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AGNIESZKA BUCKA*

NATURAL MATERIAL IN SUSTAINABLE CONSTRUCTION WITH REGARDS TO "STRAW BALE" TECHNOLOGY – SELECTED ISSUES

MATERIAŁ NATURALNY W BUDOWNICTWIE ZRÓWNOWAŻONYM NA PRZYKŁADZIE TECHNOLOGII *STRAW BALE* – WYBRANE ZAGADNIENIA

A b s t r a c t

The article raises issues of natural architecture, presenting the advantages of ecological construction and demands of sustainable development. It presents an example of the use of natural material (straw) to erect buildings in the *straw bale* technology. On the basis of the presentation of the building it is shown that future bio-construction may be based on simple, natural and environment-friendly materials [2]. It underlines the benefits and the need to develop natural construction for the good of a mankind and the environment, with regards to the aspect of energy efficiency – both in the process of building and operation. It emphasizes that nowadays the natural architecture gives more and more possibilities of building passive objects or even zero-energy ones. The idea of the publication is also to sensitize the audience to the fact of the use of straw to create objects representing contemporary polemic against the traditional solutions of form and architectural building blocks.

Keywords: *natural architecture, construction of straw, straw bale, natural construction materials, traditional construction materials, straw, ecological houses, energy efficiency, sustainable construction, bio-construction*

S t r e s z c z e n i e

W artykule poruszono problematykę z zakresu architektury naturalnej, prezentującej walory budownictwa ekologicznego i postulaty zrównoważonego rozwoju. Przedstawiono przykład wykorzystania materiału naturalnego (słomy) do wznoszenia budynków w technologii *straw bale*. Na podstawie zaprezentowanego budynku wykazano, że biobudownictwo jutra może być oparte na prostych, pozyskiwanych wprost z natury i przyjaznych środowisku materiałach [2]. Podkreślono korzyści i potrzebę rozwoju budownictwa naturalnego dla dobra człowieka i jego otoczenia, poprzez wzgląd na aspekty energooszczędności – zarówno w procesie budowania, jak i eksploatacji. Zaakcentowano, iż architektura naturalna daje dzisiaj coraz częściej możliwość powstania obiektu pasywnego czy wręcz zeroenergetycznego. Ideą publikacji jest także uwrażliwienie odbiorcy na fakt zastosowania słomy do wznoszenia obiektów stanowiących współczesną polemikę wobec tradycyjnych rozwiązań formy i bryły architektonicznej budynku.

Słowa kluczowe: *architektura naturalna, budownictwo ze słomy, straw bale, naturalne materiały budowlane, tradycyjne materiały budowlane, słoma, domy ekologiczne, energooszczędność, budownictwo zrównoważone, biobudownictwo*

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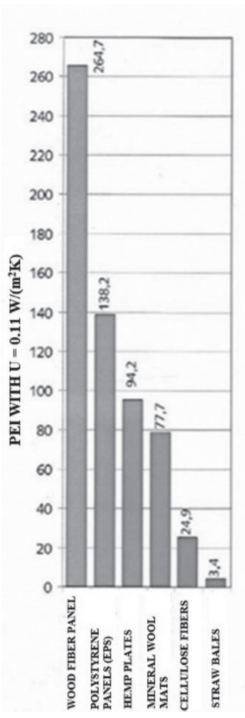
1. Introduction

Natural materials are becoming increasingly important in modern times, especially in the context of environmental protection, which means that the choice of construction material, to a great extent, shapes the eco-footprint of the building. One way to protect it is to act in accordance with the principles of sustainable development, which sustainable construction is a part of. Attention was paid to analyze the legitimacy of the selection of construction materials problem in the context of energy efficiency (with regards to *straw bale* technology). The validity of the use of natural materials in contemporary construction was also demonstrated, especially as it is one of the criteria taken into account in the LEED or BREEAM global organic certification.

2. Organic material in the context of energy efficiency



Energy is needed to produce any construction material. In comparison to industrially processed products, the more natural material is the less embedded PEI energy[1] it comprises. Although this assumption is not always so obvious – as it can be seen in the graph on insulating materials (Fig. 1), a wood fiber panel has almost twice the PEI value in comparison to polystyrene panels (EPS) for the heat transfer coefficient U = 0.11 W/(m^{2}K), which is normally sufficient for the implementation of passive building. Slabs of wood fiber definitely have the highest content of embedded energy (produced by means of wet method). Although hemps, like straw, are agricultural products – hemp plates are less preferred as insulation material because of the value of PEI, than mineral wool mats. Low PEI value for straw bales is due to the fact that straw is a waste product; therefore the energy required for the cultivation of straw is not taken into consideration, as in the case of hemps, which are grown for the production of thermal insulation materials. However, if the processes of cultivation of grain for the production of straw would be taken into account, than its embedded energy value would be at the level of the value presented for cellulose fibers.

Fig. 1. Embedded energy content with heat transfer coefficient U = 0.11 W/(m^{2}K) [6]

[1] An adopted Polish term *embedded energy* is a translation of the German PEI – Primärenergieinhalt. According to [6]: "Energy required to produce a given material is defined as energy embedded in it. The content of PEI embedded energy applies to »all initial and production processes up to the finished product ready for sale. This criterion takes into account only the energy from non-renewable sources. The energy content of wood, water, sun etc. is not included here«. [Kohler/Klingele (ed.) 1995]. Therefore, PEI describes the amount of non-renewable energy, which is needed to produce a product (for example a construction product)".

The walls can be insulated with various materials. The graph (Fig. 2) shows the content of the embedded energy in conventional partitions (includes fragments of walls with no details) in juxtaposition with partitions with straw bales. As a point of reference of submitted comparison there were selected: a wall of calcium silicate bricks, thermally insulated with polystyrene foam (EPS), on the inside covered with resinous plaster, and on the inside with cement and lime plaster (position 1). Energy intensity of a thermal insulation is increased by replacing the EPS with wood fiber panels (position 2). On the next combination of layers of partition wall, with included replacement of wood fiber panels on straw bales, it can be seen a dramatic reduction in the PEI value. Replacement of the supporting layer made of silicates with panels made of glued laminated timber resulted in further reduction of PEI. Analyzing the chart below, it can be finally stated that the use of straw bales significantly reduces the content of PEI embedded energy, where the last option (position 9) turns out to be the most favorable, where the content of PEI is equal to about 10% of the original option.

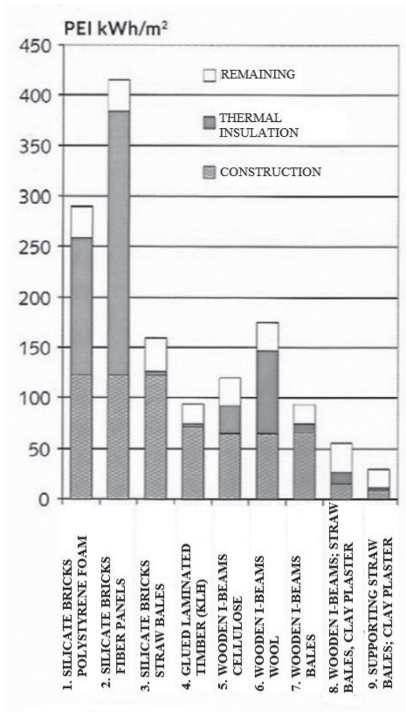
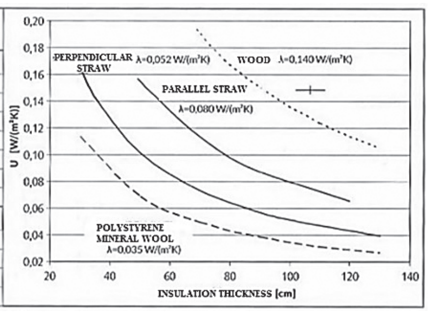


Fig. 2. Embedded energy content for walls of different structure with heat transfer coefficient $U = 0.11$ W/(m^{2}K) [6]

A significant aspect of the formation of construction materials is a method of their production and processing. It is important to take into account the fact that there is a fundamental difference in the level of PEI energy value of construction material for the production and processing when using the traditional method, and using the industrial method.

THICKNESS OF THE LAYER OF STRAW WALL d [M]	COEFFICIENT U FOR THE WALL [W/(m²·K)]
PERPENDICULAR HEAT TRANSFER	
0,31	0,16
0,36	0,14
0,50	0,10
0,70	0,07
0,90	0,06
1,00	0,05
1,30	0,04
PARALLEL HEAT TRANSFER	
0,41	0,19
0,49	0,16
0,80	0,10
1,20	0,07



Material thickness for which $U = 0.11$ W/(m^{2}K) are:
46 cm (perpendicular straw $\lambda = 0{,}052$ W/(m^{2}K))
72 cm (parallel straw $\lambda = 0{,}080$ W/(m^{2}K))

Fig. 3. The value of heat transfer coefficient U for walls made of straw bales depending on the thickness of the straw layer and on the arrangement of stalks [6]

3. Straw as a natural material in *straw bale* technology

A *straw bale* technology [11] is one of the bio-construction technologies. The straw is formed into cubes of specific dimensions by means of a press. Strong compression of straw fibers placed in the press hampers the access of air to the interior parts of structure, which in turn ensures its high fire resistance class. Such modules, made of straw, are deposited in a wooden frame construction of the building or are prepared to be used as wood and straw prefabricated elements. In the construction process de facto it is necessary to build a foundation and to impregnate wall face with clay and protect it with plaster, which would provide straw modules protection against: moisture, rotting processes and against rodents and insects.

Straw is one of primary waste products in agricultural production. It is a renewable resource and in the context of the construction it is a material, which is: very cheap, widely available in most climate zones and not causing any recycling problems. Due to the natural provenance it is characterized by a low value of primary energy (PEI) – approx. 3 kWh/m^2 [3], as compared to the products obtained industrially. It can be a very good thermal and acoustic insulation and the wall built in this technology, which has suitably a thick layer of plaster, is characterized by excellent energy parameters (thermal insulation, heat storage) and it has a high resistance to fire. The very construction the process is classified as ecologically pure, low-energy and optimized in terms of cost. In objects built with straw and clay there is a proper microclimate, resulting from a high absorption and commissioning of steam capacity and also the steam-permeability. An additional advantage generates the possibility of replacing heavy foundation with the foundation points.

With many indisputable advantages of this type of construction the opponents can detect few flaws. The use of clay creates a possibility of crack occurrence during drying the plaster. In addition, a special attention must be paid to the need for highly accurate protection of the straw against moisture acting here as one of the biggest threats. The thickness of buildings' walls from 50 to 60 cm (approx. 20 to 23 inches) can be considered as a minus point because it may translate into an increase in floor space with the same usable floor space. There are also aspects of a social nature situating described construction in the experimental field, which does not raise such a high confidence among users as traditional technologies.

4. Passive buildings as an example of *straw bale* technology

The technology under discussion has, over the past decade, gained great popularity in Western Europe. The objects already built provide not only an innovative approach of abroad cities to alternative construction but also they show great sense of aesthetics and workmanship.

"Larix Haus" (*House of larch*) [9] (Fig. 3), is the first in the Iberian Peninsula passive house, whose design is based on the use of straw and wood. The building is located in the

Fig. 4. Wooden building envelope [9]

Fig. 5. The construction of a “Haus Larix” house (2013) [9]

town called Collsuspina, approx. 70 km (43.5 miles) north of Barcelona. It is a two-story building with a usable floor space of 94 m^2 (approx. 112 square yards). The construction took only five months for the sake of the use of prefabricated elements (Fig. 5), which saved time, minimized costs and eliminated waste on site. Construction of the building was based on a wooden frame filled with straw bales. Materials used in the construction are mostly natural and fully renewable (certified wood, straw and cork from a local source) – which minimized energy consumption and CO_2 emission associated with the construction of the house. Unnecessary heat losses have effectively been reduced by executing a tight housing of the building, insulation made of straw and insulating cork and the use of three-glass windows covered with low-emissivity coating and filled with argon. The building was certified as a passive house (to which also contributed: ventilation system with heat recovery, thoughtful placement and orientation of windows equipped with additional shading systems, electric heaters, fireplace using biomass, compact air heat pump, installation of a photovoltaic system, system of recovery of rainwater).

A special system of prefabricated modules with a height of the entire floor was developed for passive residential-training building in Austrian city of Stollhof (Fig. 6). Moreover, a typical vapor barrier has been replaced by a new clay-woven technology. In addition, the building was covered with green roof with extensive vegetation. Good insulation and high class joinery in cooperation with the installation of heat recovery and controlled ventilation minimize thermal losses. Glazing on the southern facade allows for passive solar gain and for the protection against overheating of the rooms they are equipped with external blinds.

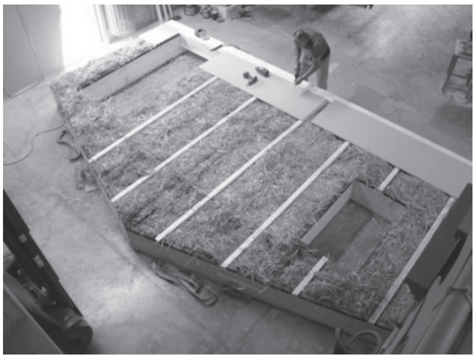


Fig. 6. Prefabricated elements based on wood and straw [9]

5. Straw bales in Polish natural architecture

What is optimistic is the fact that many of the successful implementations of the straw bales are also present in Poland. The facilities created, over the past years, are attractive both from technical and visual point of view and are in no way inferior to Western examples. Recently great popularity was gained by a trend of prefabrication of wall and ceiling elements insulated with straw, which has an impact on the reduction of dependence on weather conditions during installation.

One of the most interesting is the building situated in the town called Gajowiec, located near the town called Mirsk (Fig. 7 and 8), that by decision of SARP (Polish Architects Association) in Jelenia Góra received the first place in the Regional Architectural Review called KASA in 2013 [11].

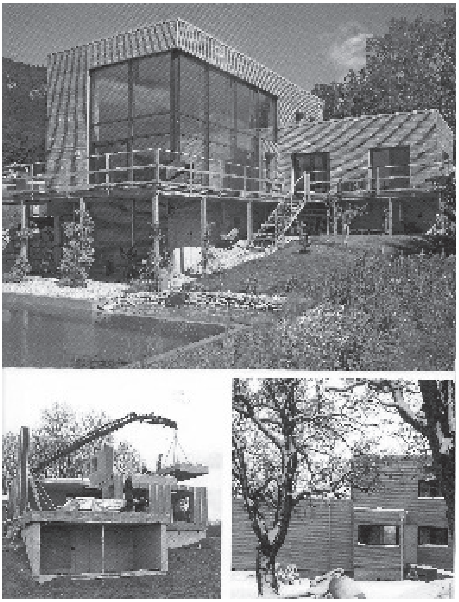


Fig. 7. Residential-training building in Stollhof, Austria [6]

Fig. 8. Holiday cabin situated in Gajowiec near Mirsk (author's archive)

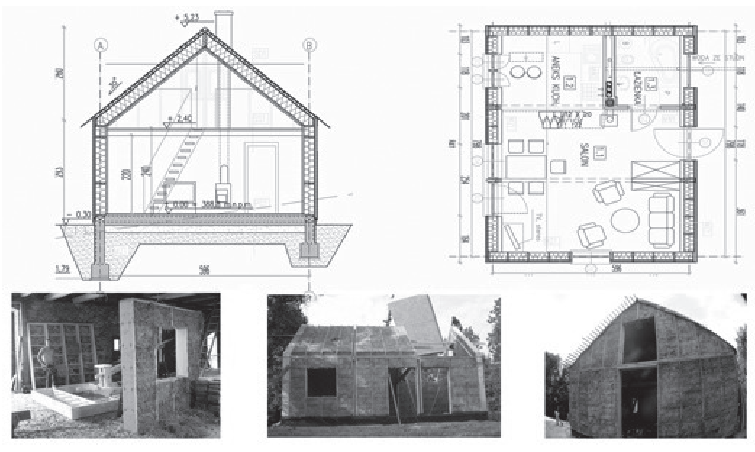


Fig. 9. Summer building situated in Gajowiec near Mirsk – plan, section, the assembly process [11]

Bearing walls of this building are 2.5 m × 2.5 m (8.2 × 8.2 feet) wooden modules filled with straw bales (same dimensions were used in the roof) with cladding, DWD plates and elevational decking on counterbattens. Clay plasters with chaff and with lime plaster were made inside. The thickness of the partition is of 36 cm (approx. 14 inches). Straw bales with a thickness of 30 cm (approx. 12 inches) were used as thermal insulation of external walls and the roof [11].

