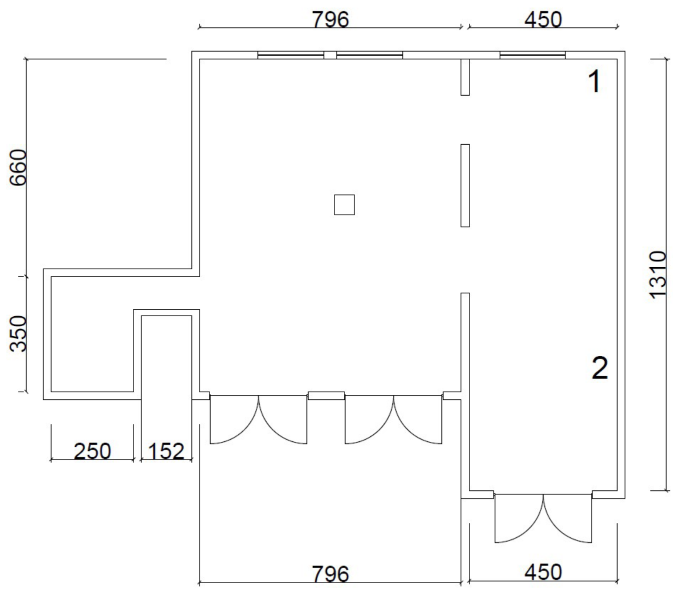

Fig. 1. Floor plan of the garage with marked probes' locations: 1 and 2 where CO probe and IAQ probe (which measures carbon dioxide content) respectively

The building is located in a county town in the north-east part of Poland. It is constructed with perforated brick and insulated with Styrofoam. The shop is ventilated neither with stack effect nor with the mechanical ventilation. The only form of ventilation is infiltration through the relatively big and not sealed doors, the windows' frames are made with PVC.

Measurment methodology

The one-week experiment is a part of the experiment series which is conducted in the different seasons in one location. It have been conducted in autumn, November 2018, which was during the heating season and for this reason the garage door was being opened only when a car was being driven into or out. A probe for carbon monoxide concentration measurement and other probe for carbon dioxide content measure are placed at 170 cm above flooring. The probes' location is shown in **Figure 1** with numbers 2 and 1 respectively. CO probe is a sensor of this gas only, while CO_2 concentration is determined with IAQ probe which additionally measures absolute pressure, relative humidity, dry-bulb temperature, wet-bulb temperature, and dew point. Each probe is connected to a separate Testo 435-4 gauge. The measurement ranges and accuracy are presented in **Table 3**. The measured values were recorded every 5 minutes in the gauges' storage.

Tab. 3. Specification of the applied sensors and gauges

Type of probe	Measured quantity	Accuracy
IAQ probe	Molar fraction of CO_2	±(75 ppm ±3 % measured value) (0 do +5000 ppm) ±(150 ppm ±5 % measured value.) (+5001 do +10000 ppm)
CO sensor	Molar fraction of CO	±5 ppm (0 do +100 ppm) ±5 % measured value.) (+100,1 do +500 ppm)

The computations

After the measurement period, which in the case was from 17th up to 23rd November 2018, the results were copied from the gauges' storages to the personal computer's hard disk. Since, the results were measured as mole fractions expressed in ppm, the conversion into concentration C expressed in a SI unit is necessary, which is done applying the formula:

$$C = \frac{273.15\mu y p}{22.4 \cdot 1013.25\left(t + 273.15\right)} \quad \left[\frac{mg}{m^3}\right] \tag{1}$$

where:
μ is mole mass [g/mol],
y is a measured mole fraction [ppm],

p is a measured absolute pressure [hPa],
t is a measured temperature [°C].

Then, there were calculated arithmetic mean in each hour, the results are plotted in **Figure 2** and **Figure 3**. The measurement uncertainties are estimated as square root from the sum of the squares of fixed errors and random ones of the system of apparatus. Estimation is done at significance level 0.05. As the fixed error Binst the corresponding value from the third column of **Table 3** is taken. Because of the assumed significance level the random errors are equal to doubled standard deviation σrun that is determined in each experiment hour.

$$\sigma_{run} = \sqrt{\frac{\sum_{i=1}^{n}\left(\bar{x}-x\right)^{2}}{n}} \qquad (2)$$

where:
x is a measured quantity,
x is an arithmetic mean in a given hour,
n is a number of the measurements in given hour (n=12 if measures were done amid all the hour).

Eventually, the measurement uncertainty δx is defined by the formula:

$$\delta_x = \sqrt{\left(B_{inst}\right)^2 + \left(2\sigma_{run}\right)^2} \qquad (3)$$

The results of Eq. (3) are plotted in the **Figure 2** and **Figure 3** as the error bars.

Eight-hour exposition

So as to investigate whether exposition amid 8 h was exceed the algorithm described in the Regulation of ME [9] is applied. The maximum, eight-hour average is calculated from moving averages, calculated every hour from eight one-hour averages over a 24-hour period. Each calculated average is assigned to the day on which it ends. The first calculation period for each day is the period from 17:00 on the previous day until 1:00 on a given day. The last period for each day is the period from 16:00 to 24:00. In this way, daily averages for CO_2 and CO were determined, which are presented in **Figure 4** and **Figure 5**.

The results

The desirable value 1000 ppm after conversion by Eq. (1) under the averaged values of absolute pressure and internal temperature is at 1883.27 mg/m^3 which is presented as bold horizontal line in **Figure 2**.

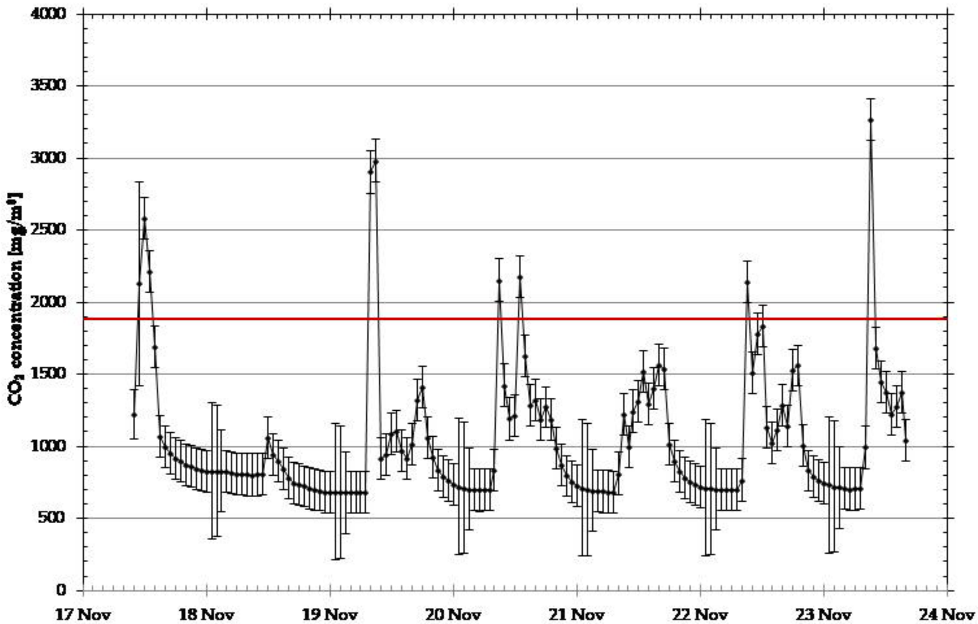

Fig. 2. Graph of hourly averaged carbon dioxide concentration. Bold horizontal line represents 1000 ppm converted into the concentration at averaged measurement conditions

The recommended CO_2 level 1000 ppm was being exceeded on 17th Nov for 3 hours (from 11 to 13) with the maximal value at 2578.1 mg/m^3 (cf. **Figure 2**). The greater concentration was recorded on 19th Nov for two hours (8 and 9) at the maximal level 2982.5 mg/m^3. On 20-23, there were sporadically occurred one-hour CO_2 overruns, whose concentration values reached up to 3264.4 mg/m^3.

In the case of carbon monoxide, the maximal measured value was 480.88 mg/m^3 on 22nd Nov at 9:32.

The short-term exposure limit according to WHO recommendation [2] (100 mg/m^3 per 15 minutes) was exceeded two times. The first exceedance lasted 50 minutes on 22nd Nov between 8:57 and 9:47 at average value 212.07 mg/m^3, the fifteen-minute means changes from 117.45 mg/m^3 to 402.91 mg/m^3. For the second time the limit was exceeded 10 hours later, i.e. between 19:22 and 19:42, at average value 112.04 mg/m^3. The Polish regulation was failed the first time which coincide with the first exceedance of WHO recommendation. In the second case, it lasted 15 minutes from 19:27 to 19:42 at 119.02 mg/m^3.

The thirty-minute exposure limit (60 mg/m^3 in WHO recommendation [2]) was exceeded 6 times. The first exceedance occurred on 19 November and lasted from 17:57 to 18:27 at 64 mg/m^3. The second case took place on 20th November from 18:17 to 19:42 at 68.88 mg/m^3. The third one was measured on 21st November between 15:57 and 16:27 at 62.77 mg/m^3. The last three nonfulfilments were on 22nd November, between 8:47 and 10:52 with average value 142.03 mg/m^3 and later between 11:12 and 11:42 at 64.03 mg/m^3. The last one was happened between 19:07 and 20:02 at 79.88 mg/m^3.