6. Conclusions

Bio-construction unquestionably benefits from low-processed materials of organic origin in respect to the environment. However, as shown above – not always natural materials (on which such a strong emphasis is put because of a natural origin in the certification system) have a lower PEI indicator than materials produced from fossil or mineral resources. Perhaps this observation should be considered when formulating and specification of the criteria of certification of BREEAM or LEED type?

Building with straw bales abounds with numerous benefits. First to mention here would be: wide availability of the material, its universality, the possibility of recovery, lack of toxicity, waste minimization, and environmental friendliness because of its plant origin and binding of carbon dioxide during the time of the use [7]. Moreover, the presented technology has good thermal insulation parameters, and therefore is predestined for buildings in passive standard and proves that it is possible to build houses that are: healthy, energy economical and affordable.

Using this relatively inexpensive and existing since ages construction material does not need to have a negative impact on the form of designed buildings and bring them into the form of: ancient huts, primitive mud huts or 'fantastic' houses from Tolkien's books, thus being a technically regression. A XXIth century building form in *straw bale* technology does need not be a quote from the past but a refreshing and contemporary release of natural architecture that exists for centuries. These structures not only have positive impact on human's body and safety of the environment but also it can be beautiful, functional and modern, more and more as objects with passive standard. In the context of discussion the following statement seems to be justified: "(...) Natural construction is more necessary for actual architecture rather than multiple neo-, post-, or ultra-modernism" [6].

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IRENEUSZ CHRABĄSZCZ*, MAREK DUDZIK*, MATEUSZ KOŹLAK**, JANUSZ PRUSAK*, KRZYSZTOF BOCZOŃ***

THE PROPOSED NEW RAIL ROUTE BETWEEN KRAKÓW AND ZAKOPANE WITH THE USE OF CIVIL ENGINEERING STRUCTURES – TUNNELS

PROPOZYCJA NOWEJ TRASY KOLEJOWEJ KRAKÓW–ZAKOPANE PRZY WYKORZYSTANIU INŻYNIERSKICH OBIEKTÓW BUDOWLANYCH – TUNELI

Abstract

The existing railway from Kraków to Zakopane is characterised by complex horizontal (curves) and vertical (slopes and rises) profiles. Although the railway is attractive to tourists, it is not highly valued by carriers. This article describes a new route with profile modifications. The new route would be possible mainly due to civil engineering structures such as tunnels. It would make it possible to reduce travel time significantly and reduce energy consumption.

Keywords: electric traction, tunnels, railway route profile, energy consumption

Streszczenie

Istniejąca linia kolejowa Kraków–Zakopane charakteryzuje się złożonym profilem poziomym (łuki) i pionowym (spadki i wzniesienia). Pomimo turystycznej atrakcyjności tej linii, jej ocena przez przewoźników nie jest wysoka. W artykule przedstawiono propozycję nowej trasy o skorygowanym profilu. Nowy przebieg trasy uzyskano głównie dzięki inżynierskim obiektom budowlanym – tunelom. Nowa trasa pozwoliłaby na znaczne skrócenie czasu przejazdu i zmniejszenie zużycia energii.

Słowa kluczowe: trakcja elektryczna, tunele, profil trasy kolejowej, zużycie energii

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1. Introduction

In 1884 a local railway connecting Podgórze (today a district of Kraków) with Sucha was built. After the construction of the Chabówka–Zakopane section, the existing Kraków––Zakopane railway was completed in 1899. It is mainly a single-track railway. Electrification of the railway was completed in December 1975. The current 150 km long Kraków–Zakopane route – and the rolling stock used on it – failed to satisfy the passengers' expectations. The route goes around many hills and includes a number of sharp curves. During the construction of the railway embankments, flyovers and tunnels were avoided due to cost savings. As a result, the traction conditions of the route are poor and requires trains to slow down considerably. It is much faster to cover the distance by car, resulting in an enormous amount of traffic congestion on the road from Kraków to Zakopane, especially during summer and winter holidays, as well as during weekends. In periods of heavy traffic, travel time can be extended by as much as 400% over particular stretches of the route, compared to normal conditions. The new route using civil engineering structures (tunnels), as described in this article, could shorten the travel time of trains and reduce energy consumption [1, 2].

1.1. The Proposed New Rail Route from Kraków to Zakopane

The new rail route could significantly reduce the level of traffic on national roads No. 7 and 49 in several sections between Kraków and Zakopane, as well as replace the existing inefficient rail route. Passengers would be able to travel from the capital of Małopolskie Province to Zakopane and other towns located along the new railway much faster than what is currently possible. On weekdays, students and commuters could use a fast and comfortable means of transport instead of a tiring (at high levels of traffic) car drive.

1.2. The New Route and Its Characteristics

The new route would be a fast rail connection from Kraków to Zakopane, passing through Myślenice and Nowy Targ. This connection could be possible by constructing a new railway from Kraków to Chabówka (with the use of tunnels) and modernising the existing railway from Chabówka to Zakopane [3]. Given that the existing railway is to be modernised, then the route is already basically defined and would only need to be changed at the sections which require railway modifications (due to increases in curve radiuses).

1.3. Technical Assumptions for the New Route

Travel time from the Kraków Main Station to Zakopane – approx. 60 min:
at the B-C-D-E section – proposed route – Category M200 (Fig. 1), maximum speed: 200 km/h;
at the E-F section – from Chabówka to Zakopane – Category P120 (Fig. 1), maximum speed: 120 km/h.

The existing route at the E-F section would be modernised in order to meet the requirements of the adopted category. The reason for the speed limit is the short distance between stations. This section of the railway would be a panorama rail route, with the maximum speed of 120 km/h.

1.4. Speed Distribution

While designing the speed distribution for the new railway, the following elements [4, 5, 6] were taken into consideration:
– the maximum speed of passenger trains according to the railway type;
– the maximum speed of freight trains;
– the longitudinal profile of the railway;
– stops for passenger and freight trains.

This route would enable trains to maintain a constant speed over the longest possible sections and allow them to reach the maximum permitted speed for a given railway type across most of its length. It is recommended that the total length of sections with the maximum permitted speed would not be less than [3]:
– 85% of the total railway length for constructed railways;
– 60% of the total railway length for the P120 type modernised railways.

2. The New Route

On the basis of the guidelines [7] for the maximum altitude differences and curve radiuses for each route category, a railway plan [3] was developed.

While designing the new route, the following factors were taken into consideration: housing and industrial density and topography, which greatly influences the technology and cost of railway construction. The starting station of the proposed railway is the Kraków Main Station, and the starting point from Kraków would be the curve of the existing Kraków–Wieliczka railway. The new route was designed based on the available maps (Fig. 1). Altitudinal measurements were conducted using satellite measuring tools, and maps were made available by the Małopolska Infrastruktura Informacji Przestrzennej (Spatial Information Infrastructure of Małopolska) [3], which helped develop elevation profiles along the route.

The Kraków Main Station has been chosen as the destination station for high-speed trains. An integral part of the Kraków–Zakopane railway line project is the construction and connection of the Bieżanów 1 junction with the Kraków Main Station. For this purpose, the existing Kraków–Tarnów railway line will be used, linking with the line in the direction of Wieliczka, then turning south and continuing along a section of this route, at which point the new line bends towards the west, forming the Bieżanów 1 junction, where it ultimately leaves Kraków.

The main obstacles to the construction of the proposed line is the diverse topographical profile within the whole southern part of the Małopolska region. This region is characterised by a number of solitary mountaintops, while the valleys are densely populated and industrialised. The Raba River between Myślenice and Lubień floods in rainy conditions, limiting the use of the land, which is classified as floodplains. (Section D-E) (Fig. 1).

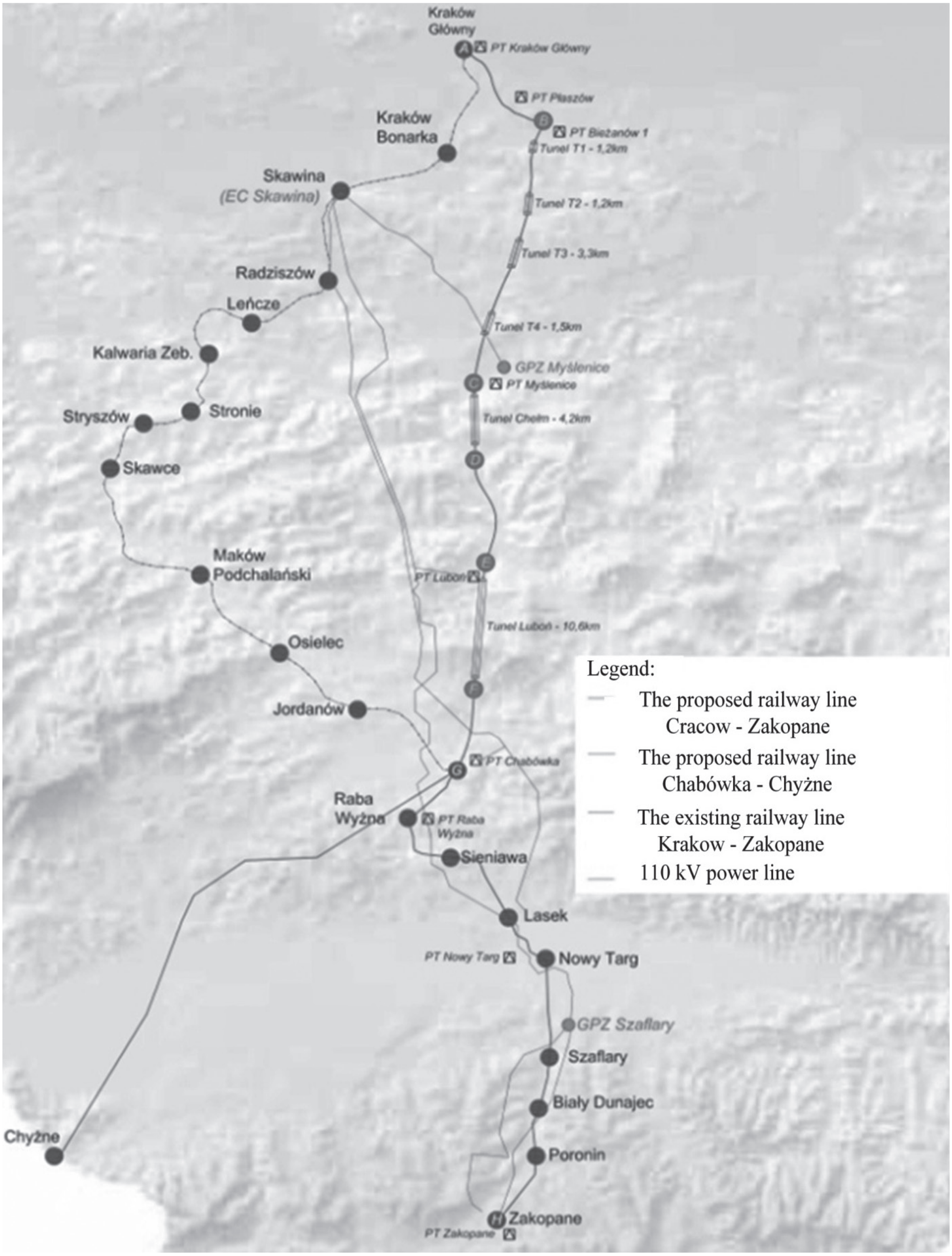

Fig. 1. Map of the new railway route

3. Technical Solutions

On the basis of the aforementioned assumptions and the existing natural obstacles, the construction of 6 new tunnels would be a prerequisite of obtaining the required parameters of the route (curve radiuses and altitudes) with a direct bearing on the maximum train speed. Another important issue would be the necessity of laying tracks on a steel sheet piled embankment, which would also serve as a flood embankment on the east bank of the Raba River along the D-E section (Fig. 2). Such a solution would fulfil the necessary parameters along the upper section and protect the inhabited areas from floods. Additionally, along the D-E section, a road would run parallel to the railway line, providing a connection with the area behind the railway line, because the numerous bridges distributed along the way will have to be removed, as they are obstacles to the newly designed railway line. Along the Chabówka–Zakopane section, due to the densely situated railway stations, the train speed would not exceed 120 km/h. Within the above section, the railway line would be partly modernised to adjust to the parameters, in particular the radiuses of curves according to the technical requirements set by Polskie Linie Kolejowe (Polish Railways) [7].

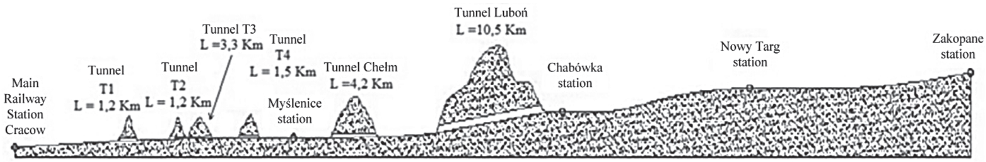

Fig. 2. New route profile

4. Type of Rolling Stock and Traction Assessment – Choice of Rolling Stock

The state-of-the-art three-unit Elf EMU [3] has been chosen for the proposed route in order to achieve much higher speeds than the current rolling stock, as well as significantly shorten travel times.

The minimum capacity of the rolling stock has been established based on the timetables of buses and coaches, which now dominate passenger transport on the Kraków–Zakopane route, and has increased by 50% due to the anticipated increase in demand for rail transport.

Buses leave the Kraków bus station approximately every 15 minutes, taking 30 passengers on average. The travel time is 2.5 h under normal traffic conditions. The train travel time of 60 minutes means that one train with a capacity of 300 passengers can replace seven buses.

5. Routes and Frequencies

It has been assumed that all trains will be operated by multiple units of identical traction characteristics.

In order to optimise transport efficiency, it has been assumed that the following basic routes will be serviced with high frequency:

a) Kraków–Zakopane – all day every 60 minutes alternately with trains (Kraków–Myślenice–Nowy Targ–Zakopane)
b) Zakopane–Kraków – all day every 60 minutes alternately with trains (Zakopane–Nowy Targ–Myślenice–Kraków).

The travel time on the Kraków–Zakopane route has been determined based on the theoretical drives for the assumed timetable speeds, allowing for the following technical provisions (Table 1).

Table 1

Selected travel times for basic routes according to variants

Routes		Current time	Projected time	Train type
Kraków	Zakopane	4:12	0:57	regular
Kraków	Zakopane	3:57	0:50	express

6. Traction Assessment

In order to determine the loading conditions acting on the newly designed railway line, theoretical drives were performed, from which the following parameters were obtained: total energy consumption, specific energy consumption, and results such as the technical speed and total travel time obtained over the course of the assessment of the analysed route for particular types of trainsets.

It was assumed that the drive will be performed twice along the analysed section.

a) the first drive was performed for a three-unit EMU, based on a timetable,
b) the second – return – drive was performed for the same unit,
c) the third drive was performed for a three-unit EMU without stops,
d) the fourth – return – drive was performed for the same unit.

The weight of each unit was increased by the weight of seated passengers, each weighing 80 kg (Table 2).

Table 2

Results of theoretical drive calculations

3-unit ELF EMU Kraków–Myślenice–Chabówka–Zakopane	3-unit ELF EMU Zakopane–Chabówka–Myślenice–Kraków	3-unit ELF EMU express train Kraków–Zakopane	3-unit ELF EMU express train Zakopane–Kraków
$S = \Sigma\Delta S = 99.5$ km	$S = \Sigma\Delta S = 99.5$ km	$S = \Sigma\Delta S = 99.5$ km	$S = \Sigma\Delta S = 99.5$ km
$T = \Sigma\Delta t = 70$ min	$T = \Sigma\Delta t = 66$ min	$T = \Sigma\Delta t = 57$ min	$T = \Sigma\Delta t = 50$ min
$A = U \cdot \Sigma I\Delta t = 1154$ kWh	$A = U \cdot \Sigma I\Delta t = 414$ kWh	$A = U \cdot \Sigma I\Delta t = 1179$ kWh	$A = U \cdot \Sigma I\Delta t = 630$ kWh
$j = \frac{A}{m \cdot s} = 88.53 \left[\frac{\text{Wh}}{\text{brtkm}}\right]$	$j = \frac{A}{m \cdot s} = 31.75 \left[\frac{\text{Wh}}{\text{brtkm}}\right]$	$j = \frac{A}{m \cdot s} = 90 \left[\frac{\text{Wh}}{\text{brtkm}}\right]$	$j = \frac{A}{m \cdot s} = 48 \left[\frac{\text{Wh}}{\text{brtkm}}\right]$
$V_t = \frac{S}{T} = 85.3 \frac{\text{km}}{\text{h}}$	$V_t = \frac{S}{T} = 90.45 \frac{\text{km}}{\text{h}}$	$V_t = \frac{S}{T} = 104.6 \frac{\text{km}}{\text{h}}$	$V_t = \frac{S}{T} = 119.4 \frac{\text{km}}{\text{h}}$

Where: S – distance [km], T – total travel time [min], A – total energy consunption [kWh], j – specific energy consumption $\left[\frac{\text{Wh}}{\text{brtkm}}\right]$, V_t – average speed [km/h].

7. Summary and conclusions

The preliminary analysis suggests that a new Kraków–Zakopane railway connection could be built, which, thanks to modern civil engineering structures such as tunnels, would allow much higher speeds. The article discusses the passenger variant. It was assumed that the line would be operated by three-unit PESA Bydgoszcz ELFs (WE21), for which the results have been presented in this paper.

High-speed railways are characterised by different technical parameters from those of the existing rails and result in specific track requirements, particularly curve radius, longitudinal tilt, and intertrack space.

For these reasons, the costs of construction exceed the corresponding costs of modernisation to the existing railways. On the other hand, the investment would significantly reduce travel times.

The calculation results of theoretical drives for the new railway suggest that the travel time from Kraków to Zakopane would be 57 minutes, with a return journey of only 50 minutes. The difference is attributable to differences in elevation between Kraków and Zakopane, which is about 600 m. The Zakopane-Kraków trains travel downward, encountering less resistance, thereby achieving a maximum speed with reduced energy consumption (Table 2).

By comparison, train travel time from Kraków to Zakopane now is much longer than three hours (Table 1).

This short travel time along this route is possible only if tunnels are constructed. Because of tunnels, the problem of the curve radiuses and steep slopes, which significantly affect train movement, would be eliminated.

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STATIC AND DYNAMIC ANALYSIS OF THE STEEL VIEWING PLATFORM

ANALIZA STATYCZNO-DYNAMICZNA STALOWEJ PLATFORMY WIDOKOWEJ

A b s t r a c t

This article outlines static and dynamic analyses of the viewing platform in Trzęsacz. The steel construction consists of two parallel lattice girders placed on concrete columns. The elements of the girders are made of tubular profiles. Ultimate limit state and serviceability limit state criteria were fulfilled in accordance with algorithms from Eurocodes. This paper also presents an analysis of the platform's dynamic responses from rhythmical motion caused by human activity. The results of these calculations were checked with the comfort levels of people standing in the platform during the vibrations. Robot Structural Analysis Professional was used for the linear load case of static analysis and modal analysis.

Keywords: viewing platform, dynamic analysis, human body motion

S t r e s z c z e n i e

Artykuł przedstawia wyniki statycznej oraz dynamicznej analizy platformy widokowej w Trzęsaczu. Konstrukcja składa się z dwóch równoległych kratownic. Obiekt wykonany jest z rur stalowych o zmiennych przekrojach w zależności od wielkości sił przekrojowych. Na podstawie procedur zawartych w Eurokodach dokonano weryfikacji stanu granicznego nośności i użytkowalności wybranych elementów obiektu. Przeprowadzono ocenę wpływu intencjonalnego oddziaływania dynamicznego na konstrukcję. Sprawdzono czy nie dochodzi do przekroczenia dopuszczalnych wartości przyśpieszenia drgań z uwagi na komfort użytkowników. W programie Robot Structural Analysis Professional wykonano przestrzenny model konstrukcji, następnie przeprowadzono statyczną oraz modalną analizę.

Słowa kluczowe: platforma widokowa, analiza dynamiczna, oddziaływanie użytkowników

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1. Introduction: viewing platforms – characteristic and tasks

Viewing platforms are constructions designed for pedestrians, rather than for vehicular traffic, whose main purpose is to enable visitors to admire breathtaking views of the surrounding natural scenery. Observation decks can complement the landscape and visually link two distinct areas. Due to the fact that they are usually suspended over precipices or water obstacles, viewing terraces intensify the impressions and emotions of the people who use them. Platforms also enhance the attractiveness of tourist areas.

In many countries they are both functional objects and beautiful works of art and sculpture. Observation decks are characterized by unique shapes and forms. These constructions are one of a kind, which arouses people's interest in them.

Due to the nature of their location and function, terraces are under the influence of various kinds of loads (excitations). These are mainly atmospheric effects such as wind, rain, snow and temperature changes. A significant influence on observation decks is the pedestrian load, which determines the dynamic response. The increase of vibration problems in modern steel structures yields a significant amount of evidence that viewing platforms should be designed not only for static loads, but also for dynamics ones.

2. Viewing platform in Trzęsacz

The object of this article is the steel viewing platform (Fig. 1a, 1b), which is located near the ruins of a 12th century church situated high on the edge of a cliff in Trzęsacz (in the north of Poland). This spectacular observation deck was opened in 2009, thereby enabling tourists to admire the sea, the coast, beaches and the ruins of the historic church from an exceptional perspective.

a) b)

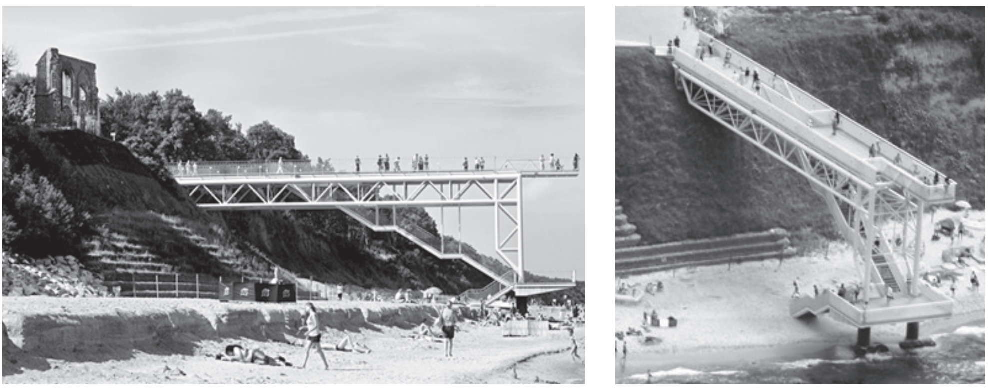


Fig. 1. The steel viewing platform in Trzęsacz: a) from the west, b) from the north

The steel construction reaches 15 meters high and consists of two parallel lattice girders, which are over 36 m long. The structure is located on two pillars placed 4.6 m from each other. The elements of the girders are made of tubular profiles and joined by welds.

Two terraces are designed within the structure: the upper one is situated 15 m above sea level and the lower one is placed 4 m above sea level. Both terraces are connected by steel stairs. A special lift for disabled tourists is also planned. Because of harsh maritime atmospheric conditions, all surfaces are covered with special protective layers.

The truss structure is a stable prop for the pedestrian deck. The bridge is designed as a grid supported by a framework of gusset plates and slides.

3. The numerical model of the platform

The three-dimensional model of the viewing platform was created in Robot Structural Analysis Professional (Fig. 2). It consists of 525 elements, mainly tubular profiles, which are connected by vertical and horizontal welds.

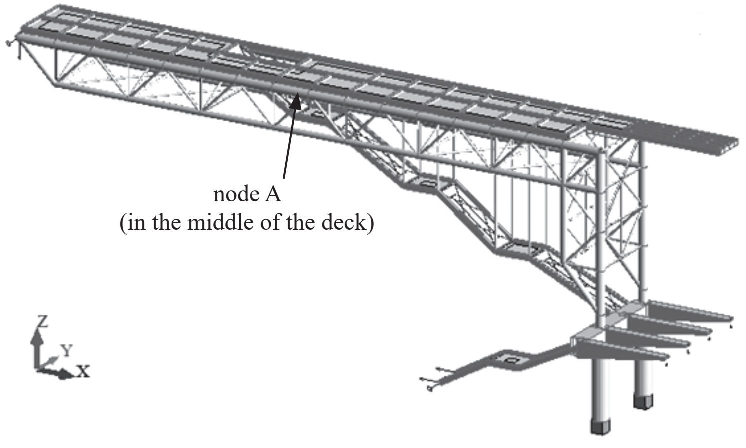


Fig. 2. The numerical three-dimensional model of the viewing platform in Trzęsacz

The construction was propped up in three places. The pillar on the land side was designed as a cross tilting support roller with the possibility of horizontal movement (in the direction of the x-axis). The concrete pillars were created as brackets. The prop on the stair side was designed as a cross tilting support roller with the possibility of vertical movement (in the direction of the z-axis).

After finishing the three-dimensional model of the structure, applying loads, and creating combinations of loads, a series of static, modal and time history analyses were made. The results were used for the calculations carried out in this work.

The structure was tested by various kinds of influences: the weight of the structure itself, environmental effects (like snow, frost, wind, and temperature changes) and a crowd occupying the upper deck of viewing platform. The largest values of internal forces were generated by structure's weight and crowd load. Maximum displacement caused by these influences occurred in the middle node of the upper deck (Fig. 2).

4. Static analysis of steel the viewing platform

There are two essential conditions which have to be considered at the design stage: the ultimate limit state (ULS) at failure and the serviceability limit state (SLS) under working loads. The ultimate limit state and serviceability limit state criteria are used to verify that the structure remains stable and can withstand multiple loads. It is important to check that the structure satisfies these criteria in order to ensure the safety of people or objects inside the structure.

The automatic calculation results of steel member verification and design were made in Robot Structural Analysis Professional to carry out the static analysis of the structure. This procedure analyzes an individual element and its nodes according to a theoretical algorithm from Eurocodes. The element verification gives a positive result, ensuring that he structure satisfies ULS and SLS criteria. The bearing capacities of every element of the steel viewing platform are enough to carry the loads. Occurred deflections do not exceed acceptable deformation.

5. Analysis of the dynamic response of rhythmical motion caused by human activity

Different types of rhythmical motion caused by human activity (walking, running, jumping, dancing, lateral body swaying etc.) can cause variable steady-state vibrations in structures. Table 1 defines the different types of activity and gives the estimated ranges of their vibration rates in structures.

Table 1

Activity rate for different types of motion

Type of motion	Activity rate [Hz]
Walking	1.6–2.4
Running	2.0–3.5
Jumping	1.8–3.4
Dancing	1.5–3.0

The natural frequencies of the construction were evaluated in Robot Structural Analysis Professional. The first frequency f_u = 2.68 Hz is associated with vertical vibrations. The typical frequency of jumping equals 1.8 Hz÷3.4 Hz, f_u = 2.68 Hz lies within this range.

The structure was tested by the force of one person jumping in the middle of the upper deck of viewing platform. The largest vertical displacements caused by structure's weight and crowd load occurred in this area of the structure. The force was divided into equal halves and applied to each of two lattice girders.

The dynamic characteristics of the steel viewing platform derived from the modal analysis made in Robot Structural Analysis Professional are presented in Table 2.

The first natural frequency exceeded the value of 1 Hz. It can be concluded that the viewing platform is characterized by high rigidity. The dynamic analysis of the structure does not take into account the dynamic influence of wind because it would not affect the results of analysis.

Table 2

The dynamic characteristics of the steel viewing platform

No. of mode shape	Frequency [Hz]	Pulsation [1/s]	Period [s]	Description
1	2.68	16.87	0.37	vibrations in the vertical (dominant) and horizontal direction
2	3.70	23.26	0.27	torsional vibrations
3	3.81	23.95	0.26	vertical vibrations (occurring only on the cantilever of the upper deck)
4	5.09	31.95	0.20	vertical vibrations
5	7.03	44.19	0.14	vertical, horizontal and torsional vibrations

The forcing function due to a person's rhythmical body motion can be mathematically described by a Fourier series of the form:

$$F_z(t) = G + \sum_{i=1}^{n} G\alpha_i \sin\left(2\pi i f_u t - \varphi_i\right)$$

where:

G – human's weight (average pedestrian weight: G = 800 N),

α_i – Fourier coefficient of the i-th harmonic (estimated values for f_u = 2.68 Hz)

α_1 = 1.732,

α_2 = 1.164,

α_3 = 0.564,

i – number of the i-th harmonic (i = 1, 2, 3),
n – total number of harmonic components,
f_u – activity rate,
t_c – the contact time of the user's feet to the structure (t_c = 0.187 s),
φ – phase lag of i-th harmonic relative to the 1st harmonic $\varphi_2 = \varphi_3 = \pi(1 - f_u t_c) =$ = 1.571.

For the parameters above, the forcing function $F_z(t)$ of the dynamic interaction caused by a person jumping was created. The graph below (Fig. 3) shows that the function is periodic.

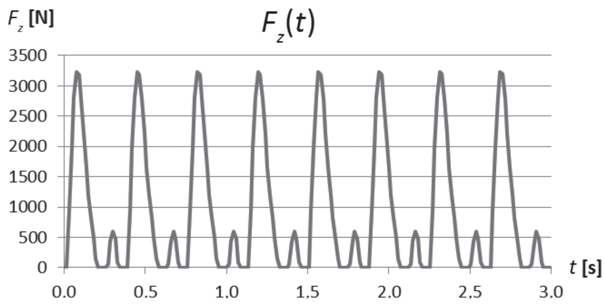


Fig. 3. Forcing function from jumping one person during 3 seconds

The time history analysis was carried out using the Newmark method to define the dynamic load of the structure. The Rayleigh model of damping was introduced in analysis. The damping coefficient (α) equal 0.34. Calculations obtained the maximum vibration acceleration, which equals 0.3 m/s^2. Fig. 4a and 4b present vertical displacement and vibration acceleration measured in the middle node of structure in 15 s.

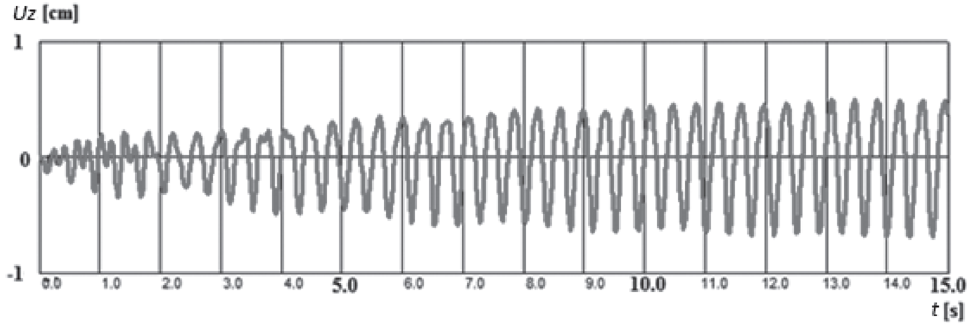
The quantity of maximum vibration acceleration measured in the middle node of the structure (0.3 m/s^2) does not exceed the range at which people on the platform express discomfort over the movement of the structure, which is given in various sources (see Table 3).

Table 3

Acceptable vibration acceleration given in different sources

Acceptable vibration acceleration	Source	Check
$0.5f_u^{0.5}$ = 0.82 [m/s^2]	BS 5400 (1978)	✓
0.7 [m/s^2]	PN-EN 1990/A1 (2004)	✓
10% g = 0.98 [m/s^2]	Bachmann, Ammann (1987)	✓
$1.0f_u^{0.5}$ = 1.64 [m/s^2]	Tilly, et al.	✓

a)



b)

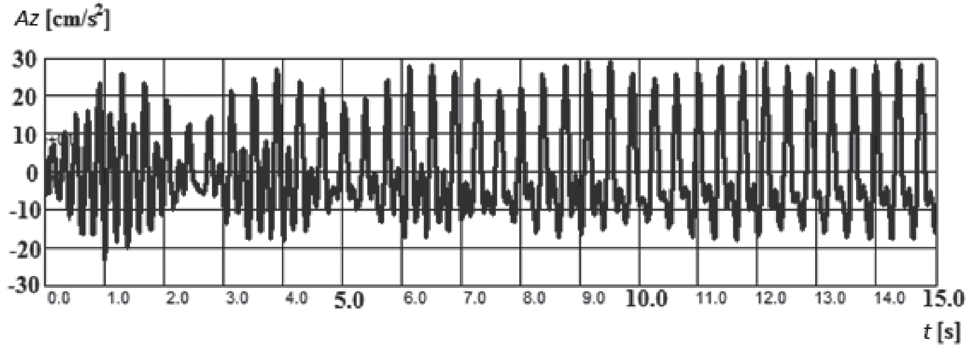


Fig. 4. Graph of: a) vertical displacement measured in node A of structure (Fig. 2) within 15 s, b) vibration acceleration measured in node A of structure (Fig. 2) within 15 s

6. Conclusions

The results of the analyses which were carried out in this article allow for the following conclusions:

– The steel viewing platform in Trzęsacz fulfills the ultimate limit state and serviceability limit state criteria in accordance with algorithms provided by Eurocodes. The observation deck satisfies the criteria for the safety of people and objects inside the structure.
– Based on the measurement of the structure's natural frequency, it can be concluded that the viewing platform is characterized by high rigidity. The platform is not susceptible to the impacts of the dynamic interaction of wind.
– The numerical dynamic analysis proved that vibrations caused by the rhythmical motion of human activity do not disturb the comfort of those on the platform.
– The vibrations are discernable to pedestrians on the viewing platform, but they are not uncomfortable nor inconvenient.
– If several people (a maximum of three, according to the research) are involved in an activity, their motion will be practically synchronized. The dynamic forces increase almost linearly with the rise of number of people on the platform.