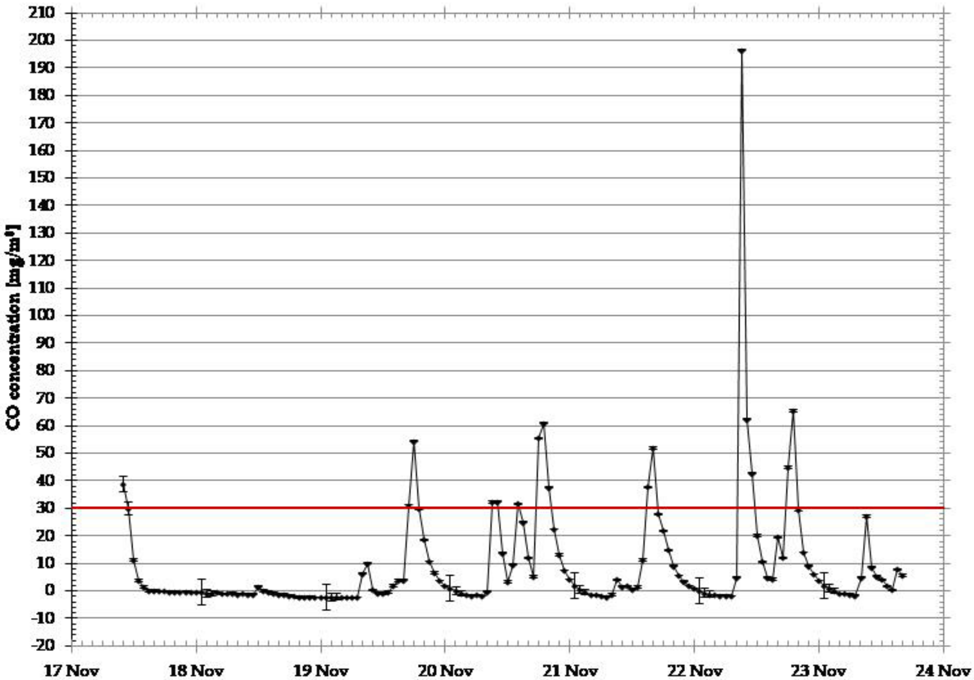

Fig. 3. Graph of hourly averaged carbon 3monoxide concentration. Bold horizontal line represents maximal acceptable by WHO [2] concentration within one hour

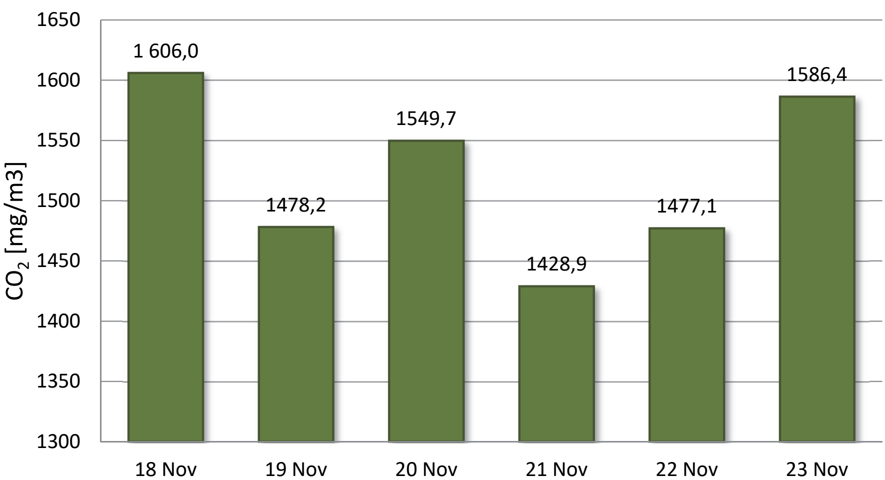

Fig. 4. Time-weighted average (8-hour average) carbon dioxide concentration

The one-hour exposure was greater than WHO recommendation (30mg/m^3) in 8 long-last periods. The first time it was on 17th Nov between10:37 and 11:52 at 31.53 mg/m^3. There was Sunday on 18th Nov which was day off work. The second period started on 19th Nov at 17:02 and ended at 19:52 with average concentration at 44.22 mg/m^3. The three consecutive exceedances happened on the next day between 8:57 and 11:27 at 30.75 mg/m^3, 14:02 and 15:37 at 35.07 mg/m^3, 17:42 and 21:22 at 51.80 mg/m^3. CO concentration was beyond the limit on 21st Nov between 14:52 and 17:42 at 45.04 mg/m^3. For the last two times the WHO recommendation was broken on 22nd Nov between 8:17 and 12:22 at 92.74 mg/m^3, as well as between 17:37 and 20:52 at 51.34 mg/m^3. On November 23, no overruns was recorded.

There was no exceedance of time-weighted average CO2 concentration (cf. **Figure 4**). However, time-weighted average CO concentration was too high in four consecutive days from 20th Nov to 23rd Nov (cf. **Figure 5**).

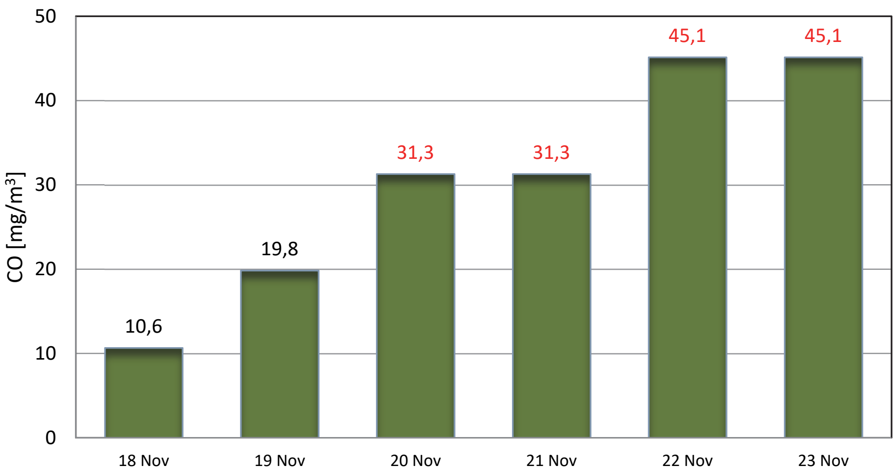

Fig. 5. Time-weighted average (8-hour average) carbon monoxide concentrations

Conclusions

The results of the measurements lead to the conclusion a work in the garage can threaten workers' health. The lack of any ventilation is not acceptable which results in the numerous nonfulfillments of WHO [2] recommendations. What is worse the Regulation of Minister of Economy and Labour [3] was breached in four constitutive weekdays. Such situations origins from the lack of fulfilment the Guidelines of European Garage Equipment Association [8].

So as to improve the work conditions and to save the workers from a poisonous carbon monoxide it is recommended an installation of an exhaust extraction system which satisfies EGEA indications.

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Author Contributions: A.G. and K.J. conceived and designed the experiments; K.J. performed the experiments; A.G. created a calculation algorithm; K.J. did the computations;. A.G. and K.J. analyzed the data and wrote the paper.

Conflicts of Interest: The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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Anna Justyna Werner-Juszczuk

Bialystok University of Technology
Faculty of Civil and Environmental Engineering
Department of HVAC Engineering
a.juszczuk@pb.edu.pl

THE ANALYSIS OF USE OF RADIANT FLOOR HEATING AS COOLING SYSTEM

keywords: floor cooling, radiant floor, heat flux, surface temperature, numerical simulation

Abstract:

The aim of this paper is to analyse the operational parameters of radiant floor heating type A, made in wet technology, working as cooling system, in order to determine the values of heat flux and the temperature, that can be obtain on the floor surface. The influence of variable air and water temperature, pipe spacing and heat resistance of floor covering on surface heat flux and temperature was analysed. The admissible values of water temperature, which ensures the thermal comfort defined by standard ISO 11855, were determined for analysed variables. Calculations were performed with the use of software ANSYS: Steady State Thermal, for steady state conditions.

Introduction

The radiant floor heating is widely use in Poland, especially in single family houses. The growing usage of this system is the result of its many advantages, like ensuring thermal comfort, no radiators in rooms, heat exchange mostly by radiation not convection.

Floor heating systems are low temperature heating systems, what means that the temperature of water supplying particular loops does not exceed 50-55°C (the most often used water temperature is less than 40°C). For this reason floor heating system can cooperate with low temperature sources of heat, such as condensing boilers, and devices which use the renewable energy resources, like heat pumps. In work [1] it was proved that cooperation of floor heating with condensing boilers improves boiler efficiency, and consequently decreases the fuel consumption. When using the heat pump as heat source, the low temperature of water in floor heating system increases pump efficiency, what results in lower electric energy consumption [1].

Some constructions of heat pumps allow to use a floor heating system as a cooling system. This is due to the possibility of the reversible work of a heat pump. In the heating season the reversible heat pump transports heat from the bottom heat source (e.g. ground) and transports it to the building. In the summer season the heat pump works in cooling mode and then the heat is taken from the building and transferred to the bottom heat source. The advantage of this solution is the cooling effect in the building without necessity of installing additional cooling devices. The transmission of the heat to the bottom heat source in summer season increases the temperature of the ground and causes the thermal regeneration of the source. Therefore, the efficiency of the heat pump in heating season increases or does not decrease due to long-term exploitation of the ground. The examples of usage of a heating/cooling radiant floor with reversible ground-coupled heat pump were presented in papers [2, 3].

Surface cooling systems are not often used in Poland. However, in recent years there has been an increase in the use of surface cooling systems in many countries in different climate zones. Radiant cooling systems are used in hot and humid climate, e.g. in Southest Asia and China, an in mild climate, in Europe and North America [4-9]. The most commonly used and tested surface cooling systems are ceiling and floor cooling [10].

One of the advantages of using the heating system as a cooling system is to reduce investment expenditures on the cooling system, as there is no need to purchase additional equipment for air conditioning [11]. The use of a surface cooling system reduces the energy consumption of the building compared to conventional air-conditioning systems. This is related to the high temperature of water in the surface cooling loops, which affects the efficiency of the refrigeration devices [10]. Thermal comfort in a room with surface cooling is ensured due to the small vertical gradient of air temperature and low air velocity, what has been proved with CFD simulations, as a result of experimental research [12] and based on questionnaires conducted among surface cooling users [8].

Although there are many advantages to using underfloor heating as a cooling system, the system also has significant drawbacks. Surface cooling is characterized by low cooling capacity compared to traditional air-conditioning systems, which is especially important in hot and warm climates, where the required cooling capacity is mainly the result of high temperature. In moderate climates, such as in Poland, the cooling loads depend more on the solar or internal heat loads than on high temperature. Hence, surface cooling can be an alternative to traditional air conditioning systems [13].