– If three people jump in a synchronized manner, they generate vibrations, which accelerate to 0.9 m/s^2. This quantity exceeds the values allowed by British [5] and Polish engineering standards [6]. Rhythmical motions caused by human activity are classified as unusual loads. Exceeding the criteria for the comfort levels of people on the platform is acceptable because these structures are designed only for usual and habitual loads.

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ENERGY-EFFICIENT CONSTRUCTION OF APARTMENT HOUSES IN SLOVAKIA

BUDOWNICTWO ENERGOOSZCZĘDNE NA PRZYKŁADZIE BUDYNKÓW APARTAMENTOWYCH NA SŁOWACJI

A b s t r a c t

The latest revision of national standards, aimed at the thermal performance of structures, conformed to internationally applicable standards of energy-efficient construction, low-energy construction, ultra-energy construction, and nearly zero-energy construction. This paper analyzes the requirements of thermal revised standards in the context of the construction of apartment buildings. The mentioned required standards involve improved and more detailed project planning, leading to the comprehensive realization of building projects as they are intended. Currently, in addition to traditional ways of building, there is an increasing prevalence of modern methods of construction. MMC are using the potential of prefabricated parts of structures. In this article, the aforementioned methods will be compared from an energy conservation and economic point of view.

Keywords: modern methods of construction, apartment buildings, case studies

S t r e s z c z e n i e

Ostatnia zmiana norm krajowych (na Słowacji) miała na celu dostosowanie wydajności termicznej budynków i budowli do międzynarodowych standardów budownictwa energooszczędnego, budownictwa nisko-energetycznego, ultraenergetycznego i bliskiego zeru budownictwa energetycznego. Artykuł analizuje wymagania zmienionych norm cieplnych w kontekście budowy budynków apartamentowych. Wymienione wymagania normatywne narzucają przygotowanie projektu na wyższym poziomie szczegółowości i większą jakość realizacji. Obecnie, oprócz tradycyjnych systemów budowlanych, coraz częściej są stosowane nowoczesne sposoby realizacji. MMC wykorzystują potencjał prefabrykowanych elementów konstrukcji budowlanych. W artykule zostaną porównane powyższe metody budowy z punktu widzenia efektywności energetycznej i ekonomicznej.

Słowa kluczowe: nowoczesne metody budowy, apartamentowce, studium przypadków

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1. Introduction

On 17 November 2009 [1] the European Parliament and Council set the year 2020 as a deadline for all new buildings to be nearly zero-energy buildings (*Action Plan for Energy Efficiency: Realising the Potential*). Buildings are responsible for 40% of energy consumption and 36% of CO_2 emissions in the EU. It is estimated that, by strengthening the provisions of the Directive on energy performance, the EU could achieve a reduction in its greenhouse gas emissions equivalent to 70% of the current EU Kyoto target.

Therefore from 1 January 2013 the newly revised Thermal STN 73 0540-2: 2012 came into force, from which time only new low-energy buildings can be built, and only ultralow-energy buildings may be built from 1 January 2015. New buildings constructed after 2015 will need to meet the standards for ultralow-energy buildings, and after 2020 the standard will be zero-energy. Therefore, the conditions under which the new buildings must be designed are clearly set out. This applies to all forms of construction, including apartment buildings. There is presently an increasing need for the design and realization of new apartment buildings, as the existing residential structures are insufficient at meeting the demands of the housing market. Consequently, modern methods of construction (MMC) have been developed to replace traditional methods of construction (TMC). MMC are based on prefabricated construction materials consisting of interconnecting components, which are made from a variety of materials, such as wood, steel, concrete, or any combination of these, along with others. MMC have become fast, high-quality, and affordable means of construction, resulting in structures that satisfy the highest energy requirements.

The focus of this paper is a comparison of a group of apartment buildings according to their methods of construction. It also provides context on the purchasing and operating costs of construction.

2. Standards in the area of energy-efficient buildings

From 1 of January 2013 the newly revised standard thermal STN 73 0540-2: 2012 came into force [2]. It includes, among other things, clearly defined terms such as energy-efficient buildings, low-energy buildings, ultralow-energy buildings and buildings with nearly zero-energy needs. **Energy-efficient buildings (the minimum requirement)**, are buildings which reduce the need for heating compared to the earlier generation of buildings and fulfil requirements for the thermal performance of building structures. **Low-energy buildings (the desired requirement)** are buildings where heat energy demand is at least 50% less than conventional buildings, which were constructed after 1983 and unable to comply with the heat and technical regulations that were passed in 1992). **Ultralow-energy buildings (the recommended requirement)** are buildings designed so that the maximum heat demand is less than half of what is intended for low-energy buildings. **Buildings with nearly zero-energy needs (the target recommended requirement)** are buildings with very high energy performance. These buildings use a large portion of energy from renewable resources inside of the buildings themselves or in their vicinity. The more commonly used term, passive building (energy consumption ≤ 15 kWh/m^2), is not used in the the text of the Slovakian law concerning construction regulations.

It is necessary to note that for apartment houses, there are different limits on energy consumption.

According to STN 73 0540-2: 2012, the minimum performance of thermal properties of building structures involve five criteria [2]:

– minimal thermal insulation construction (maximum value of heat transfer coefficient U structures),
– minimum temperature of the inner surface (hygiene criterion),
– minimum average air exchange in the room (air exchange rate criterion),
– maximum specific heat demand for heating (energy criterion),
– heat consumption (criterion of minimum energy performance requirements for buildings).

New buildings should therefore comply with the thermal performance requirements for buildings from 1 January 2013. Standard requirements also stipulate major renovations of outdated buildings. If this is not functionally or technically feasible, all renovated buildings must meet at least the minimum energy-efficient requirements.

The **energy performance of buildings** is defined as the amount of energy needed to fulfil all the energy needs during the typical use of the building, particularly the energy required for heating and hot water, cooling and ventilation, and lighting. **Energy certification** is a process by which a building is classified according to its energy class (A to G). **Energy performance certificates** are issued for a maximum duration of 10 years.

3. The implementation of modern methods of construction in residential buildings

The boom in panel construction lasted for approximately 50 years, until to 1995. The absence of state subsidies in housing construction caused a decrease not only in panel construction but in the construction of any types of residential buildings. Regardless, the demand for new housing grew. The construction industry is constantly growing and requires a fast, high-quality, and economically feasible option, which became the goal of every construction project. Other requirements have involved a philosophy of building sustainability, especially in the energy and environmental fields. These requirements can be fulfilled by MMC. The costs incurred for the construction and maintenance of buildings, as well as the critical state of the environment and the finiteness of natural resources, means that before construction begins, it is necessary to consider the selection of construction methods for realization. Today it is no longer unusual to build apartment houses using timber frame construction, modular construction, or prefabricated skeletal structure with masonry infill. Studies on MMC technology in the construction of apartment houses are numerous.

A **study in Malaysia** [3] presented an analysis of the energy- and cost-effectiveness of three lightweight construction systems – wood frames, light steel frames and SIP sandwich panels. A **study in Sweden** [4] dealt with wood construction systems for apartment buildings designed to achieve a high level of energy efficiency. Another **Swedish study** [5] analyzed the material bases of apartment buildings and the impacts of different insulation materials on issues such as primary energy and CO_2 emissions created during their production. A **study from South Korea** [6] has advanced another idea to ensure the high energy efficiency of new apartment buildings By conducting the operational evaluation in the early design phase. The study developed a methodology for the measurement of dynamic service ratings of new apartment buildings using advanced assessments and considerations, as well as stochastic methods. The issue of MMC implementation methods for apartment buildings is also the subject **of research in Slovakia**. MMC potential in this segment of construction was studied for comparison on 8 selected types of buildings [7]. The first five studies involve MMC building technologies. The last three involve traditional building technology. The results demonstrate that MMC can be used I the construction of energy-efficient buildings in addition to lower construction costs.

3.1. Construction of energy-efficient apartment buildings in Slovakia – case studies

The purpose of these case studies is to prove that the apartment buildings are capable of being built in energy-efficient ways. It also examined MMC potential in the realization of apartment buildings and energy savings. A group of selected types of apartment buildings was studied in reference to their energy efficiency, which has a direct impact on the purchasing and operating costs. The group consisted of six apartment buildings erected by different construction methods. **Case study No. 1 – Zelené átrium, Trnava [8]**: The apartment building construction is designed as a reinforced concrete frame with masonry infill. It belongs to the "passive" house energy class (ultralow-energy). It offers 45 apartments on four storeys (with a floor space of 39–88 m^2). **Case study No. 2 – Petržalské dvory, Bratislava II.etapa [9]**: This apartment house is one of the first apartment buildings with regenerative ventilation in Bratislava. The apartment house construction is designed as a reinforced concrete frame with masonry infill. There are 5 floors with 56 apartments (44–81 m^2). **Case study No. 3 – Jedlička apartment house, Poprad [10]**: The low-energy Jedlička apartment house consists of 4 floors and offers 18 new apartments with variable floor areas (30–92 m^2). The supporting structure consists of a reinforced concrete frame with fillings made of bricks and additional thermal insulation in the building envelope. **Case study No. 4 – Apartment house, Moldava nad Bodvou [11]**: The low-energy apartment building was constructed through the VELOX system. It has 5 floors and 28 apartment units (44–151 m^2). **Case study No. 5 – Apartment house, Selice [12]**: The apartment house contains three storeys and 13 apartments (29–57 m^2). The apartment house is designed as a wood frame construction. **Case study No. 6 – Orechov Dvor apartment house, Nitra [13]**: The Orechov Dvor apartment house was constructed through the KOMA container system. It has 28 housing units with a standard floor area of 49 m^2. The house has low-energy status.

3.2. Comparison and evaluation of case studies

The collected data are arranged in Table 1. The first two buildings were constructed as ultralow-energy buildings (max. 27 kWh/m^2 per year), whereas other buildings are low-energy (max. 55 kWh/m^2 per year). Buildings are assigned to energy classes on the basis of their total energy needs. Current buildings that comply with energy efficiency and carbon dioxide emissions standards are assigned to the energy classes from A to G. Class A includes the most economical buildings, and class G includes the least economical buildings. Buildings No. 1, 2, 3 are structurally designed as reinforced concrete frames with masonry infill, which is a traditional method of construction (TMT). Buildings No. 4, 5, 6 are designed using MMC. Apartment prices were collected and calculated on the basis of floor area, with values rendered as the price per single square meter. The annual energy consumption for each square meter of each apartment was also computed. Annual energy costs were recalculated based on the price of 0.78 EUR/month (9.36 EUR/year). This price was selected from the electricity supplier price list. The average apartment size is determined by dividing the total area of all dwellings to the total number of apartments.

Table 1

Comparison of selected apartment buildings

No.	Construction technology	Energy class	Average apartment size (m^2)	Energy consumption (kW/m^2per year)	Average price of m2 floor (EUR)	Annual energy costs (EUR per year)
1	TMT	A	74.67	13.5	1142	126.00
2	TMT	A	62.84	10.8	1702	101.00
3	TMT	B	51.04	28.2	1017	264.00
4	MMC	B	74.59	35.0	977	328.00
5	MMC	B	43.53	49.0	701	459.00
6	MMC	B	48.99	50.0	1312	468.00
TMT – traditional methods of construction MMC – modern methods of construction						

The savings on operating costs for ultralow-energy apartment houses is clear. This confirms their nature and the requirements of their design. The costs of purchasing ultralow-energy apartments are on average, higher than in low-energy energy class. Apartment building No. 2 has both the highest energy savings and the highest price per square meter of floor space. The optimal balance between operating and purchase costs belong to apartment building No. 4, built through the VELOX system. The modular apartment house (No. 6) has the highest operating costs as well as a high price per square meter of floor area, which explains the low interest in this method of construction for residential buildings, in addition to the lack of information about this modern method of construction with the public and developers.

If we want to know which method of construction is most cost effective, we can clearly observe in Table 1 that MMC (No. 4) and TMT (No. 1) are almost the same size. However, the average price for each square meter of floor space is radically different. MMC methods are preferable to TMT.

4. Conclusions

This paper deals with the construction of energy-efficient apartment buildings in Slovakia. There were six residential buildings selected as case studies, built according to both traditional and modern methods of construction and belonging to classes A and B, in terms of energy efficiency. The research confirmed that buildings with higher energy standards have higher prices, but the operating costs are lower. Apartment houses with lower energy savings have lower prices, but the operating costs are higher. Both the choice of construction method and energy standards variously influence purchase and operating costs. Traditional methods of construction have the ability to achieve high standards of energy efficiency (mainly due to their insulation). Due to the structural differences (wood frame construction and modular construction), modern methods of construction involve a wide variation of purchasing and operating costs. Among selected modern methods, wood construction appears to be the most energy-efficient. They have the potential for buildings in higher classes of energy efficiency, while the price per square meter of floor space would be lower than with traditional technologies.

In residential housing it is difficult to find many buildings constructed by the same MMC method. Traditional methods still have a strong market position, but this article demonstrates that MMC methods are not far behind them. They present a challenge to the current construction industry concerning how to build efficient and economical buildings.

The article presents a partial research result of project VEGA – 1/0677/14 "Research of construction efficiency improvement through MMC technologies".

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ADVANTAGES AND DISADVANTAGES OF MODERN METHODS OF CONSTRUCTION USED FOR MODULAR SCHOOLS IN SLOVAKIA

ZALETY I WADY NOWOCZESNYCH METOD ZASTOSOWANYCH W KONSTRUKCJI MODUŁOWYCH SZKÓŁ NA SŁOWACJI

Abstract

Term of "modern methods of construction" (MMC) comes from the United Kingdom as a common name for off-site and on-site methods of construction. Modular constructions consist of three-dimensional objects known as modules (off-site methods of construction). Modules are joined together at the construction site. Currently, the construction of modular schools in Slovakia is supported by the state government. This paper presents the advantages and disadvantages of MMC emerging at the technological preparation and implementation stages of buildings, which are manifested in modular schools.

Keywords: modern methods of construction, off-site methods of construction, modular schools

Streszczenie

Termin „nowoczesne metody budowy" (*modern methods of construction*) w skrócie MMC, pochodzi z Wielkiej Brytanii i jest to potoczna nazwa oznaczająca zarówno metody realizacji konstrukcji modułowych poza miejscem budowy, jak i na miejscu budowy. Konstrukcje modułowe składają się z obiektów trójwymiarowych – modułów (metod poza miejscem budowy), które są łączone ze sobą na miejscu budowy. Obecnie budowa szkół modułowych w Słowacji jest wspierana przez państwo. Przedstawiono wady i zalety MMC na etapie przygotowania technicznego budynków i budowli oraz realizacji dla szkół modułowych.

Słowa kluczowe: nowoczesne metody budowy, metody poza miejscem budowy, szkoły modułowe

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1. Modern methods of construction

1.1. Definitions and classification of modern methods of construction

The majority of buildings are still constructed using traditional technology (masonry, concrete). However, in the last few years there has been an increasing use of modern methods of construction (MMC) for housing, driven by a range of factors including demands for faster construction, skill shortages, and sustainability.

The modern methods of construction primarily involve the manufacture of components in factories, with potential benefits such as faster construction, fewer housing defects, and reductions in energy use and waste [1, 6], all of which offer significant potential to minimize both construction waste [2] and construction safety risks.

The term, modern methods of construction (MMC), comes from the United Kingdom as a common name for off-site and on-site methods of construction. Off-site MMC refers to modern methods of construction which has predominantly been manufactured and assembled in a factory-controlled environment. On-site MMC refers to modern methods of construction which brings together systems or components that are predominantly assembled on site. Virtually all high quality products are built in factories around the world. Cars, planes, ships, computers, printers, cell phones – even the pen you write with – are built in factories. In addition, even homes built on site use many components that were produced in factories [3].

By studying the works of various authors [1, 2, 4, 5, 6] the following classification of MMC was prepared. According to this, we can divide the off-side MMC products into sets, which are further divided into systems. Systems are then subdivided into components.

- volumetric construction
  - modular construction
  - pod construction
- hybrid construction
  - semi-volumetric construction
- panel construction system
  - open panels
  - closed panels
  - structural insulated panels – SIPS
  - composite non-structural insulated panels
  - prefabricated parts
  - light-weight composite solid precast sandwich panel
- natural materials from renewable sources
  - timber frame construction
  - multi-layered engineered timber (solid)
  - components from renewable materials
- light-weight facades
  - brick slips
  - facade cladding
  - external insulation accessories

- sub-assemblies and accessories systems
  - floor or roof cassettes
  - pre-cast concrete foundation assemblies
  - pre-assembled products.