Low cooling capacity is strongly connected with a high risk of condensation on the cooling surface. When the surface temperature drops below the dew point temperature for the humidity in the room, the water vapor in the air will condense. For this reason the floor cooling capacity is limited by the minimum water temperature in the system, for which the surface temperature is higher than the dew point temperature. This is one of the main disadvantages of the radiant cooling system which causes problems with its applications, especially in humid climates. In the middle climate, in which the required cooling capacity is not very high, due to relatively low humidity and air temperature, this problem is not so significant. In order to avoid the risk of surface condensation, it is recommended to use a parallel ventilation system with humidity regulation [10, 11] or to apply control methods for radiant cooling system to control room air or water temperature [14].

Since the construction of radiant floor in a heating and cooling mode is the same, the efficiency of cooling system depends on the construction of a heating system. The purpose of this paper is to analyse the operating parameters of a radiant floor heating working as a cooling system, in order to determine the value of the temperature and the heat flux values, that can be obtained on the floor surface. The influence of the variable air and water temperature, pipe spacing and thermal resistance of the floor covering on the surface heat flux and temperature was analysed.

One of the most important parameters determining the use of particular type of cooling system in building is the thermal comfort provided by this system. The analysis took into account the requirements of standard ISO 11855 [15] regarding the minimum floor surface temperature for which thermal comfort is ensured among surface cooling users. According to the standard, the temperature of the floor cooling surface should not be lower than 19°C. The results of numerical calculations were compared with the requirements of the standard. For all analyzed variables the permissible values of the temperature of the water supplying the floor cooling system were determined, at which the thermal comfort in the room would be ensured.

The analysis was based on the results of numerical calculations of two-dimensional steady heat transfer in a floor heating/cooling slab made with the commercial software ANSYS: Steady State Thermal.

Materials and methods

In the analysis the most widely used in Poland construction of a floor heating was considered: type A, with pipes attached to the thermal insulation and placed in the cement screed layer. The value of a thermal resistance of thermal insulation is consistent with requirements of standards 1264 [16] and ISO 11855 [15] for floor heating system located in the ceiling between heated areas, and amounts to 0.75 m^2K/W.

During the construction of the floor heating calculation model, which was used in numerical simulation, the following physical properties of materials were adopted:

- floor covering: R = 0.02, 0.05, 0.10, 0.15m^2K/W, height d = 0.015 m,
- cement screed: d = 0.065 m, heat conduction coefficient λ = 1.3 W/mK,
- thermal insulation EPS: d = 0.03 m, λ = 0.04 W/mK,
- reinforced concrete: d = 0.15 m; λ = 1.7 W/mK,
- pipe 16x2mm: λ = 0.35 W/mK.

On the upper and bottom surface of floor cooling the III type boundary condition was set, which is described by the value of air temperature and the heat transfer coefficient. Many researchers investigated the values of heat transfer coefficient for a floor cooling, taking into account the radiative and convective coefficient separately, and variable conditions, like air velocity, temperature, distance from cooled surface [10, 17, 18]. Due to variable values presented by researchers, in this analysis the values of a heat transfer coefficient were set as constant and were derived from the standard ISO 11855 [15]:

- 6.5 W/m^2K for the upper surface of the floor heating slab,
- 11 W/m^2K for the bottom surface of the floor heating slab.

Inside the pipe the III type of boundary condition was also set. The value of heat transfer coefficient for surface between water and pipe depends on the type of flow inside the pipe, and is calculated from various formulas, depending on the value of Reynolds number. In this paper constant water velocity 0.25 m/s was assumed, which for analysed pipe inner diameter means the turbulent flow. For this reason the heat transfer coefficient hw for surface between water and pipe was calculated from following formula [19]:

$$hw = 0{,}116(Re2/3 - 125)Pr1/3\ (1+(di/L)2/3)\lambda p/di\ [W/m^2K] \qquad (1)$$

where:

L – characteristic length [m],
λp – thermal conductivity of the pipe [W/mK],
di – inner diameter of a pipe [m],
Re – Reynolds number [-],
Pr – Prandtl number [-].

At the intersection of the floor cooling plate, no heat exchange was assumed, which means the value of heat flux density q = 0 W/m^2.

Numerical simulations were performed for 2D model with the use of Workbench 19.2 ANSYS: Steady State Thermal Analysis System, which uses the Mechanical APDL solver. The calculations were performed for the following variables:

- pipe spacing: 0.1, 0.125, 0.15, 0.2 m,
- air temperature in the cooled room: 24, 26, 28, 30°C,
- water temperature: 10, 12, 14, 16, 18, 20, 22°C,
- thermal resistance of floor covering: 0.02, 0.05, 0.1, 0.15 m^2K/W.

A computational grid was generated for each analysed pipe spacing. Figure 1 shows the mesh for pipe spacing of 0.1 m.

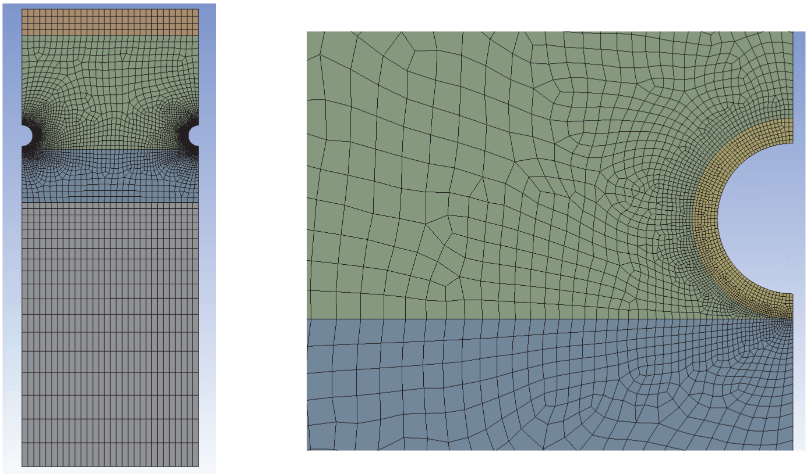

Fig. 1. Mesh for pipe spacing 0.1 m generated with the use of Workbench 19.2 ANSYS: Steady State Ther-mal Analysis System

Results

As a result of the calculations, values of heat flux and temperature on the surface of floor cooling were received, which can be obtained by using underfloor heating as a cooling system. The highest value of the heat flux on the floor cooling surface and the lowest average surface temperature were obtained for the lowest pipe spacing 0.1 m, the lowest thermal resistance of floor covering 0.02 m^2K/W and the lowest temperature of cooling water 10°C. For these parameters and design air temperature 26°C the heat flux equaled 62.5 W/m^2 and the average surface temperature 16.4°C (Figure 2).

The lowest value of the heat flux and the highest average surface temperature were obtained for the pipe spacing 0.2 m, the thermal resistance of floor covering of 0.15 m^2K/W and the water temperature of 22°C. The minimum heat flux was 8.6 W/m^2, and the average surface temperature was 24.7°C, assuming the room temperature was 26°C.

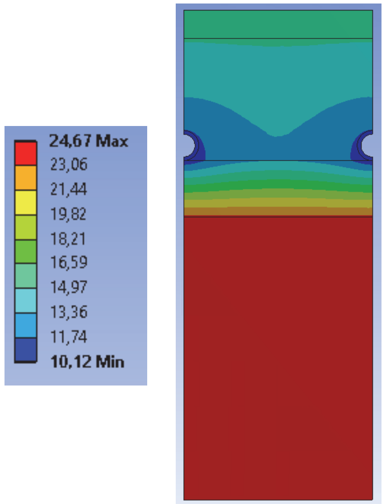

Fig. 2. Temperature distribution in the floor cooling slab (air temperature 26°C, water temperature 10°C, resistance of floor covering 0.02 m²K/W, pipe spacing 0.1 m)

Based on the results it can be concluded that operational parameters of floor cooling strongly depended on the water temperature and the air temperature in a cooled room. The lower temperature of water in cooling system loop, the lower value of surface temperature and the higher heat flux (Figure 3).

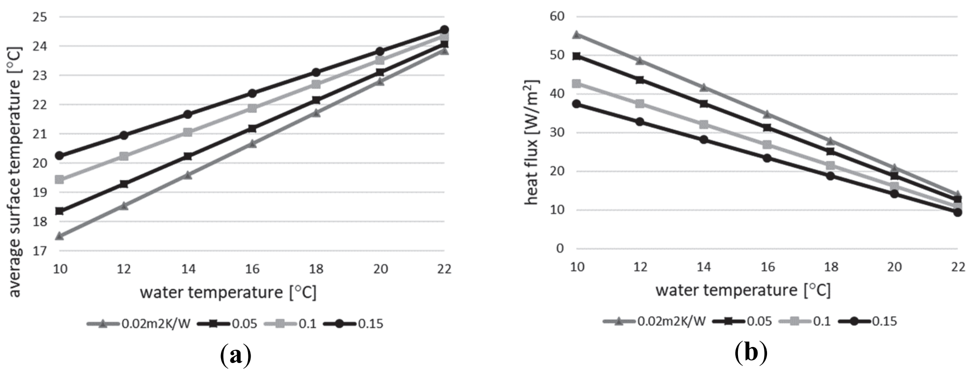

Fig. 3. Relation between: (a) average surface temperature on the floor cooling; (b) heat flux on the surface of floor cooling, and the temperature of cooling medium for the variable thermal resistance of floor covering (pipe spacing 0.15 m, room temperature 26°C)

With the increase of air temperature in cooled space, the surface temperature and the heat flux at floor cooling surface increases (Figure 4).