1.2. Modular construction as one of the components of MMC

As shown in the outline above, modular construction is one of the modern methods of construction. Each modular construction consists of several separate modules. A module is characterized as a three-dimensional object, which, by its size, is able to provide utility space. Each module consists of a frame, floor, ceiling, walls, and other accessories [7]. The modules are intended for permanent or temporary living, sanitary purposes, storage, etc. The comfort grade of the module depends on customer requirements or offers from suppliers. The modules are not assigned only for new buildings; they may be used for additions and superstructures to buildings, or they may be built into existing buildings. The steel structure consists of hollow profiles and rolled, self-supporting, anticorrosion primer, and polyurethane topcoat paint. The standard container module has a galvanized profiled sheet. Atypical containers can have final surface treatment such as wood, metal, fiber-cement or plaster. Figure 1a) shows the steel frame construction; 1b) is the complete module.

a) b)

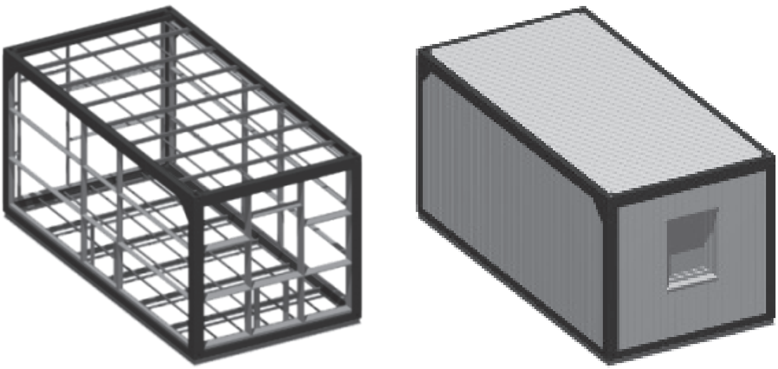

Fig. 1. The supporting structure of module: a) steel frame, b) complete module [7]

2. Modular schools in the Slovakia

The construction of modular schools in Slovakia is supported by the state government. The Ministries of Education, Science, Research and Sport, together with the Ministry of Finance in consultation with the Office of the Plenipotentiary for Roma Communities, has decided to provide financial support for the construction of modular schools for regions with insufficient capacity of school facilities. Villages could apply for the support from a school project known as "Challenges for social and cultural needs and solutions extremely unfavorable situation of marginalized Roma communities" [9], worth up to 200,000 EUR. Overall, in the first stage of the project in 2013, the state managed to build or expand the capacity of several primary schools. The project is based not only on state funding, but also significant contributions by municipal governments, which provide project documentation, land and any other necessary infrastructure.

Based on the analysis of the basic design of five modular schools (Tab. 1) built in Slovakia in 2013, it is clear that two specific schools are identical in terms of the number of classes, the number of modules for each class, or the total number of modules. Classes consist of three modules, with one module having dimensions of 2604 mm × 6830 mm. Cabinets for teachers are composed of two modules. The total number and the design of the modules for each modular school vary depending on the number of floors [7].

Table 1

Overview of modules of modular schools built in Slovakia in 2013

	Village	Number of classes		Number of modules for classes	Total number of modules
		Ground floor	First floor		
	Strane pod Tatrami	8	–	24	33
	Podhorany	4	4	24	40
	Krizova Ves	4	4	24	28
	Jarovnice	8	–	24	33
	Kecerovce	5	6	29	40

By analyzing the information obtained from abroad and in Slovakia, we can conclude that modular technology has significant potential in modern architecture. As reported by foreign authors, modular construction has a number of benefits over traditional construction. On the website of the Ministries of Education, Science, Research, Sport, and Finance [10], it is stated that the investment in the construction of modular schools in Slovakia is only about a quarter of the cost for the construction of a traditional masonry school.

3. Advantages and disadvantages of modern methods of construction

Many of the benefits of using MMC for housing are still unproven or contentious. On the other hand, the advantages and disadvantages are closely related to the drivers and barriers of prefabrication use [8].

Table 2

Advantages and disadvantages of modern methods of construction

Advantages of MMC	Disadvantages of MMC
Smaller demands on facilities and equipment construction site	requirements for size and site equipment for handling MMC components MMC
Safer working environment at the off-site production of building components; faster construction over labor costs	security risks when mounting MMC components MMC at the construction site
The possibility of using state budget funds, special purpose funds, or foundations	higher costs for construction products (prefabricated and higher costs for subcontracting)
Fewer design errors and better quality in the manufacturing of components	initial costs of setting up a production line for manufacturing components
Easier quality control at the factory	time-consuming proposals
Less waste on the construction site and less environmental pollution during construction easier quality control at the factory	compliance and quality control in the contact joints
Less waste on construction site and less environmental pollution during construction	multiple transport materials: into the factory and from factory to construction site

According to Doherty, [4] there are always three aspects that are the most fundamental for an investor: cost, time and quality. The Eternal Triangle states that you cannot alter any aspect without directly affecting the other two. Authors [1] divided the advantages of MMC according to three pillars: a) *economic* – MMC houses typically have fewer defects and can be built more quickly, the components are of better quality and higher standards, the construction process can be sped up by the mass production of prefab components in factories; b) *social* – there may be fewer accidents and less impact on local residents during construction, it reduces labor-intensive activities and provides a safer working environment, designers from different disciplines can work closely together in the early design stage to help to reduce abortive work; c) *environmental* – the houses can be more energy-efficient, may involve less transport of materials, and produce less waste.

On the basis of foreign studies, we have summarized the advantages and disadvantages of modern methods of construction used of modular schools (Table 2).

4. Conclusions

This article focused on the advantages and disadvantages of modern methods of construction used for modular schools. We can establish the main advantages of MMC used for modular schools: less partial processes (specialized team) on the construction site; smaller demands on facilities and equipment at the construction site; lower labor costs; the possibility of using state budget funds, special purpose funds, or foundations; safer working environment at the off-site production of building components; faster construction; higher productivity in construction; fewer design errors and better quality in the manufacturing of components; easier quality control at the factory; less waste at the construction site; less environmental pollution during construction; better working and social conditions in the manufacturing. Among the disadvantages we can include: new (non-traditional) technological processes; requirements for size and site equipment for handling MMC components; higher costs for construction products (prefabricated); higher costs for subcontracting; initial costs of setting up a production line for manufacturing components; security risks when mounting MMC components at the construction site; time-consuming proposals; lack of experience with the implementation of MMC; compliance and quality control in the contact joints; multiple transport materials: into the factory and from factory to construction site; distrust of the new system.

The project was implemented by the Ministries of Education, Science, Research, and Sport, in cooperation with the Ministries of Finance, Government Plenipotentiary for Roma Communities, and representatives of regions continuing in 2014. After a positive response in the regions and more requests from the municipalities, the government has allocated 3 000 000 EUR for additional modular schools. The construction of modular schools has proceeded in other villages: Chminianske Jakubovany, Gemerská Ves, Muránska Dlhá Lúka, Dunajská Lužná, Miloslavov and Žehra.

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ŁUKASZ ŁUKASZEWSKI*

APPLICATION OF SCANNING MEASURMENTS TO DOCUMENT THE BEHAVIOR STATES OF VARIOUS ENGINEERING AND BUILDING CONSTRUCTION COMPONENTS

ZASTOSOWANIE POMIARÓW SKANINGOWYCH DO DOKUMENTOWANIA STANÓW ZACHOWANIA RÓŻNYCH ELEMENTÓW KONSTRUKCYJNYCH I OBIEKTÓW BUDOWLANYCH

A b s t r a c t

Laser scanning is currently a very fast developing field of science. By creating it for the purpose of geodetic, the possibility of using it in other branches of science was quickly observed. Development of measuring devices and the increase of accuracy and simplicity in performing measurements enabled finding a wider audience and extend its use. In the article the author presents the results of experimental studies aimed at identifying the use of scanning triangulation in the research which allows a comparison of behavior states of selected structural elements before and after their deformation. The study was performed using triangulation scanner that uses a white light. The results were compared in the corresponding computer program that allows the analysis of point clouds and to create models from TIN grids.

Keywords: *analysis of behavior state, artifact, cloud points, deformation, laser scanning, TIN grids*

S t r e s z c z e n i e

Skaning laserowy jest aktualnie bardzo szybko rozwijającą się dziedziną nauki. Tworząc go na potrzeby geodezyjne, szybko zaobserwowano możliwość zastosowania w innych gałęziach nauki. Rozwój urządzeń pomiarowych oraz zwiększenie dokładności pomiarów i prostota w wykonywaniu pomiarów umożliwiły znalezienie szerszego grona odbiorców i rozszerzenia jego przeznaczenia. W artykule autor przedstawia wyniki badań doświadczalnych, mających na celu wskazanie zastosowania skaningu triangulacyjnego w badaniach umożliwiających porównanie stanów zachowania wybranych elementów konstrukcyjnych przed i po ich deformacji. Badania wykonano przy pomocy skanera triangulacyjnego wykorzystującego białe światło. Wyniki badań porównano w odpowiednim programie komputerowym umożliwiającym analizę chmury punktów i tworzenia modeli z siatek TIN.

Słowa kluczowe: *analiza stanów zachowania, artefakt, chmura punktów, deformacja, skaning laserowy, siatka TIN*

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1. Introduction

The analysis of strain measurements in structural elements and building structures is of great importance not only in terms of their quality, performance, operation, but also the consumption which is vital for the life of the item or object by way of its use and destination (installation, use). It is therefore very important currently to apply the laser scanning, which is derived from geodesy. It has been observed that there is a possibility of measuring its properties also in the other fields of science. With a wide range of product measuring we can easily explore various interesting objects, buildings, structures and areas.

Through the development of measuring systems, we can study objects at a distance of 0.05 m to 4000 m for terrestrial geodetic scanners and perform readings with an accuracy of 0.02 mm between subsequent points for triangulation scanners. The opportunity of recording a vast number of points with high accuracy in a relatively short period of time is used in the monitoring of deformation in order to analyze the structural stability of the building structure and the structure of the element. Laser scanners provide, through high density of the points, a better representation of the deformation that occurs over time [1].

In comparison with the conventional precision measurement techniques used for monitoring the deformation, such as total stations or contact sensors, the accuracy of the laser scanner seems better for measuring small objects [2]. The main disadvantage of these conventional techniques is the fact that they only offer a single point measurement, and therefore they require prior knowledge of the critical zones. Moreover, modeling using a digital 3D image, can be used to facilitate a detailed study, artifacts without direct contact with delicate surfaces. Software compatible with these devices offers innovative analysis tools, ranging from the ability to zoom in, examine and measure small surface details or to detect traces of destruction left by other elements. The opportunity to study the results from a distance in a visual and mathematical way, allows us to better understand the tested object. The author of the article focuses on presenting examples of the scanner to document the conservation status of tested objects and describes one of the conducted tests.

2. Examples of laser scanner applications

2.1. Analysis of deformations in the brick arch

Thanks to a trial modeling of a brick arch in the laboratory, movements could be analyzed so as to reproduce the real conditions in the arch. Researchers have used laser scanning to monitor the tested object.

Comparative measurement with a total station has provided researchers with an accurate measurement of deformations with an indication of the global trend of these deformations and showed the possible critical zones.

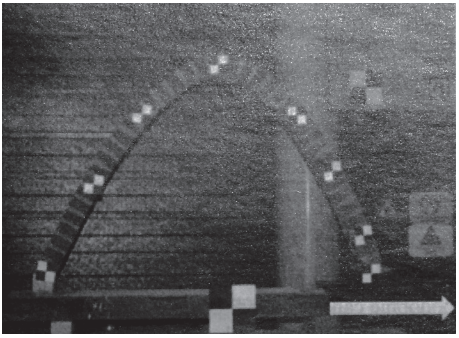

Fig. 1. Image of a brick arch model with paper targets [2]

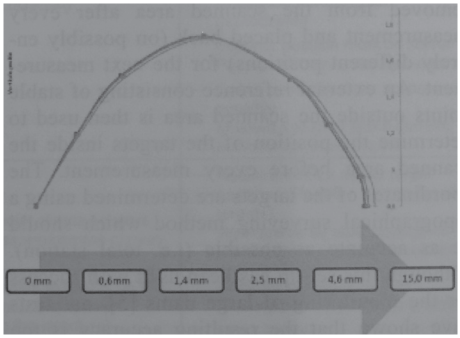

Fig. 2. The diagram of further deformations applied in the arch [2]

2.2. The application when reconstructing the construction defects

Another example of the laser scanner application is an inventory of an iron bridge in Coalbrookdale, which in 1986 was inscribed on the UNESCO list. The aim of the measurement was to enable the analysis of the entire bridge - existing structure in such a way that the object was maintained in the process of strengthening the components and eliminating the defects of the original appearance.

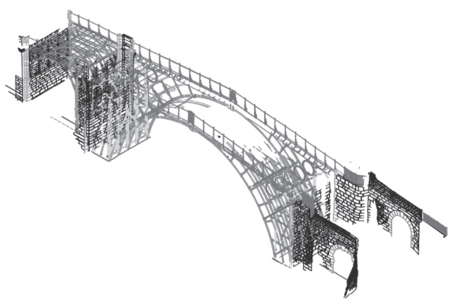

Fig. 3. Image of inventoried object [3]

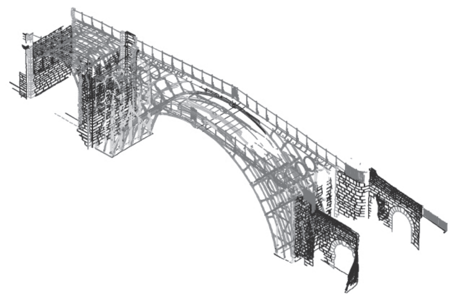

Fig. 4. Photograph of defects reconstruction and applied reinforcement on a performed earlier measurement [3]

2.3. The application of scanning for testing artifacts

The UNESCO Convention from 2001 established a rule that in order to protect underwater cultural heritage in situ protection should be treated as a prime one. However, with regard to organic artifact in situ protection is not compatible with security rules and the use of their possessions. The long bureaucratic way and costly conservation and restoration procedures

Fig. 5. Photograph of artifact measurement [4]

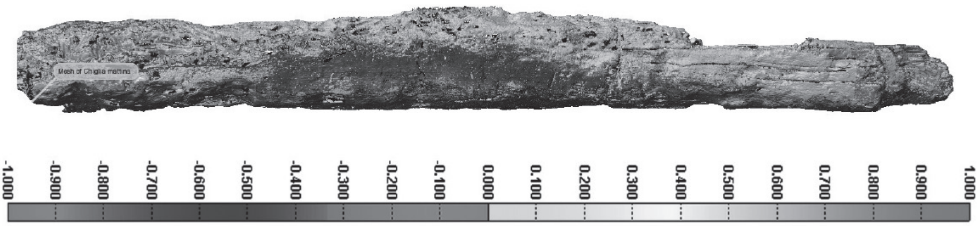

Fig. 6. Determination of color between dimensions made in the morning and in the afternoon [4]

a) b) c)

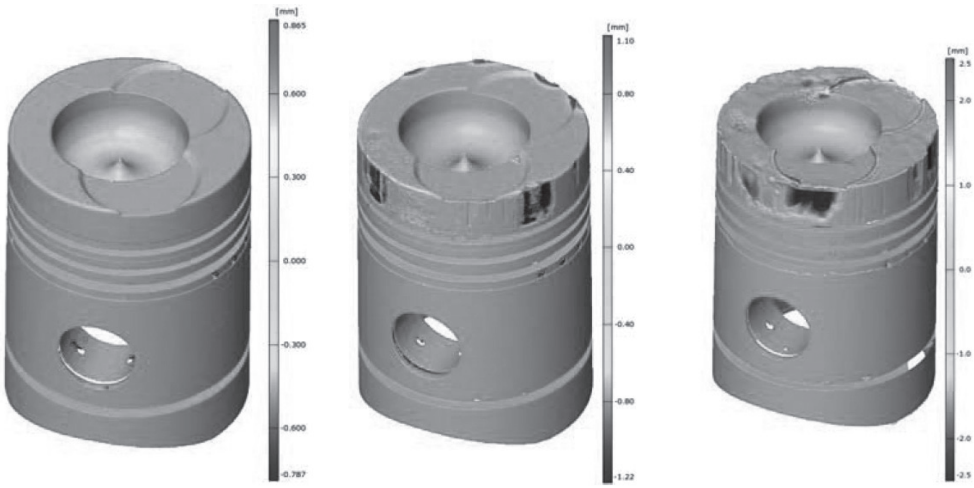

Fig. 7. Engine pistons SW-680: a) the new engine; b) a piston with a damaged side surface; c) a piston with a damaged surface and burns of a piston top [6]

forced scientists to find an alternative solution to the physical reconstruction of submarine monuments. Thanks to the use of digital technology, testing artifacts without any direct contact with sensitive surfaces offers an innovative analytical tool [4, 5].

2.3. The application of the scanner in the analysis of pistons damage

Another study is focusing on the use of triangulation scanner to examine pistons damage that is their tops and the side surface between the top and the first seal ring. Distortions of the tested elements could not be accurately presented by the flat images and measurements of the damages depth were very difficult to measure and were inaccurate. Only after using the scanner the accuracy and transparency were achieved

3. Research on a sample

The author subjected an aluminum profile to mechanical deformation. Using a triangulation scanner he assessed the behavior state of the sample before and after the deformation. After completing the readings in both trials, spatial deformations were presented. They were caused by deformation of a cloud of points with respect to a reference sample.

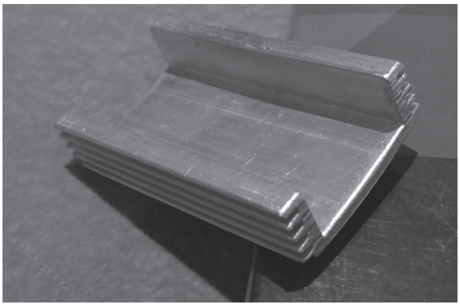

Fig. 8. Photograph of the tested object

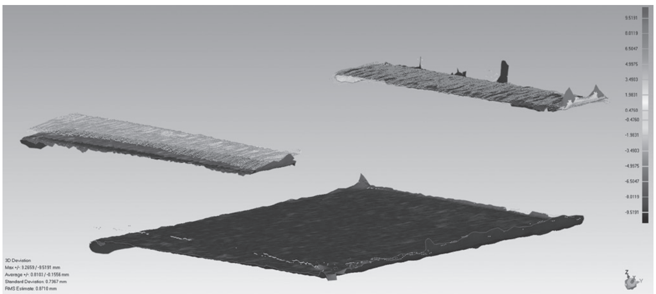

Fig. 9. The spatial screening of deformations

Fig. 10. The cross-section of the tested sample deformations

4. Conclusions

To summarize some examples of using a laser scanner to the research, the following conclusions result from the process of scanning and analysis of the object states:

- The speed of the scanning process and a very large amount of data at the subsequent stages allow the researchers to analyze the test subjects more accurately and design construction elements flawlessly.
- At any time during exploitation of an object or construction, scanning measurement enables us to compare and analyze the state of the object in relation to the reference measurement.
- The accuracy and versatility of the use of traditional techniques, measurement systems used to monitor deformation of the tested object is much smaller than the measurement of a laser scanner [2], which is used to test integrated building management systems "BIMS" and in application development GIS programs, using the method of "BISM MACHINE" for playback studied spherical surface parts of buildings with accuracy 1 μ = 0.0001 mm [7].

When carrying out the tests with a laser scanner we should pay attention to accuracy and the conditions under which it is carried out in an area where we do not have stable conditions.

The test results have convinced the author that in further studies it is necessary to deal with the analysis of assessing the accuracy of spatial models created from point clouds with the help of the laser scanner.

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TOMÁŠ MANDICÁK*, PETER MESÁROŠ*, JOZEF SELÍN*

DOCUMENT MANAGEMENT SYSTEMS FOR DATA SHARING IN CONSTRUCTION PROJECT MANAGEMENT

SYSTEM ZARZĄDZANIA DOKUMENTAMI DLA DANYCH DOTYCZĄCYCH ZARZĄDZANIA PROJEKTEM BUDOWLANYM

A b s t r a c t

Management of construction projects is being carried out through modern information-communication and knowledge technologies. These innovative technologies are to be implemented extensively in the process of construction as much as possible. Document management systems are information systems which ensure an efficient exchange of data and information between the participants in the construction project. Current data and information facilitates decision-making, as well as serving to improve control over projects. Modern DMS are among the most used in construction worldwide, including in Slovakia and Poland.

Keywords: document management system, data sharing, construction project management

S t r e s z c z e n i e

Zarządzanie projektami budowlanymi jest realizowane za pośrednictwem wiedzy i nowoczesnych technologii informacyjno-komunikacyjnych. Innowacyjne technologie wykorzystuje się w procesie budowy tak często, jak jest to możliwe. Systemy zarządzania dokumentami to systemy informatyczne, które zapewniają skuteczną wymianę danych i informacji między uczestnikami projektu budowlanego. Aktualne dane i informacje ułatwiają podejmowanie decyzji, a także służą poprawie kontroli projektów. Nowoczesne DMS są jednymi z najczęściej używanych w budownictwie na całym świecie, w tym na Słowacji i w Polsce.

Słowa kluczowe: system zarządzania dokumentami, udostępnianie danych, zarządzanie projektem budowlanym

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1. Theoretical review

Information and communication technologies (ICTs) have made significant progress [1]. Investment in research on information and communication technologies are transformed into new hardware formats that are accessible for everyday tasks, whether at home or at work [2]. These innovations are not only included in hardware features, but also in software solutions and applications, which support effective ways of communication in the management of construction projects.

Information and communication technologies represent complex hardware and software, including means of communication that enables processing and data manipulation [3]. These technologies include a document management system, which are often inseparable from the information system whose main priority is to manage the processes of documents. According to Čarnický, information is data that has a particular meaning for the recipient, and it satisfies the specific need for objective information.

1.1. Data sharing

When defining the information system used for the exchange of information in construction project management, which includes an integrated exchange of data and information, it is necessary to define the concept of data and information.

The term "data" is broader than the term "information". One conception is that data stands for received information, but it does not. Data are messages that have some explanatory power. Often they are obtained by observing, measuring, or other methods. They represent a specific data bank which includes data with similar content [4].

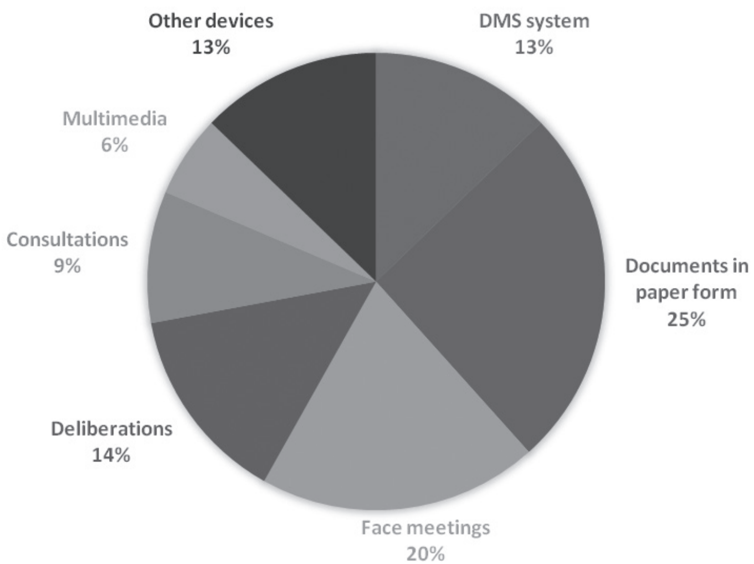

Fig. 1. Data sharing and DMS in the management of construction projects [6]

The growing importance of data and information as critical resources for business enterprises led to systematic work in obtaining, storing, and sharing data and documents, resulting in document management systems [5]. It is also important to look at ways of sharing and exchanging data and documents among participants in construction projects. In their study, Lee and Lin [6] highlighted the general methods of knowledge sharing between participants in construction projects.

Construction projects include a number of participants who usually have different data and documents. The exchange and sharing of documents are very important. The study shows that only 13% of participants who are involved in construction projects use document management systems for document sharing, and 22% of the documents are in printed format. To increase the efficiency of these processes, it is necessary in the future to take the steps that will lead to the implementation of innovative technologies for document sharing.

1.2. Document management systems in construction industry

Document management systems (DMS) are systems whose main function is to store and share documents in different formats. Document management systems are important tools for businesses because they help streamline business processes and improve methods of cooperation between employees.

Electronic document management systems have been developed to track and store electronic documents, while allowing “storage” (retention) of documents [7]. The basic feature is document sharing in real time, which allows documents to be edited efficiently. Then perfect integration with enterprise systems and other applications must be ensured in order to produce documents, as well as allow them to be corrected. These systems enable multiple users (participants in a building project) to edit one document simultaneously.

There are also document management systems for working with unstructured data. System DMS is one such filing service. These systems protect content by storing documents as objects. EDM systems (Electronic Document Management) are designed to manage electronic documents as digitized paper documents, e.g. documents converted into digital form by scanning.

A storage site or archive for documents often includes a document management system. The information that they contain can be stored for however long, and transferred from one storage medium to another (Hierarchy Storage Management), and can be eventually deleted from the system.

2. Problem statement and methodology

IT support in business processes has become indispensable for a host of enterprises in every field [8]. Moreover, innovative IT systems generally offer great opportunities to make companies, including construction firms, more competitive [9].

ICTs have been extensively applied across many sectors in order to achieve their main goal of increasing competitiveness and reducing costs [10]. The average annual growth rate of ICT investment in the construction industry is increasing every year and currently constitutes a significant part of the total project cost. However, some studies indicate that the scope of ICT utilization is still relatively low in construction. This study discusses the current problems in construction, particularly concerning data and document sharing.

This paper discusses the exchange of economic information between selected participants in construction. The main aim of this paper is to highlight the need and possibilities for information sharing, as well as to make an overview of available DMS in construction project management. The basic research objectives are summarized as follows:
– describing document management systems, and perspectives on data and document sharing,
– an overview of current document management systems.

3. Overview of available solutions for document management systems in construction projects

There are many DMS solutions. Table 1 displays a brief overview of available solutions for document management systems which are often used in the management of construction projects. These software solutions frequently offer much more functionality than simply document management. In many cases, there are possible extensions to other applications and software solutions, enabling a number of features that are important for the management of construction projects.

Table 1

Overview of available solutions for document management systems in construction projects

Software	Size of project	Cloud solution	Participants in construction projects
Procore	SM projects	yes	Investors, developers, contractors, sub-contractors, architects, designers, planners, state agencies
Aconex	SM projects		Investors, developers, contractors, sub-contractors, architects, designers, planners, state agencies
CMIS (Construction Management Information System)	SM projects		Investors, developers, contractors, sub-contractors, architects, designers, planners, state agencies
SAGE 300	SM projects	C/S	Investors, developers, contractors, sub-contractors, architects, designers, planners, state agencies
ComputerEase	SM projects	C/S	Investors, developers, contractors, sub-contractors, architects, designers, planners, state agencies
Mawwell Systems ProContractorMX	SM projects	C/S	Investors, developers, contractors, sub-contractors, architects, designers, planners, state agencies

Continue Table 1

Software	Size of project	Cloud solution	Participants in construction projects
Jonas Enterprise	S projects	C/S	Investors, developers, contractors, sub-contractors, architects, designers, planners, state agencies
Jonas Premier	S projects	yes	Investors, developers, contractors, sub-contractors, architects, designers, planners, state agencies
HC S S Equipment360	SM projects	n/a	Investors, developers, contractors, sub-contractors, architects, designers, planners, state agencies
BuildTools Construction Management Platform	SM projects	yes	Investors, developers, contractors, sub-contractors, architects, designers, planners, state agencies
AccuBuild Construction Project Management	SM projects	n/a	Investors, developers, contractors, sub-contractors, architects, designers, planners, state agencies
BuilderTREND	SM projects	yes	Investors, developers, contractors, sub-contractors, architects, designers, planners, state agencies
Co-construct	SM projects	yes	Investors, developers, contractors, sub-contractors, architects, designers, planners, state agencies
Paskr Project Management Suite	SM projects	yes	Investors, developers, contractors, sub-contractors, architects, designers, planners, state agencies
Primavera P6 Profesional Project Management	SM projects	n/a	Investors, developers, contractors, sub-contractors, architects, designers, planners, state agencies
Project DocControl	S projects	n/a	Investors, developers, contractors, sub-contractors, architects, designers, planners, state agencies
Prolog	SM projects		Investors, developers, contractors, sub-contractors, architects, designers, planners, state agencies
Structure	SM projects		Investors, developers, contractors, sub-contractors, architects, designers, planners, state agencies
UDA ConstuctionSuite	SM projects		Investors, developers, contractors, sub-contractors, architects, designers, planners, state agencies
eSUB	M Project	yes	Contractors, sub-contractors
EADOC	SM projects	n/a	Investors, developers, contractors, sub-contractors, architects, designers, planners, state agencies

SM projects – small and medium sized projects, S project – small projects [11].

4. Conclusions

Construction project management is a complex process. Currently there are a diverse range of options for effective project management. One possibility is the Document Management System. The sharing of data and documents is necessary for project management, because building projects have many participants who exchange various types of documents (economic or otherwise). Keeping track of these technologies is crucial. The results of the analysis present a number of possible solutions for the construction industry. The list is by no means exhaustive. This warrants further research to determine what extent individual DMS are used.

The paper presents the results of the project "Identification of key competencies of university students for the needs of knowledge society development in Slovakia", which is supported by the Ministries of Education, Science, Research, and Sport of the Slovak Republic to provide incentives for research and development from the state budget in accordance with Act No. 185/2009 Z. z. on incentives for research and development and on supplementing Act. 595/2003 Z. z. Income Tax, as amended by Act No. 40/2011 Z. z.
The paper presents partial results of the research project VEGA No. 1/0562/14 "The impact of Business Intelligence tools on corporate performance".

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TOMASZ MILEWSKI*, KRZYSZTOF STAROWICZ*, GRZEGORZ BOSAK*

NUMERICAL ANALYSIS OF COOLING TOWER SURFACE BASED ON WIND TUNNEL STUDIES IN TERMS OF AERODYNAMIC INTERFERENCE

ANALIZA NUMERYCZNA WPŁYWU INTERFERENCJI AERODYNAMICZNEJ NA KONSTRUKCJĘ CHŁODNI KOMINOWEJ

A b s t r a c t

Before the widespread use of computers, the only way to design a structure with complex shape was to build a prototype model and perform the necessary tests. Nowadays, designers are able to create an accurate and complex engineering design by effective mathematical models. The paper describes the numerical analysis of cooling tower carried out by a finite element method. The FEM analysis was performed with Lusas software. The cooling tower represents the real structure located in Kozienice, Poland. During the calculations, different load cases based on wind tunnel tests were taken into account. The evaluation of the influence of different wind directions and configuration of obstacles on internal forces and displacements were analyzed. Proper dimensions, material proprieties and method factors were applied to the model. In the further part, the dynamic evaluation was presented. The Eigen modes with corresponding values and shapes were created and described. Estimation of impact of dynamic wind action on the object will be also released. Time history of amplitude and displacements was attached. As a result of the dynamic studies, the dynamic evaluating indicator was calculated.

Keywords: *cooling tower, Finite Element Method, time variable analysis, Lusas*

S t r e s z c z e n i e

Przed rozpowszechnieniem komputerów, jedyną metodą projektowania obiektów o skomplikowanym kształcie, było zbudowanie modelu w celu przeprowadzenia niezbędnych badań. Obecnie, projektanci mogą tworzyć dokładne i złożone projekty poprzez dokładny model matematyczny. Referat opisuje analizę numeryczną chłodni kominowej metodą elementów skończonych przeprowadzoną w programie LUSAS. Chłodnia kominowa jest odzwierciedleniem obiektu zlokalizowanego w Kozienicach. Podczas obliczeń, wzięto pod uwagę wiele przypadków obciążenia wiatrem bazując na wynikach badań przeprowadzonych w tunelu wiatrowym. Zbadano ocenę wpływu różnych kierunków wiatru i lokalizacji sąsiadujących obiektów na siły przekrojowe i przemieszczenia. Odpowiednie wymiary, właściwości materiałowe i współczynniki zostały zastosowane. W następnej części przedstawiono oszacowanie efektu dynamicznego. Zaprezentowano wartości własne i odpowiadające im postaci własne. Przeprowadzono analizę czasową amplitudy i przemieszczeń. Jako podsumowanie badań dynamicznych oszacowano wskaźnik dynamiczny.

Słowa kluczowe: *chłodnia kominowa, Metoda Elementów Skończonych, analiza czasowa, Lusas*

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1. FEM model

1.1. Geometry, loading and mesh

The Finite Element Analysis was executed with LUSAS 14.7-10 software. Geometry of the cooling tower was performed by making the hyperbolical surface line (meridian). The meridian was divided into 4 elements: a column, from top of the column to the stiffening ring at the height of 15.86 m, between, the stiffening ring, and the upper platform (135.75 m), and the last fragment from the stiffening platform up to the top of the tower. The column is tangent to line and its extension. The surface of the tower is connected rigidly with columns. The thickness of the surface varies from 30 cm on the top, through 20 cm on, the narrowness, up to 110 cm on the bottom. At the height of 15.86 m a stiffening ring is placed (60 cm thick, 90 cm length). At the top, a stiffening platform is also located.