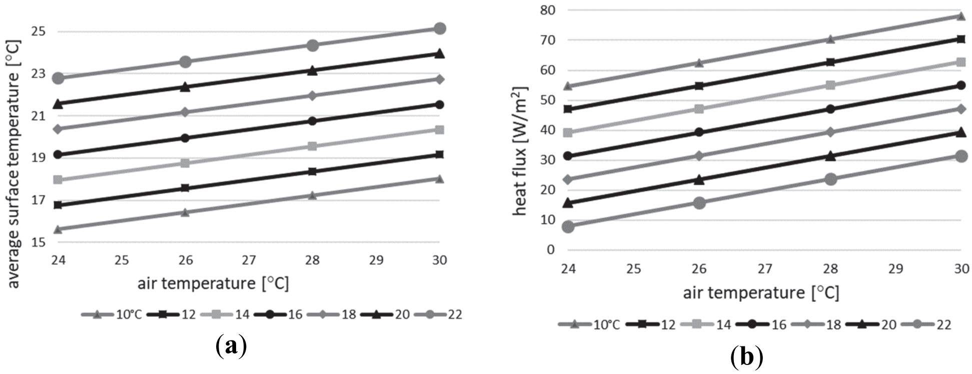

Fig. 4. Relation between: (a) average surface temperature on the floor cooling; (b) heat flux on the surface of floor cooling, and the air temperature for the variable cooling medium temperature (pipe spacing 0.1 m, thermal resistance of floor covering 0.02 m²K/W)

The surface temperature and heat flux of floor cooling depended on the thermal resistance of floor covering. The higher thermal resistance, the higher surface temperature and lower heat flux (Figure 5).

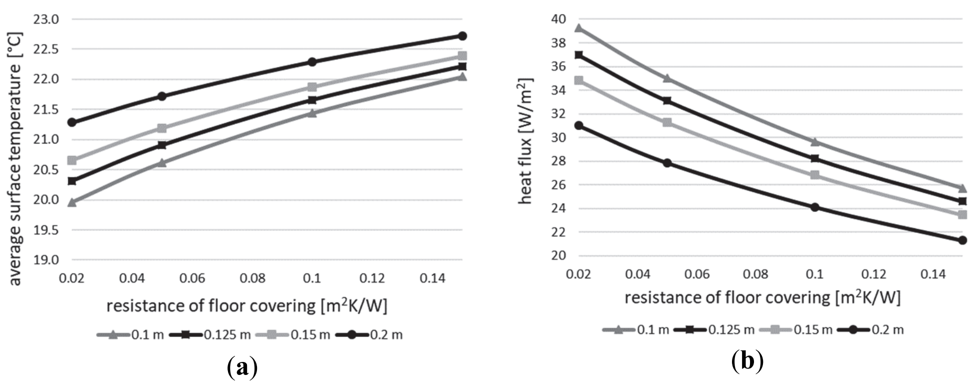

Fig. 5. Relation between: (a) average surface temperature of floor cooling; (b) heat flux at the surface of floor cooling, thermal resistance of floor covering for variable pipe spacing (water temperature 16°C, room temperature 26°C)

A summary list of the results of numerical calculations for air temperature in a room of 26°C is presented in Table 1 and Table 2. For the variable thermal resistance of floor covering R, the pipe spacing and the temperature of cooling water TC, in Tables 1 and 2, the following parameters are collected: the minimum T_{min}, maximum T_{max} and average T_{av} surface temperature, and the maximum q_{max} and average q_{av} heat flux on the surface of floor cooling.

Tab. 1. Surface temperature and heat flux of radiant floor cooling for variable pipe spacing, water temperature and thermal resistance of floor cooling 0.02 and 0.05 m²K/W

R = 0,02 m²K/W											
pipe spacing 0.1 m						**pipe spacing 0.125 m**					
T_C	T_{min}	T_{max}	T_{av}	q_{max}	q_{av}	T_C	T_{min}	T_{max}	T_{av}	q_{max}	q_{av}
°C	**°C**	**°C**	**°C**	**W/m²**	**W/m²**	**°C**	**°C**	**°C**	**°C**	**W/m²**	**W/m²**
10	16,4	16,4	16,4	62,9	62,5	10	16,9	17,0	17,0	59,8	58,8
12	17,5	17,6	17,6	55,1	54,8	12	18,0	18,1	18,1	52,5	51,6
14	18,7	18,8	18,8	47,3	47,0	14	19,1	19,3	19,2	45,1	44,3
16	19,9	20,0	20,0	39,5	39,3	16	20,3	20,4	20,3	37,6	37,0
18	21,2	21,2	21,2	31,6	31,4	18	21,4	21,5	21,4	30,1	29,6
20	22,4	22,4	22,4	23,7	23,6	20	22,5	22,6	22,6	22,6	22,2
22	23,6	23,6	23,6	15,8	15,7	22	23,7	23,7	23,7	15,1	14,8
pipe spacing 0.15 m						**pipe spacing 0.20 m**					
T_C	T_{min}	T_{max}	T_{av}	q_{max}	q_{av}	T_C	T_{min}	T_{max}	T_{av}	q_{max}	q_{av}
°C	**°C**	**°C**	**°C**	**W/m²**	**W/m²**	**°C**	**°C**	**°C**	**°C**	**W/m²**	**W/m²**
10	17,3	17,7	17,5	57,1	55,4	10	18,1	19,0	18,5	52,8	49,2
12	18,4	18,7	18,6	50,1	48,6	12	19,0	19,8	19,4	46,3	43,2
14	19,5	19,7	19,6	43,0	41,7	14	20,0	20,7	20,4	39,8	37,1
16	20,5	20,8	20,7	35,9	34,8	16	21,0	21,6	21,3	33,3	31,0
18	21,6	21,8	21,7	28,8	27,9	18	22,0	22,4	22,2	26,6	24,8
20	22,7	22,9	22,8	21,6	20,9	20	23,0	23,3	23,2	20,0	18,7
22	23,8	23,9	23,9	14,4	14,0	22	24,0	24,2	24,1	13,4	12,5
R = 0,05 m²K/W											
pipe spacing 0.1 m						**pipe spacing 0.125 m**					
T_C	T_{min}	T_{max}	T_{av}	q_{max}	q_{av}	T_C	T_{min}	T_{max}	T_{av}	q_{max}	q_{av}
°C	**°C**	**°C**	**°C**	**W/m²**	**W/m²**	**°C**	**°C**	**°C**	**°C**	**W/m²**	**W/m²**
10	17,4	17,5	17,4	56,0	55,7	10	17,8	18,0	17,9	53,4	52,7
12	18,5	18,5	18,5	49,1	48,9	12	18,8	19,0	18,9	46,8	46,2
14	19,5	19,6	19,5	42,1	41,9	14	19,8	20,0	19,9	40,2	39,7
16	20,6	20,6	20,6	35,2	35,0	16	20,9	21,0	20,9	33,6	33,1
18	21,7	21,7	21,7	28,2	28,0	18	21,9	22,0	21,9	26,9	26,5
20	22,8	22,8	22,8	21,1	21,0	20	22,9	23,0	22,9	20,2	19,9
22	23,8	23,8	23,8	14,1	14,0	22	23,9	24,0	24,0	13,5	13,3

pipe spacing 0.15 m						pipe spacing 0.20 m					
T_C	T_{min}	T_{max}	T_{av}	q_{max}	q_{av}	T_C	T_{min}	T_{max}	T_{av}	q_{max}	q_{av}
°C	°C	°C	°C	W/m²	W/m²	°C	°C	°C	°C	W/m²	W/m²
10	18,2	18,5	18,4	51,1	49,7	10	18,8	19,6	19,2	47,4	44,3
12	19,1	19,4	19,3	44,8	43,6	12	19,7	20,4	20,0	41,6	38,8
14	20,1	20,4	20,2	38,5	37,5	14	20,6	21,2	20,9	35,7	33,4
16	21,1	21,3	21,2	32,1	31,3	16	21,5	22,0	21,7	29,8	27,9
18	22,1	22,2	22,1	25,7	25,1	18	22,4	22,8	22,6	23,9	22,3
20	23,0	23,2	23,1	19,3	18,8	20	23,3	23,6	23,4	17,9	16,8
22	24,0	24,1	24,1	12,9	12,6	22	24,2	24,4	24,3	12,0	11,2

Tab. 2. Surface temperature and heat flux of radiant floor cooling for variable pipe spacing, water temperature and thermal resistance of floor cooling 0.10 and 0.15 m²K/W

R = 0,10 m²K/W											
pipe spacing 0.1 m						pipe spacing 0.125 m					
T_C	T_{min}	T_{max}	T_{av}	q_{max}	q_{av}	T_C	T_{min}	T_{max}	T_{av}	q_{max}	q_{av}
°C	°C	°C	°C	W/m²	W/m²	°C	°C	°C	°C	W/m²	W/m²
10	18,7	18,8	18,7	47,4	47,2	10	19,0	19,2	19,1	45,4	44,9
12	19,6	19,7	19,6	41,6	41,4	12	19,9	20,0	19,9	39,8	39,4
14	20,5	20,6	20,5	35,7	35,5	14	20,7	20,8	20,8	34,2	33,8
16	21,4	21,5	21,4	29,8	29,6	16	21,6	21,7	21,7	28,5	28,2
18	22,3	22,4	22,3	23,8	23,7	18	22,5	22,6	22,5	22,8	22,6
20	23,3	23,3	23,3	17,9	17,8	20	23,4	23,4	23,4	17,2	17,0
22	24,2	24,2	24,2	11,9	11,9	22	24,2	24,3	24,3	11,4	11,3
pipe spacing 0.15 m						pipe spacing 0.20 m					
T_C	T_{min}	T_{max}	T_{av}	q_{max}	q_{av}	T_C	T_{min}	T_{max}	T_{av}	q_{max}	q_{av}
°C	°C	°C	°C	W/m²	W/m²	°C	°C	°C	°C	W/m²	W/m²
10	19,3	19,6	19,4	43,6	42,7	10	19,8	20,4	20,1	40,7	38,4
12	20,1	20,4	20,2	38,3	37,4	12	20,5	21,1	20,8	35,7	33,7
14	21,0	21,2	21,1	32,9	32,1	14	21,3	21,8	21,6	30,7	28,9
16	21,8	22,0	21,9	27,4	26,8	16	22,1	22,5	22,3	25,6	24,1
18	22,6	22,8	22,7	22,0	21,5	18	22,9	23,2	23,0	20,5	19,3
20	23,5	23,6	23,5	16,5	16,1	20	23,6	23,9	23,8	15,4	14,5
22	24,3	24,4	24,3	11,0	10,8	22	24,4	24,6	24,5	10,3	9,7