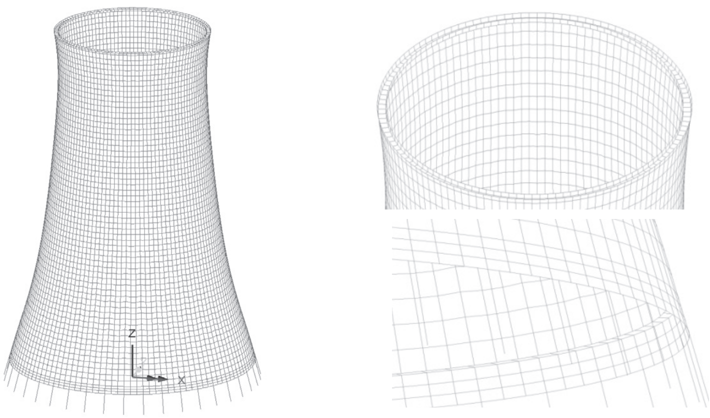


Fig. 1. FEM model and mesh [1]

For the shell of the cooling tower, quadrilateral shapes of elements with the quadratic interpolation order were adjusted (QTS8). The shell was divided into 120 horizontal and 64 vertical FEM elements. The mesh was refined on the base of the shell. Stiffening ring and stiffening platform were meshed with accurate density, adequate to the stiffness of the element. The columns are relatively short and stiff comparing to the cooling tower. Due to that fact, columns were divided only into three elements; three dimensional thick beams as a structural element type were selected. The linear interpolation order was applied. The elastodynamic analysis was performed.

In the performed analysis only dead and wind loads were taken into account. The dead load was applied to the structure automatically by the software, based on material properties. Both internal and external wind pressures were taken from the wind tunnel studies describes in [1]. Due to the fact that studies were focused on the influence of wind direction and location of obstacles on internal forces, the cracking of concrete and its impact on stiffness of structure was omitted.

2. Results of static analysis

2.1. Dead load

In the following pictures the N_x, N_y forces and M_x moments are presented, N_x means meridians forces, and the N_y means parallel forces, the notation of moments is identical. The wind pressure consists of internal pressure and external pressure. Characteristic design values were taken into calculations. All the safety factors in load combination are equal to 1. The internal forces calculated only for dead loads (see Fig. 2) are fully symmetrical. The results show, that the shell is close to the membrane state. The moments are relatively small, and are not significant. Disorders of the membrane state can be caused the stiffening elements located on the surface. According to [2] such a size of disturbance is natural in hyperbolical shells with these kinds of loads.

An enormous increase of values appears near the columns. Assuming the FEM theory; the values may tend up to infinity. It can be noticed in all kinds of forces. It is caused by the connection of bar elements to the surface. The values located in that areas are invalid and should be omitted during design process. Enlargement of values caused by stiffening rings is also visible near the top of the tower.

2.2. Dead load and Wind loads

The results are presented in such a way that wind direction is parallel with axis *X*. (see Fig. 2). As it was noticed before the wind pressure come from wind tunnels studies [1]. The analysis of all wind directions was performed, however only two directions are presented in this paper. The wind acting on single cooling tower without any objects in neighborhood, and the second case when the tower is surrounded by power house facilities .In single situation (without surroundings) the increase of negative values of N_y up to –95 kN/m in upper windward section in comparison to leeward section is visible. The maximum negative values of N_y are reached for the lowest vertical division (left, right, windward), maximum value about 300 kN/m. On the sides in upper division the positive values appear, however the values are close to zero. When it comes to the N_x forces the biggest positive forces are reached for the whole windward section 150 kN/m, in this part only positive values are observable. In both upper sides, the values are positive (maximum 130 kN/m). However, in the lower rings the maximum negative values appears – up to 1.3 MN/m. In the leeward section situation is similar to sides, but in the lower rings the absolute negative values are much smaller – maximum 700 kN/m. Interference situation (I_{135}) is characterized by significant differences in comparison to the previous one. Differences are noticeable in all kinds of forces and displacements. In N_y forces, the biggest changes are observable in windward section. There is a significant decrease of absolute values both negative and positive. Even the change of sight in upper part, from negative to positive is visible; however the positive values are close to zero. Leeward section in upper part is characterized by the increase of positive values up to 35 kN/m. Also the change of signs from positive to negative in the middle of leeward section is visible. In the other sections of tower, rather the decreases of the absolute values are visible, while the distribution of forces is unchanged.

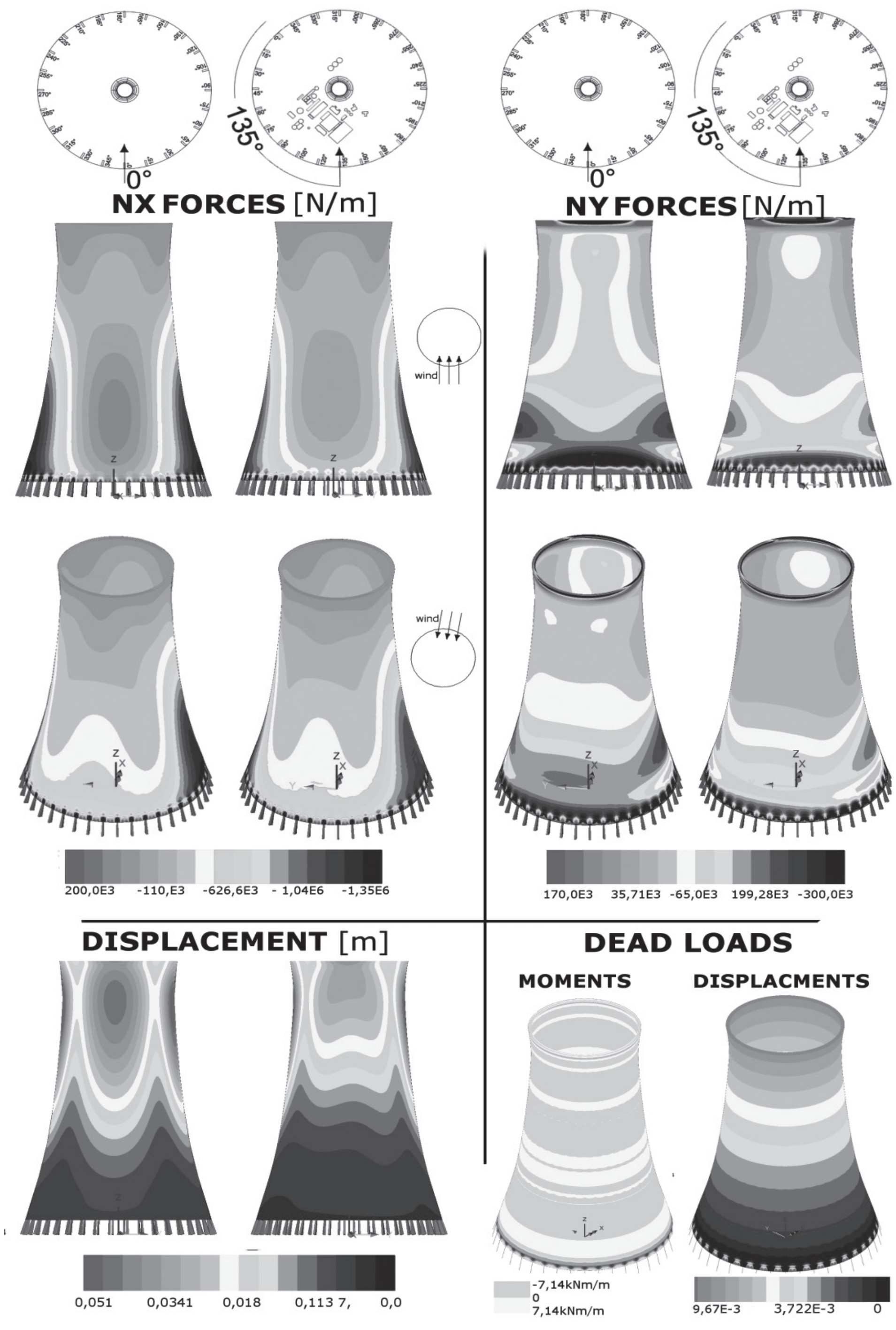


Fig. 2. Internal forces and displacements [1]

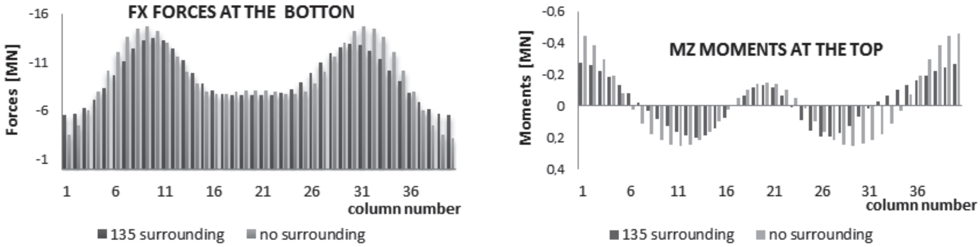
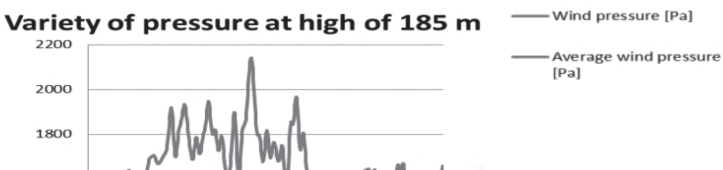


Fig. 3. Internal forces in columns [1]

When it comes to the N_x there are no big changes, the decrease of absolute values with the same distribution of forces occur. There are no significant disturbances in the line symmetry of N_x forces, only the disturbances of displacements are observable. The longitudinal forces are presented in Fig. 3, F_x notation means longitudinal forces which cause the compression of columns (sign –), the values are gathered in the base of the columns. The windward direction is located between 20 and 21 column, while the leeward orientation is near the column 1 and 40.

3. Estimation dynamic wind action impact on cooling tower

In order to facilitate the analysis, several simplifying assumptions have been implemented. Without these assumptions, it would be impossible to evaluate the vulnerability of the structure due to the dynamic wind load. Wind field applied to the model has a stationary nature, when in the reality; the wind acting on the tower is strongly inhomogeneous and variable in time and space. The variability of the wind field in time is implemented in model by multiplying the C_{Pe} coefficients by a corresponding values of the wind pressures – only the multiplier is time variable. Values of wind pressure were achieved from the Wind_Sym software for the height of 185 m.



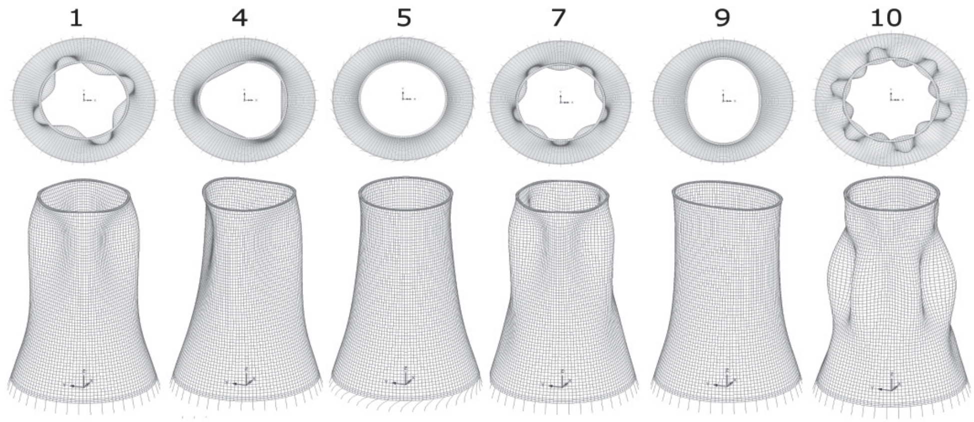
	Value
Young's modulus	37,0E9
Poisson's ratio	0,2
Mass density	2,54842E3
Mass Rayleigh damping constant	0,03
Stiffness Rayleigh damping constant	0,02

Fig. 4. Diagram of variety of pressure at reference and material properties [1]

The software imitates the wind field velocity adequately, however in nature the variations occur also in respect to height. In dynamic analysis the same C_{Pe} coefficients as in static analysis were used. Lusas software has been used to carry out the dynamic analysis.

The geometric and FEM models have remained unchanged in comparison to the static analysis. Through the entire procedure, only the wind load was taken into the account, model has been released from the dead load. Again, only two situations were taken into consideration, the single situation without surrounding and the interference situation (I_{135}). However, the different values of the wind pressure were used, so there is no correlation between dynamic and static results included above.

Procedure has been based on processing the structure to the action of time variable wind load in strictly defined period of time. The period was 35 seconds long and the sampling rate was equal to 20 per second, what gives 700 samples with the 0.05 second long of each one. Additionally the time constant analysis was implemented to estimate response time of construction in the initial phase of dynamic analysis. Respecting the fact that only the wind loads are applied into the model, as an indicator of the dynamic vulnerability, solely the displacements of individual nodes were used.



MODE	EIGENVALUE	FREQUENCY	PERIOD
1	23,377	0,770	1,300
2	23,378	0,770	1,299
3	35,563	0,949	1,054
4	35,565	0,949	1,054
5	44,029	1,056	0,947
6	46,039	1,080	0,926
7	46,039	1,080	0,926
8	46,307	1,083	0,923
9	46,309	1,083	0,923
10	58,487	1,217	0,822

Fig. 5. Natural modes with corresponding eigenvalues and frequency, Lusas [1]

3.1. Eigenmodes and shapes

Totally ten eigenmodes have been created. Nonetheless only 6 of them have been published, because of the fact that some of shapes are equivalent to another, only the rotation appears. From the tables presented below, it is visible that the second mode is similar to first, third to fourth, sixth to seventh and eighth to ninth. The fifth mode has a torsion nature. The simpliest is decidedly mode number 9.

4. Dynamic Results

Scrupulous dynamic analysis is presented for points, in which maximum resultant displacement in static analysis occurred. Control of response of structure were executed by applying a constant load in time. It was necessary to estimate the time in which dynamic results would be uncontaminated by natural response of the structure. For further analyzis of dynamic results, time from 0 to 12 seconds were omitted.

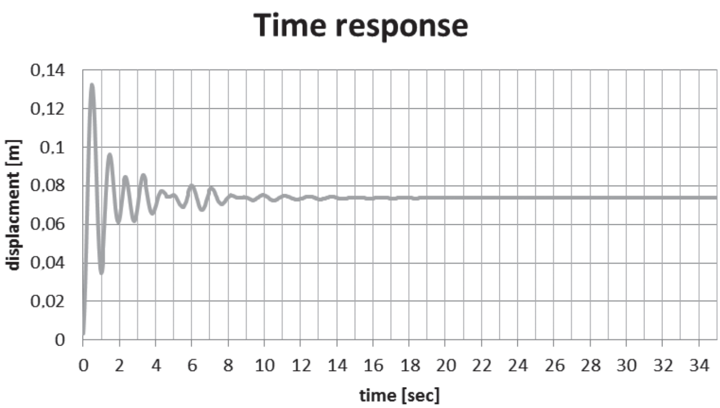


Fig. 6. Response of structure diagram and material properties [1]

The diagrams of amplitudes (A) were performed with formula:

$$A(t) = U(t) - U^{d}_{avg} \tag{1}$$

$$U_{avg} = \frac{\sum_{t=12}^{t=35} U(t)}{n} \tag{2}$$

where:

U_{avg} – average value of displacement from 12 to 35 second,
$U(t)$ – value of displacement in time,
n – number of time steps (460).