R = 0,15 m²K/W											
pipe spacing 0.1 m						pipe spacing 0.125 m					
T_C	T_{min}	T_{max}	T_{av}	q_{max}	q_{av}	T_C	T_{min}	T_{max}	T_{av}	q_{max}	q_{av}
°C	°C	°C	°C	W/m²	W/m²	°C	°C	°C	°C	W/m²	W/m²
10	19,7	19,7	19,7	41,1	41,0	10	19,9	20,0	20,0	39,6	39,2
12	20,5	20,5	20,5	36,0	35,9	12	20,7	20,8	20,7	34,7	34,3
14	21,2	21,3	21,3	30,9	30,8	14	21,4	21,5	21,5	29,8	29,5
16	22,0	22,1	22,0	25,8	25,7	16	22,2	22,3	22,2	24,8	24,6
18	22,8	22,8	22,8	20,7	20,6	18	22,9	23,0	23,0	19,9	19,7
20	23,6	23,6	23,6	15,5	15,4	20	23,7	23,7	23,7	14,9	14,8
22	24,4	24,4	24,4	10,3	10,3	22	24,5	24,5	24,5	10,0	9,9
pipe spacing 0.15 m						pipe spacing 0.20 m					
T_C	T_{min}	T_{max}	T_{av}	q_{max}	q_{av}	T_C	T_{min}	T_{max}	T_{av}	q_{max}	q_{av}
°C	°C	°C	°C	W/m²	W/m²	°C	°C	°C	°C	W/m²	W/m²
10	20,1	20,4	20,3	38,1	37,4	10	20,5	21,0	20,8	35,7	33,9
12	20,9	21,1	21,0	33,4	32,8	12	21,2	21,6	21,4	31,3	29,7
14	21,6	21,8	21,7	28,7	28,1	14	21,9	22,3	22,1	26,9	25,5
16	22,3	22,5	22,4	23,9	23,5	16	22,6	22,9	22,7	22,4	21,3
18	23,1	23,2	23,1	19,2	18,8	18	23,2	23,5	23,4	18,0	17,1
20	23,8	23,9	23,8	14,4	14,1	20	23,9	24,1	24,0	13,5	12,8
22	24,5	24,6	24,6	9,6	9,4	22	24,6	24,7	24,7	9,0	8,6

Taking into account the requirements of the standard ISO 11855 [15] on the minimum floor temperature with surface cooling (19°C), the acceptable water temperature, for which the thermal comfort will be ensured, depended on the pipe spacing and the thermal resistance of the floor covering. In the analysis the lowest values of floor surface temperature, obtained during numerical calculations, were taken into account (Figure 6). For all analysed structural parameters of floor cooling, the water temperature should not be lower than 10°C. For the most widely used the pipe spacing in single family houses: 0.1 m and ceramic tiles as floor finishing layer, the water temperature should not be lower than 16°C. The lower thermal resistance of the floor covering, the higher the permissible value of water temperature in accordance with the recommendations of ISO 11855 [15].

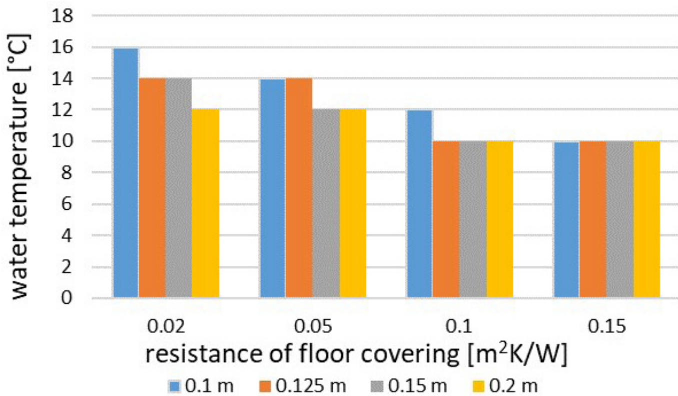

Fig. 6. The admissible value of water temperature for variable thermal resistance of floor covering and pipe spacing (air temperature 26°C)

Conclusions

The use of surface heating systems as cooling systems is not common in Poland. However, due to the increase in the use of heat pumps as heat sources, this technical solution should be taken into account when choosing a system for building cooling, due to low investment costs, improvement of heat source efficiency and providing thermal comfort among users.

It was proved that the operational parameters of floor cooling depend on a pipe spacing, a thermal resistance of floor covering, a water temperature and air temperature in cooled space. When using the floor heating as cooling system the only parameter that can be changed by the user of the system, in order to obtain required system efficiency, is a water temperature. The minimum temperature of cooling water should be set individually taking into account the design parameters of the radiant system, such as pipe spacing and the resistance of floor covering, and the permissible minimum surface temperature of floor cooling. The theoretical cooling performance of a floor system can be high. In practice cooling performance is limited by the minimum allowable surface temperature of the floor, at which there is no risk of surface condensation and also by the recommendations for providing thermal comfort in rooms with underfloor cooling, which are defined in ISO 11855.

The subject of further research will be the analysis of the minimum temperature of water in the floor cooling system, resulting from the risk of surface condensation of water vapor in Polish climatic conditions.

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Natalia Taraszkiewicz

Bialystok University of Technology
Faculty of Civil and Environmental Engineering
Department of Spatial Economy and Energy Building
e-mail: natalia.taraszkiewicz@wp.pl

AGRICULTURAL BIOGAS PLANT LOCATION SELECTION USING MCDA METHODS

keywords: agricultural biogas plants; multicriteria decision aid; investment location

Abstract:

Agricultural biogas plant is an investment that benefits both investors, inhabitants of a given region, as well as the natural environment. Such a project, despite many economic, environmental and social advantages, is also associated with the emission of unpleasant odors or noise. That is why, selecting the location of an agricultural biogas plant, is a particularly important task. The investment location was selected using MCDA methods. Of the three variants, the most favorable in terms of the adopted criteria was selected using both AHP and TOPSIS methods.

Introduction

The role of agricultural biogas plants has increased in the recent years. This was due to the draft program developed in the Ministry of Economy "Innovative Energy – Energy-Related Agriculture". This document is intended to create an agricultural biogas plant in each municipality by 2020. Such biogas plants use biomass produced not in sewage treatment plants but of plant origin. High-yielding raw materials are energy crops, such as corn (silage), rye (silage), sugar beets or potatoes. Natural fertilizers, including manure, are the supplement for them. In the methane fermentation process of such biomass, agricultural biogas, i.e. gaseous fuel, arises. Worth mentioning is the by-product of this process such as compost, which can be used for fertilizing arable fields [1].

In central, eastern and north-eastern Poland the main source of an agricultural biogas comes from mentioned energy crops, because most of agricultural production waste, that can be used as the potential substrates, are often used by the farms themselves [2].

According to [3] biogas production in the agricultural sector is a market that grows rapidly in Europe and bioenergy might be the most important renewable energy source in the next few decades as it offers an economical substitute to fossil fuels. A broad variety of usable forms of such energy to produce steam, heat and electricity, availability at low costs, etc. will be the success of biogas production. The production of biogas can be placed anywhere in the world thank to the fact that in agricultural biogas plant many products can be used as substrates such as: leaves, crops, vegetables, manure, grasses, and many more. This allows the process to be adapted in large as well as small scales [3].

Agricultural biogas plants bring benefits not only to investors or residents of a given area, but also to the natural environment. These installations are characterized by low emission of harmful substances, contribute to the reduction of methane emissions, and through the use of the hygienization process, they contribute to the elimination of pathogens, which translates into a reduction in the risk of surface and underground water pollution [4]. Biogas technology surely offers a lot of benefits. It can be useful to improve the health of users, it is beneficial to the environment as it provides a way to use human, industrial, animal and also municipal waste also agricultural biogas plants are also a sustainable source of energy [5]. Agricultural biogas, contrary to solar panels, wind power plants or hydropower plants can produce uninterrupted as well as continuous energy supply, which can lead to a continuous and uninterrupted heat and electrical power supply in smaller scale for farms or in bigger, for rural areas [6].

Despite many environmental, economic and social benefits of such installations, their location is related to the impact of agricultural biogas plants that is influenced on the environment, including the emission of unpleasant odours (odour mostly depends on the type of the used substrate), noise, etc.

Location of agricultural biogas plant

Before commencing planning work, a decision should be made regarding the selection of a specific investment location. The right choice of location will often decide whether or not to implement it. The basis for choosing a location is usually the availability of substrates to the process (i.e. crops). In regions with a large fragmentation of farms, where infrastructure is insufficient locating a biogas plant might be impossible. That's why a search for a location should be started from the identification of farms with large acreage of lands and at the same time lying close to access roads, especially provincial or national roads. The infrastructure elements necessary for the construction and operation of biogas plants include paved roads, in particular short distance from them or good access. Another thing to identify is location of the site in relation to housing. The assessment of agricultural biogas plant distances from residential areas is ambiguous, with small agricultural biogas plant (capacity to 1 MW) it is often assumed to be 500m . The proximity of residential buildings is beneficial as it increases the chances of utilizing waste heat, thereby reducing the heating costs of buildings, but it can also cause residents' dissatisfaction, protests and eventually possible cancellation of investments, therefore Polish conditions force us to look for locations situated as far away as possible from residential areas.

The subject of the assessment are plots in the municipality of Miastkowo in the southern part of Podlaskie voivodship in the western Łomża district, located in the villages of Leopoldowo, Czartoria and Łuby-Kurki. The Miastkowo commune covers an area of 115km^2. Through its terrain runs national road No. 61 from Warsaw through Łomża, Augustów and Suwałki to border crossings with Lithuania. The main branch of the economy in Miastkowo commune is agriculture [7]. Commune is dominated by farmlands (constituting 61.89% of the area), forests cover about 32.30% of the area, wasteland and other areas – 1.15%, built-up and urbanized lands – 3.17%, and land under waters – 1.49% of the area. Within the Miastkowo Commune there are the following protected areas and objects: Nature 2000 area "Lower Narew Valley", Ecological use "Bagno-Drogoszewo", 2 nature monuments, Nature 2000 site "Ostoja Narwiańska", Protected Landscape Area "Kurpiowska Plain and Lower Narew Valley" [8]. The distance from protected areas is particularly important when planning the investment of an agricultural biogas plant, especially due to its impact on the environment.

The first one of the selected locations is the plot No. 175 located in the village Leopoldowo (Figure 1.). It is a roughly rectangular land with an area equal to 1.02 ha, which is situated in the eastern part of the commune. It is located next to a municipal road, among cultivated fields (potential substrate). This alternative is situated next to forests, which gives the plot a great natural shield against potential pollution, protects it from the spread of noise, odors, etc.

The second alternative is the plot No. 193, situated in Czartoria village, in northern part of Miastkowo Commune (Figure 2.). It is a rectangular land with the area of 1,83 ha, which also means that it's more expensive than the previous one. Similarly to the first alternative, it is also located close to potential agricultural biogas plant substrates.

Fig. 1. Plot No. 175 in Leopoldowo (alternative 1)
Source: [9].

The property in the village of Czartoria is located parallel to the municipal road. It has a regular shape and although it is surrounded by cultivated fields (potential substrates), it is also the closets to the areas of the protected habitats.

Fig. 2. Plot No. 193 in Czartoria (alternative 2)
Source: [9].

The last alternative is a land No. 189 in Łuby-Kurki (Figure 3.). This village is located in central part of its commune. This property consists of an area of 2,5 ha, it's the biggest out of all the alternatives, and is located next to the national road. This square-shaped plot is situated among the crops.

Fig. 3. Plot No. 189 in Łuby-Kurki (alternative 3)
Source: [9].

Each of the presented alternatives is located in another part of the Miastkowo municipality, at different distances from residential areas, as well as from provincial or national roads and protected areas.

MCDA methods in location selection

The aim of the research is to select the most favourable location of agricultural biogas plant in the commune from three options, taking into account economic, spatial and environmental criteria, which were divided into stimulants (having the character of benefits) and destimulants (having the character of costs). Among many methods of multi-criteria decision making (referred to by the abbreviation MCDA or MCDM), two were selected: AHP (Analytic Hierarchy Process) an TOPSIS (Technique for Order Preference by Similarity to Ideal Solution).

The first one is based on the utility function and is characterised by hierarchy in the approach to the problem. In the AHP method, the decision-maker assesses the criteria by comparing them in pairs according to the 9-point Saaty's scale (1980), where 1 – means equal significance, 3 – means a slight advantage, 5 – means a strong advantage, 7 – means a very strong advantage and 9 – means the absolute advantage. The influence of the decision-maker on the assessment of criteria and the creation of comparisons by the matrix makes these judgments subjective.. The final stage of the procedure in the AHP method is to determine the ranking of the options from the most to the least favourable [10].

The TOPSIS method is one of the most popular methods used for decision problems. In it, the considered variants are compared with reference solutions – a positive (PIS) and negative (NIS) ideal solution. When determining the order, the distances of a given variant should be calculated from the reference solutions, while taking into account the weightings of the criteria and the normalization of the evaluation. This allows to find the value of a synthetic meter, by means of which a ranking of variants can be created [11]. With TOPSIS the best variant is basically chosen by at the same time the farthest distance from the NIS and the shortest distance from the PIS. The positive ideal solution and the negative ideal solution are both identified with the "hypothetical alternative" that has the best/worst attribute values [12].

Choose of the criteria used to evaluate the variants is very important. The criteria have to be a good representation of the criteria from a given group, they must provide a lot of information and they can not be repeated. Three groups of them were selected: environmental, economic, as well as spatial. Those criteria include:

- distance to residential areas [m] (C1);
- distance to energy crops [m] (C2);
- distance to the protected habitats [m] (C3);
- distance from provincial / national roads [m] (C4);
- land purchase costs (in thousands) (C5).

The presented criteria are a representation of the most important spatial, social, economic and environmental criteria. The fifth criterion is the average price of 39zł/m^2, multiplied by the size of the property (each alternative). The criteria were divided into stimulants and destimulants. To the first of these groups can be included: distance to residential areas (C1), distance to the protected habitats (C3), and the second one: distance to energy crops (C2), distance from provincial/national roads (C4) and land purchase costs (C5).

An agricultural biogas plant with a capacity of approximately 0.999 MW was analyzed along with the accompanying infrastructure. It will produce biogas from agricultural substrates available on the local market, during the mesophilic methane fermentation process as well as for its combustion in a cogeneration unit. In this process heat and energy will be generated. Using the presented methods, one of the most favourable location variant of a given installation was selected in each of them, and then they were combined with each other. The selected, most advantageous location of the agricultural biogas plant is optimal due to all designated spatial, economic and environmental criteria.

The first of the analyzes was to determine the weight of the criteria using the AHP method. A 9-point Saaty's scale (1980) was used for this purpose. The dependencies between the criteria were determined in a subjective way as shown in Table 1 Data presented below shows that the decision-maker believes that the majority of criteria have only a slight edge over the others. The biggest differences are presented in criterion 1 in relation to the fourth criterion (very strong advantage), as well as criterion 2 to criterion 4. The author has the conviction that it is the distance from the buildings (residential areas) and the distance to the protected habitats, that is most important when choosing the location of the investment, which is an agricultural biogas plant, especially in the light of Polish law.

Tab. 1. Criteria in Saaty's scale

Criteria	C1	C2	C3	C4	C5
C1	1	3	5	7	1/3
C2	1/3	1	1/3	7	1/5
C3	3	5	1	1/3	3
C4	1/7	1/7	3	1	3
C5	3	5	1/3	1/3	1

Source: own work.

Tab. 2. Estimated weights of criteria

Criteria	Estimated weights
C1	0,2215
C2	0,1635
C3	0,2536
C4	0,1672
C5	0,1941

Source: own work.

After defining global preferences, weights of individual criteria were calculated (tab. 2.). They depend on the subjective decision of the decision maker, therefore their results are not surprising, as earlier Table 2 clearly defined which criteria were more important than the others.

The first step after determining the weightings of the criteria is to create the entire decision matrix. It compares three considered decision variants, including the plot in the villages of Leopoldowo (A1), Czartoria (A2) and Łuby-Kurki (A3). Each of them is considered in terms of five variants (Table 3.). As mentioned previously, the criteria for selecting alternatives differ and describe economic, social, spatial and natural aspects.

Tab. 3. Decision table

	Distance to residential areas [m] (C1)	Distance to energy crops [m] (C2)	Distance to protected habitats [m] (C3)	Distance to provincial / national roads [m] (C4)	Land purchase costs [thousands] (C5)
Localisation 1 (A1)	560	100	6230	1800	397,8
Localisation 2 (A2)	860	150	887	2560	713,7
Localisation 3 (A3)	1030	50	5610	0	975

Source: own work.

The final ranking of the presented variants in the light of 5 presented criteria, using the AHP method, was determined using the performed calculations. According to the ranking (Table 4), it is the second alternative that indicate the most advantageous location of the planned investment, in addition it has a very big advantage over the other locations. The second variant was classified as less favorable and the least advantageous option was determined to be the first alternative.

Tab. 4. Results of the investment location selection using AHP method

	C1	C2	C3	C4	C5	
Weights	0,221539	0,163536	0,25362	0,167221	0,1941	SCORE
A1	-0,0037	0,0526	-7,8795	0,9988	0,1312	-1,798
A2	0,0226	0,4737	9,3399	0,0185	0,3650	2,525
A3	0,9810	0,4737	-0,4604	-0,0173	0,5038	0,273

Source: own work.

The second method, according to which the ranking of variants will be determined, is the TOPSIS method. It will be considered in two options. In the first of them the weightings of the criteria obtained in the AHP method will be used, while in the second one, all of the criteria will be weighted according to the ranking, where 1 means the most important and 9 – the least. To complete this analysis a decision table shown in Table 3 will be used. In each of the options of the TOPSIS method, the values were first normalized, and then, using the weights of the criteria, the calculations of the corrected assessments and the determination of the worst and best ideal solution were estimated. The PIS is the solution that is based on maximizing the benefit criteria and minimizing the cost criteria, while the NIS is based on maximizing the cost criteria (destimulants) and minimizing the benefit criteria (stimulants) [13]. The identification of the positive ideal alternative as well as the negative ideal alternative

(Table 5.) allows to determine the distance of individual variants from the best ideal and worst ideal solution.

Tab. 5. Weighted normalized value of alternatives using AHP weights in TOPSIS method; in green – positive ideal solution, in red – negative ideal solution

	C1	C2	C3	C4	C5
A1	0,085325	0,087414	0,187423	0,096182	0,060697
A2	0,131035	0,131121	0,026684	0,136792	0,108898
A3	0,156937	0,043707	0,168771	0	0,148768

Source: own work.

The final ranking of variants was determined based on global assessments (Table 6.). In spite of using the same weights as estimated in the previous method, the most advantageous alternative here is variant 3, with a slight advantage over the first variant, while the second variant is the least advantageous.

Tab. 6. Final rank of alternatives in TOPSIS method using AHP weights; Ri – global rating

Alternative	R_i	Rank
A1	0,60163	2
A2	0,205214	3
A3	0,716312	1

Source: own work.

In the last analysis, weight criteria were given according to the ranking:
- distance to residential areas (C1) – 1st rank,
- distance to energy crops (C2) – 3rd rank,
- distance to the protected habitats (C3) –2nd rank,
- Distance to provincial / national roads (C4) – 5th rank,
- land purchase costs (C5) – 4th rank.

After determining the ranking, new weighting of the criteria was determined, and then weighted normalized value of the presented variants was found. This analysis (Table 7) showed slight differences in the values of individual matrix elements, nevertheless the patterns of the positive ideal solutions and negative ideal solutions refer to the same cells of the decision matrix.

Tab. 7. Weighted normalized value of alternatives using rank weights in TOPSIS method; in green – best ideal solution, in red – worst ideal solution

	C1	C2	C3	C4	C5
A1	0,128382	0,106904	0,197064	0,038345	0,041695
A2	0,197158	0,160357	0,028057	0,054535	0,074805
A3	0,236131	0,053452	0,177453	0	0,102193

Source: own work.

Similar values of distances from best ideal and worst ideal solutions only confirmed the result of the previous analysis (Table 6 and Table 8), and thus, they maintained option 3 in the first place, as the most favorable location of agricultural biogas plants, while the least favorable was, again, the location of the land in the village of Czartoria.

Tab. 8. Final rank of alternatives in TOPSIS method using rank weights; Ri – global rating

Alternative	R_i	Rank
A1	0,598258	2
A2	0,257467	3
A3	0,775624	1

Source: own work.

All of the carried out analyzes were based on the weights of the criteria, which were clearly subjective, because they depended only on the decision-maker. Perhaps, if the investor was to make these decisions and thus he would compare the criteria with each other, the economic aspects would be the most important for him, and hence the cheapest, smallest property would have an outmost advantage.

Undeniably, the results of the carried out analysis present different results. When choosing the most optimal investment location with the AHP method, the second variant was determined as the most advantageous one, and although the TOPSIS analysis was conducted with the same weights as in AHP, the ranking of alternatives went completely different. These two methods have many differences, they use different algorithms of actions, so a dissonance between the final values and ranking is possible. There exist an option to conduct other analysis, using other multi-criteria decision making methods, to redefine the most optimal investment location. Nevertheless, during the procedure of given methods, only one decision maker influenced the weight of the criteria, for the best objectification it would be necessary to determine the weight data with an independent expert or a group of experts, decision makers.

Unfortunately, both the choice of the property by the investor, as well as obtaining all necessary permits to build an agricultural biogas plant in a given municipality, is a time-consuming and sometimes even an impossible task. Many legal restrictions related to the protection of the natural environment, as well as protests of the residents of the commune may affect conducting the investment or, in extreme cases, the inability to realize such an investment. Regardless, the construction of an agricultural biogas plant has many positive effects, which still speaks for the project to be implemented, as assumed by the Minister of Economy, in every municipality in Poland.

Summary

Multicriteria Decision Aid Methods, especially AHP and TOPSIS methods are useful for choosing the location of an investment that can impact on the local environment, people, economic and landscape. The study presents three different variations of agricultural biogas plant sites that are evaluated using mentioned ways. Used methods differ from themselves, the more, it is important to use more than one to carry out such analysis.

The choice of location is not only dependent on the spatial, economic, environmental and social criteria, but also on the policy of the given municipality. Many communes do not expect any industrial areas to be created in their region. Therefore, the construction of agricultural biogas plants in each municipality mentioned in the draft program developed in the Ministry of Economy "Innovative Energy – Energy-Related Agriculture" might be impossible to implement in the real life, even though agricultural biogas plants, in the recent years, are becoming more and more popular all over the world.

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Magdalena Stolarska

Czestochowa University of Technology
Faculty of Infrastucture and Envinronment
Dąbrowskiego Street 73
42-201 Częstochowa
e-mail: stolarska252@gmail.com

INDOOR AIR QUALITY ISSUES IN MULTI-FAMILY HOUSES

keywords: natural ventilation, hybrid ventilation, indoor air quality, multi-family buildings

Abstract:

One of the major objectives to be achieved by the existing residential buildings is to ensure indoor conditions acceptable by the occupants. Strong tendencies towards saving energy in buildings contribute to the use of materials with better thermal insulation (walls) and airtightness coefficients (doors and windows). At the same time, in the existing and new buildings traditional, gravity ventilation is used, becoming an extremely important factor in achieving the required indoor conditions. The following are some of the results of the research on this subject, which will provide a new insight. The paper describes the use of new technologies, such as hybrid ventilation, in the existing buildings. The results presented herein have been achieved from comprehensive measurements in the buildings with natural and hybrid ventilation. The aim of the paper is to present and summarize preliminary studies describing the influence of natural and hybrid ventilation as well as airtightness on an indoor environment.

Ventilation as a prerequisite for good indoor air quality

The American Society of Ventilation Engineers defines ventilation as a process of forced air exchange in a room, implemented in order to refresh it by removing pollutants. Therefore, providing the required amount of fresh air in a room (or building) is considered to be the main objective of a ventilation system. Nowadays, designing and using ventilation systems in buildings is a necessity. In modern societies, the vast majority of people spend about 2/3 of their lives in enclosed areas [1], *i.e.* in residential buildings, work and study rooms, commercial and other facilities. These buildings are intended, on the one hand, to protect users from the direct effects of changing outdoor climatic conditions and, on the other hand, to provide an adequate supply and quality of indoor air (IAQ) in the room.

Sources of indoor air pollution

The dominant influence on the quality of an indoor air is exerted by pollution [8], which occurs in the ventilated rooms. Fig. 1 presents a simplified balance of pollutants.

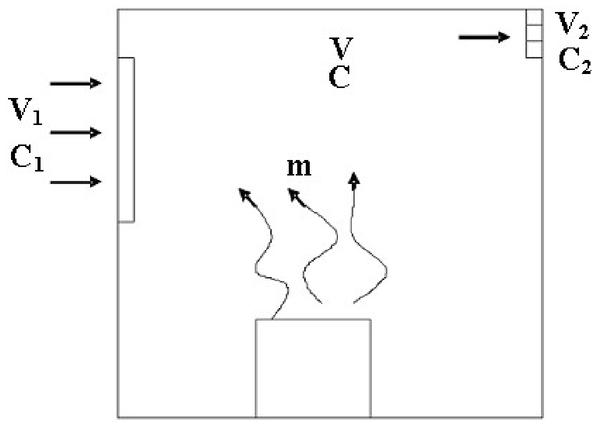

Fig.1. Balance of indoor pollutants

Symbols: V – cubic capacity (m³), C – concentration of the pollutant in the room (kg/m³), m – flux of pollutants produced in the room (m³/s), V_1 and V_2 – volume of air supplied and extracted from the room, C_1 and C_2 – concentration of pollutants in the incoming and outgoing air

The main source of pollution are the users staying in the rooms and their activities. The presence of the users causes changes of the air parameters as a result of heat, moisture and carbon dioxide they produce[3]. Other (not human) pollutants, which are often toxic (*e.g.* carbon monoxide, a result of incomplete combustion processes, smoking, etc.) and occur in high concentrations also have a significant impact on the air quality. However, sometimes even a relatively low concentration of these pollutants has a negative impact on the health and well-being of people staying in a ventilated room [5]. Significant sources of pollution in buildings are devices, *e.g.* printers and photocopiers in office rooms. The research conducted [1], [2] state that they also include building materials, elements of interior design, and even ventilation or air-conditioning systems. Moreover, cigarette smoke containing several thousand carcinogenic substances is an important source of a very large number of volatile substances harmful to health.

Outdoor pollutants in ventilation air

A separate group consists of pollutants introduced into a room together with the outdoor air, whereby air pollution is considered to be any air component that causes deviations from the normal chemical composition of the atmospheric air.

According to literature, atmospheric air is a mixture of nitrogen and oxygen. Nitrogen is 78% and oxygen 21% of the air volume. The remaining 1% contains carbon dioxide, water vapour, argon and other gases. Air pollution includes compounds contained in exhaust fumes, pollen, water vapour, but also its natural components (O_2, N_2, CO_2), if their share in the outdoor air is different from that of the classical chemical air composition. Oxygen is the most important component of the air. Its amount can drop from 21% to 16%, without any noticeable deterioration in well-being. Nitrogen is normally neutral to the human body because it does not participate in human biological processes. The carbon dioxide content of indoor air is greater than that of outdoor air due to the fact that the air exhaled by humans contains about 4% of this gas. Increasing the carbon dioxide content to 2.5% is not harmful to health. At higher concentrations, headaches, tinnitus and accelerated heartbeat occur. Increasing the carbon dioxide content to 18% is life-threatening [8]. In addition, users are exposed to dust, pollen, fungal and mould spores, as well as chemical pollutants from building materials and home furnishing. Many life-threatening harmful substances are not perceived by humans. They are odourless or colourless, their harmful effects on human body can be misleading, and some of the diseases caused by them can be disclosed after many years.

Sources of air pollutant emissions in residential areas include:

- users (residents),
- cooking, washing and cleaning, bathing,
- smoking,
- combustion processes,
- household chemicals (cleaning and laundry products, sprays, cosmetics),
- evaporation of solvents in adhesives, paints, varnishes, furniture, carpets and textiles,
- dust from textiles and home furnishings,
- mites and spores,
- pets

Due to the above-mentioned sources of pollution in rooms, lack of ventilation or inadequate and ineffective ventilation may lead to symptoms of disease in users, such as: headaches and dizziness, weakness and general exhaustion, irregular heartbeat, irritation of eye, nose and throat mucous membranes, commonly referred to as "sick building syndrome" [9].

Ventilation requirements for residential buildings

Ventilation requirements for ventilation in residential buildings are regulated by the PN-83/B-03430/Az3:2000 standard: Ventilation in collective residential and public utility buildings [10].

A standard example of ventilation systems commonly used in residential buildings is the so-called gravity (natural) ventilation, which occurs due to the difference in temperature (density) of outdoor and indoor air.

The required air streams, depending on the intended use of the rooms, are as follows:

- kitchen with gas stove – $70m^3/h$;
- kitchen with electric cooker – $50m^3/h$;
- bathroom – $50m^3/h$;
- toilet – $30m^3/h$
- living room – $30m^3/h$;
- auxiliary room (without window) – $15m^3/h$;
- hall – $15m^3/h$

The streams can also be referred to as "number of exchanges". One "exchange" corresponds to a room volume and the amount of air that must be exchanged within an hour. Requirements for multi-family buildings are the following:

- cellar – 0,3 exchange per hour;
- laundry room – 2,0 exchange per hour
- drying room – 1,0 exchange per hour
- staircase – 0,4 ÷ 0,6 exchange per hour

In buildings not higher than 9 storeys natural or mechanical ventilation may be used; in case of higher buildings mechanical ventilation is necessary, preferably supply and extract ventilation, where both removal and supply of air is forced by ventilation units.

Indoor air quality as a priority for the well-being of users

In view of the threats to health and even life presented above, the supply of an adequate amount of ventilation air of the desired composition is a basic requirement [4],[8]. Therefore, energy savings in ventilation and air-conditioning should be regarded as half measures, not always well-understood by designers, contractors and users.

Where a ventilation system is used in a building, priority should be given to providing a sufficient amount of ventilation air to ensure the desired level of quality of the indoor air. If it concerns outdoor air only, attention should be paid to its pollution causing further decrease of air quality [8]. Assessment of the impact of air pollution on human health has been the subject of intensive interdisciplinary research in recent years. The results of a number of studies indicate that undoubtedly in the temperate climate zone the predominant share in the group of threats to human health and life caused by air pollution, is accounted for by human occupancy in buildings [6], [7]. This view was formally confirmed in the resolution of World Health Organisation, which recognised indoor air quality as an important factor affecting the health of the population as a whole.

Leading and methodology of the measurements

In May 2017, a series of measurements was carried out in a multi-family, 5-storey residential building with two staircases, located in Ruda Śląska at ul. Magazynowa.

The measurements were carried out in two series in both staircases at the same time, with one staircase (no. 1) equipped with gravity ventilation [5], with brick ducts for gravity ventilation in kitchens and bathrooms, and the other staircase (no. 2) equipped with supply and exhaust system of hybrid ventilation. In this ventilation with a balanced pressure system, the ventilation air was supplied through humidity sensitive air inlets, built in the windows of residential rooms, and exhausted through grilles and brick ducts of gravity ventilation. Ventilation ducts complexes were equipped with hybrid cowls, located on the roof of the building. Additionally, in order to prevent the occurrence of negative pressure in the staircase, the staircase has been unsealed by the use of humidity sensitive air inlets in the entrance doors and windows. The apartments were equipped with instantaneous water heaters for municipal water, located in the bathrooms, where the measuring devices were also located. The diagrams below show the results of measurements carried out in two apartments, located at the same (3rd) floor, in the same way in relation to each other, but in two different staircases. The measurements were carried out on the 8th of May, continuously, every 5 minutes. In addition, there was also a continuous measurement of humidity and temperature in the apartments in question. The measurements were carried out in bathrooms in both apartments. The sensor was located at a height of about 1.2 – 1.5m from the floor level, with free access to it from each side, in order to perform the most reliable measurement result.

Fig. 2. Temperature and humidity recorder [www.conradelectronic.pl]

Table 1. Technical parameters of the recorder

Temperature measurement	
Measuring range	–40 – 70°C
Measuring unit	°C
Resolution	0,1
Accuracy	in the range between –40 – 10 °C ±2,0 °C in the range between –10 – 40 °C ±1,0 °C
Moisture measurement	
Measuring range	0 – 100 % RH
Measuring unit	% RH
Resolution	0,1 % RH
Accuracy	in the range between 0–20 % RH and 80–100 % RH ± 5% in the range between 20–40 % RH and 60–80 % RH ± 3,5% in the range between 40–60 % RH ± 3%
DATA LOGGER	storage capacity up to 32,000 results in the device memory; 16,000 entries for temperature and 16,000 entries for humidity.
Sampling time	2, 5, 10, 30 sec.; 1, 5, 10, 30 min.; 1, 2, 3, 6, 12, 24 hrs.

Fig. 3. Carbon monoxide recorder [www.conradelectronic.pl]

Measurements of air temperature and humidity in the apartments in question were carried out by means of a portable temperature and humidity recorder. DATALOGGER ST-171 records temperature in the range from -40 to +700C with 0.1 K resolution and basic accuracy ±1%, and relative humidity in the range from 0 to 100% with 0.1% resolution and basic accuracy ±2% (see Fig. 2 and Table 1). The results are stored in an internal memory with a capacity of 32,000 measurement data: 16,000 measurement data for temperature and 16,000 measurement data for humidity. Programming the recorder, e.g. setting the sampling time, alarm thresholds and presentation of the results is done using a computer, after installing the software supplied with the recorder and connecting the recorder to the USB port. Sampling time can be set from 10 seconds to 5 minutes. The diagrams below show the results of the measurements for two apartments located at the same (3rd) floor, in the same way in relation to each other, but in two different staircases. The measurements were carried out on the 8th of May, continuously, every 5 minutes. In addition, there was also a continuous measurement of humidity and temperature in the apartments in question.

Measurements of carbon monoxide concentration in the apartments in question were carried out by means of a portable carbon monoxide recorder designed to monitor and record carbon monoxide level of CO for the purposes of subsequent analysis. The recorder, chosen for measurements, measures the concentration of carbon monoxide in the range from 3 to 1000 ppm with a resolution of 0.5 ppm and a basic accuracy of ±6% (see Fig. 3). The results are stored in an internal memory with a capacity of 32,510 measurement data. Programming the recorder, e.g. setting the sampling time, alarm thresholds and presentation of the results is done using a computer, after installing the software supplied with the recorder and connecting the recorder to the USB port. Sampling time can be set from 10 seconds to 5 minutes.

Measurements' results and discussion of the results

On the basis of the measurements the following results were obtained: in the staircase no. 1 (with natural ventilation) a significant increase in the carbon dioxide concentration level was observed (Fig. no. 4) and small concentrations of carbon monoxide CO were observed in bathrooms (Fig. no. 5). Compared to the reference apartment in the staircase no. 2, equipped with balanced hybrid ventilation system - the results of the measurements show a significant decrease in the concentration of carbon dioxide (Fig. 4), with maximum values of about 700 ppm, but no carbon monoxide CO (Fig. 5) was recorded.

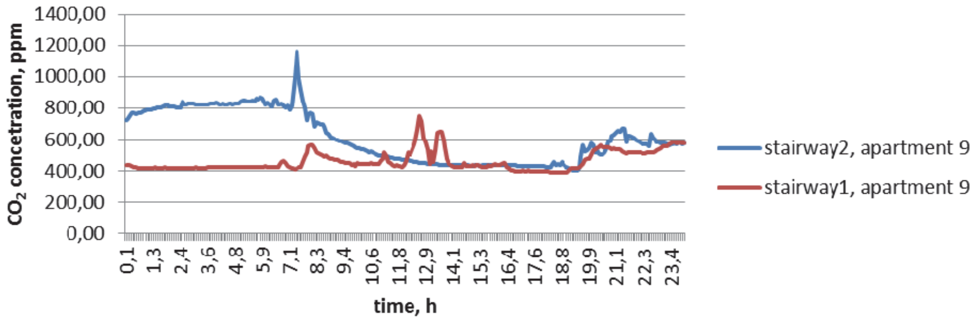

Fig. 4. Concentration of carbon dioxide [ppm] as a function of time (sampling time: 5 min.) in apartment no. 9 (3rd floor) in the staircase no. 1 (with natural ventilation) and in the staircase no. 2 (with hybrid ventilation)

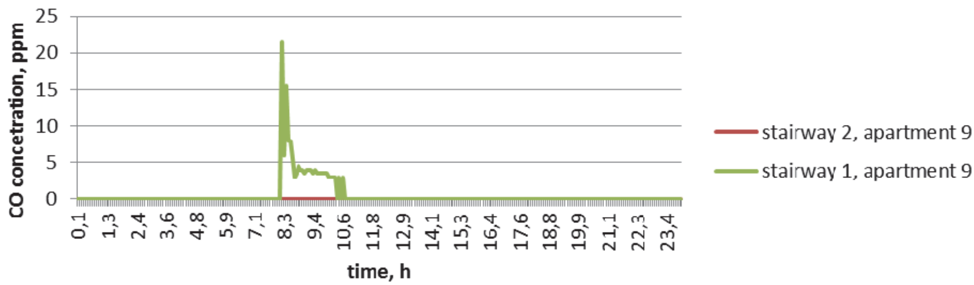

Fig. 5. Carbon monoxide concentration [ppm] as a function of time (sampling time: 5 min.) in apartment no. 9 (3rd floor) in the staircase no. 1 (with natural ventilation) and the staircase no. 2 (with hybrid ventilation)

As a result of measurements carried out in the apartment with natural ventilation, located in the examined staircase no. 1, it was found that the safe level of carbon dioxide concentration, which is considered to be 400 ppm, was exceeded significantly (by over 300%) and that small concentrations of carbon monoxide were observed in bathrooms. Compared to the reference apartment, in the staircase no. 2 equipped with a balanced hybrid ventilation, the results of the measurements indicate a significant improvement of the air quality. In terms of carbon dioxide concentrations, there has been more than a twofold decrease, with maximum values of around 700 ppm, while there has been no carbon monoxide in the reference apartment.

The results presented are those of a single continuous measurement carried out on the 8th of May. However, the same results were achieved repeatedly during the study, which indicates a visible improvement in indoor air quality in the staircase 2, where a hybrid, balanced pressure ventilation system was used.

Therefore, it should be concluded that the presence of carbon monoxide and exceeding CO2 concentrations require new solutions to be applied in existing buildings without the need to subject them to major alterations.

Conclusions

It appeared that buildings equipped in natural ventilation are strongly exposed on the weather conditions, especially external air temperature and external air density) which causes natural ventilation more or less effective. As a result of this it is clear that we can expect worse indoor air quality conditions.

On the other hand we could observe better situation in the staircase equipped in hybrid ventilation system: lower levels of carbon dioxide concentration and lack of carbon monoxide concentration.

The use of a hybrid balanced ventilation system in existing buildings seems justified, however it should be remembered that in most cases these buildings are equipped with gas-fired instantaneous water heaters, which makes it impossible to apply the above solutions under the applicable Building Law and Technical Conditions to which buildings and their location should conform.

Therefore, additional and more detailed research in this area should be carried out in order to raise awareness and make an impact on the legislator with regard to opening up to new solutions and introducing changes in the Building Law and Technical Conditions with which buildings and their location should be compliant.

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