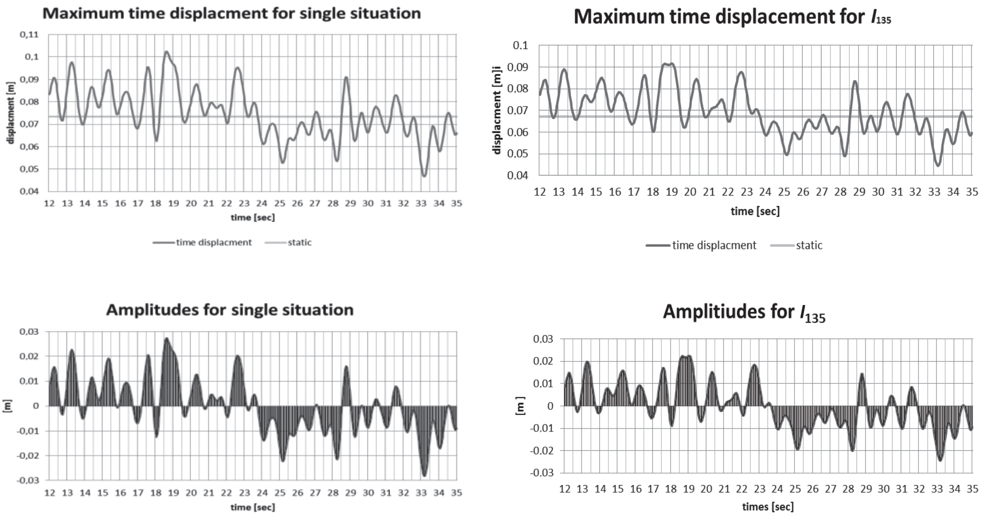


Fig. 7. Time history graphs [1]

The dynamic evaluating indicator ψ is equal to:

$$\psi_{I_{135}} = \frac{\max |A_{I_{135}}(t)|}{U^{s}_{I_{135}}} = 36.66\% \qquad \psi_{single} = \frac{\max |A_{single}(t)|}{U^{s}_{single}} = 38.48\%$$

5. Conclusions

By the application of such a powerful engineering tool like Lusas, the dynamic analysis was possible. It is easy to perform a multiple number of additional structure behavior analysis including complex non- linear problems. It is possible to solve multitude of problems like: large deformations, high levels of nonlinearity and complicated boundary conditions. The results show that location of obstacles, in surrounding of cooling tower, has a significant impact on internal forces and displacements. However, in dynamic analysis the changes are slightly smaller but still visible. It seems that an individual and detailed analysis may be very helpful in further design of cooling towers. Finally, it can result in different spacing and sizes of concrete reinforcement.

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IZABELA MURZYN*

DYNAMIC RESPONSE OF THE INDUSTRY MASONRY CHIMNEY TO SEISMIC LOAD

ODPOWIEDŹ DYNAMICZNA XIX-WIECZNEGO KOMINA PRZEMYSŁOWEGO NA ODDZIAŁYWANIE SEJSMICZNE

Abstract

The aim of this paper was to investigate the dynamic responses of the industrial masonry chimney under seismic activity. In this study peak ground accelerations equal 0.4 g were assumed for the shock. In the paper there are the results from numerical simulation. The analyses were prepared for two material models: with elastic and inelastic behavior. In both cases the homogenization model of masonry material was used. The study was prepared in ABAQUS software (Simulia, 2013).

Keywords: chimneys, industrial masonry chimneys, earthquake, seismic behavior

Streszczenie

Artykuł poświęcony jest analizie odpowiedzi dynamicznej komina przemysłowego o konstrukcji murowej obciążonego odziaływaniem sejsmicznym (trzęsieniem ziemi). W pracy zaprezentowano wyniki uzyskane drogą numeryczną. Analizę przeprowadzono w pakiecie ABAQUS (Simulia, 2013). Dla potrzeb analizy zostały wykonane dwie symulacje numeryczne: liniowo sprężysta oraz analiza uwzgledniająca uplastycznienie elementów murowych. W obydwu przypadkach wykorzystano model homogeniczny dla konstrukcji murowych. W analizie wykorzystano akcelerogramy osiągające maksymalne wartości 0,4 g.

Słowa kluczowe: kominy, kominy przemysłowe, elementy murowe, trzęsienie ziemi

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1. Introduction

The presented paper focuses on the numerical research of the seismic behavior of the masonry industrial chimney from Poland [1]. Such example of construction sprung up rapidly throughout many parts of world especially of Europe for the period of the industrial revolution. It must be noticed that a lot of existing industrial chimneys are constructed of unreinforced masonry. Such type of structures is found to be vulnerable to damage during strong seismic events [5].

The most important key feature in properly understood response of masonry industrial chimneys under different type of loads is that they have not enough tensile strength to perform suitably due to unreinforced masonry that was used in the their construction. Actually this situation is very dangerous while strong seismic ground motion [5].

The main purpose of the work is comparison between the results for two numerical analyses: the first results are for completely elastic material model the second ones are for inelastic behavior.

2. Basic geometry, material data and numerical model of the chimney

The dimensions of the chimney [1] in meters and a longitudinal section are given in Fig. 1b. The total height of the object is 75.00 m. In Fig. 1c there is numerical model with selected points to calculations. Also it must be pointed that in Fig. 1a the photography of the chimney is presented, which is taken from [1] paper.

a) b) c)

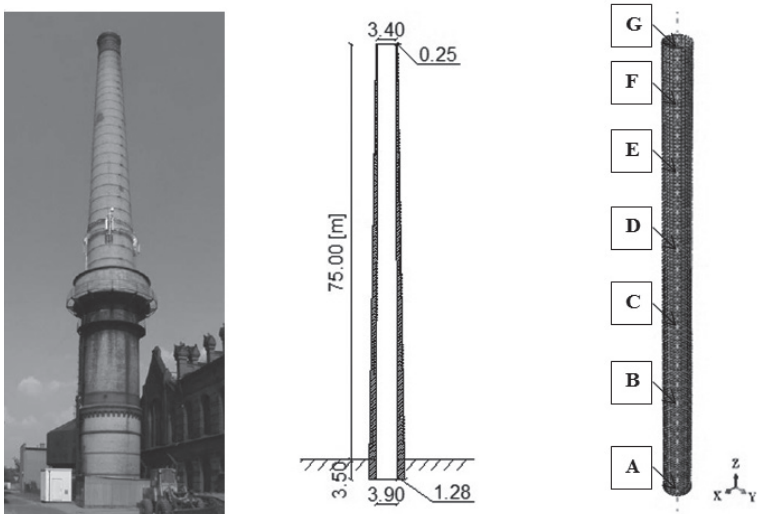

Fig. 1. Industrial chimney: a) condition before renovation [1], b) longitudinal section, c) FE model

For the study a 3D model with shell elements (S8R) has been developed to represent the seismic behavior of the chimney. The total number of nodes in the model is 39,574 and the total number of elements is 12,465. The model was created with the ABAQUS package (Simulia, 2013). The dynamic response of the masonry chimney was estimated for two types of material model: elastic and inelastic. For the inelastic case it was assumed the material model with yield stress. However for both scenarios the homogenization theory for masonry structures was used [3, 4].

Material data used for the calculation for masonry structures [2]: 1) elastic modulus E = 2.1 GPa; 2) Poisson coefficient γ = 0.25; 3) density: ρ = 1800 kg/m^3; 4) uniaxial yield stress in compression σ_{c0} = 1.4 MPa; 5) uniaxial yield stress in tension: σ_{t0} = 0.4 MPa.

3. Data of the seismic shock

The chimney analyzed in this study was subjected to actual earthquake ground motion records registered in Nocera Umbria (central Italy). The selected seismic activity event was of the September 26th, 1997 Umbria-Marche earthquake (ITACA 2015). The signals were applied as kinematic excitations of the structure. The magnitude of the shock was 6.1. In numerical simulation the phase of the ground motion of shock approximately lasted 8 s. Time histories of accelerations of the shock in three directions are presented in Fig. 3. The peaks ground accelerations (PGA) of the shock are: a_x = 4.15 m/s^2, a_y = 4.93 m/s^2, a_z = 3.98 m/s^2.

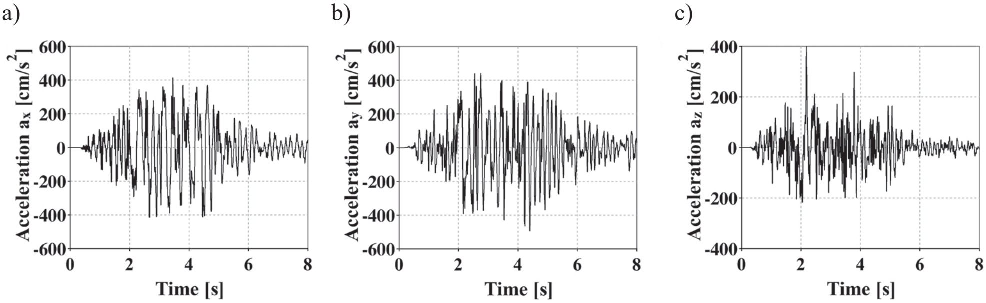

Fig. 2. Time histories of the shock accelerations: a) x direction: b) y direction; c) vertical (z) direction

4. Dynamic response of the chimney to seismic load

Two analyses were prepared in the presented work: the first for completely elastic material model and the second one for inelastic material. In Fig. 4 there is a comparison of results from this analyses. The comparison was prepared for two points from construction: point A and point G (Fig. 1c). The dynamic response of the industrial masonry chimney was estimated using full time history analysis. It was prepared with the Hilber-Hughes-Taylor time integration algorithm provided in the ABAQUS package for a direct step-by-step solution [6]. The step varied from 10^{-5} to 10^{-2} s, according to convergence requirements. For the analysis the Rayleigh model of mass and stiffness proportional damping was applied. The damping coefficients $\alpha = 1.13$ and $\beta = 0.00046$ (where α referring to mass proportional damping and β to stiffness proportional damping) were determined for damping ratios of 5.0%.

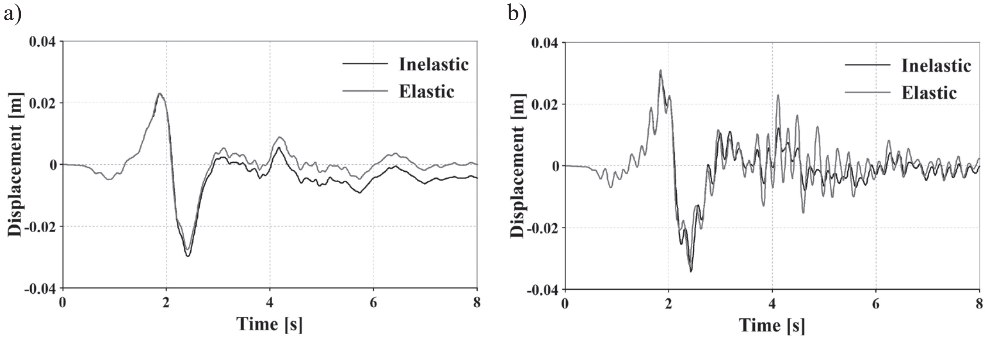

Fig. 3. Comparison of the vertical displacement for selected points: a) point A, b) point G

Taking into account the results from Fig. 4 (distribution of equivalent plastic strain) it can be noticed that this type of chimney is susceptible for fracture in upper parts, especially during strong ground motions. It must be pointed that plasticization of the upper parts of the chimney is a very dangerous phenomenon.

As it could be observed in Fig. 4 there are also the lower parts of the construction that are predisposed to destruction during the earthquake.

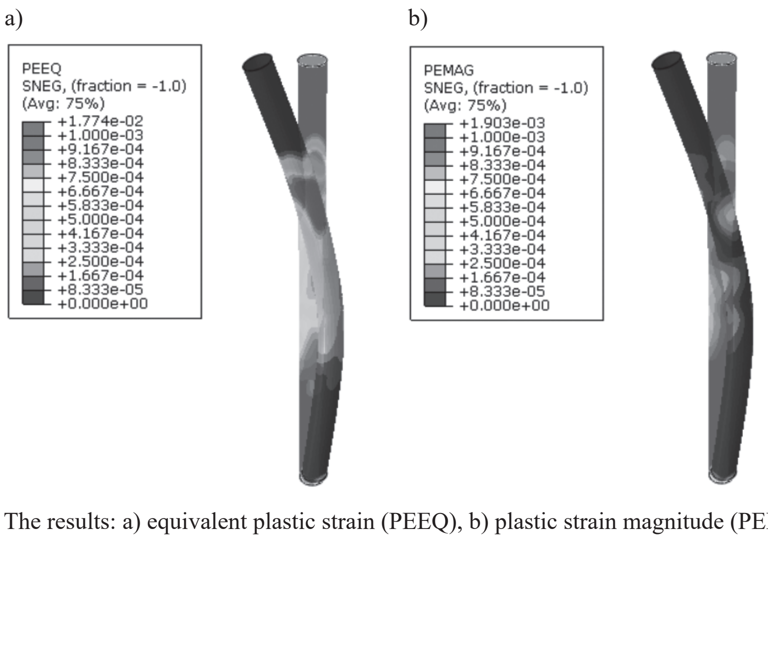

Fig. 4. The results: a) equivalent plastic strain (PEEQ), b) plastic strain magnitude (PEMAG)

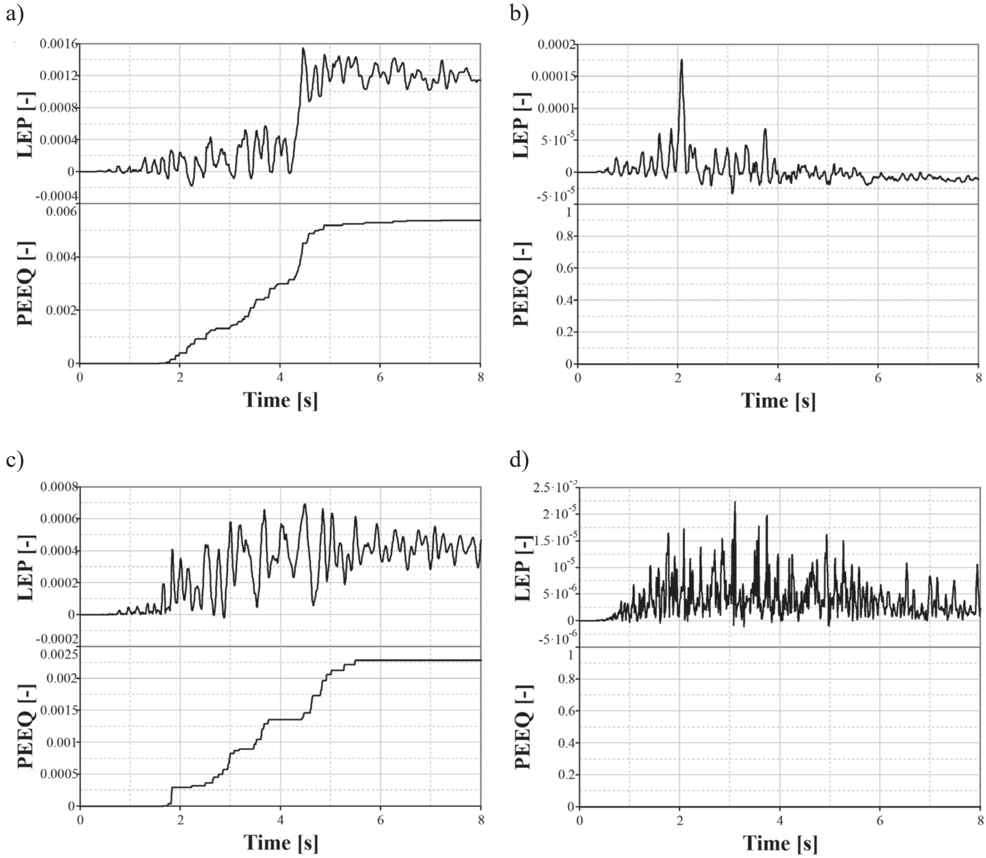

Fig. 5. Time history of plastic (LEP, PEEQ) measures at points: a) A, b) B, c) E, d) G

5. Conclusions

The following conclusions can be formulated on the basis of the results taken from the dynamic analyses of the masonry chimney subjected to strong seismic event:

1. The results obtained from numerical simulations (especially with inelastic material behavior, see Fig. 4) have shown that the crack pattern under strong ground motion can be predicted. What is more, taking into account the results it is possible to create the reinforcement for existing objects.
2. Differences in displacement values for the elastic an inelastic material model are connected with dissipation of energy during shock (Fig. 3). The part of energy taken from seismic activity is distributed on plastic strains during the analysis. For elastic material model it is impossible to calculate the influence of this phenomenon.

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KATARZYNA NOWAK-DZIESZKO*, MAŁGORZATA ROJEWSKA-WARCHAŁ*

SYMULATION OF NIGHT COOLING IN A SINGLE DWELLING OF A LARGE PANEL BUILDING

SYMULACJA NOCNEGO CHŁODZENIA W POJEDYNCZYCH MIESZKANIACH W BUDYNKU Z WIELKIEJ PŁYTY

Abstract

When analyzing large panel buildings, it is very rare to take into consideration the requirements connected with the overheating effect. The paper presents the results of the annual computational simulations of thermal comfort conducted for one flat of W70 multi-family large panel building. Basing on the simulations the authors analyzed the influence of night cooling on thermal comfort inside the flat. Different simulation steps were taken into consideration: windows with and without shading systems, opened during entire night or just during given periods of time to keep specific thermal conditions.

Keywords: large panel building, thermal comfort, PMV (Predicted Mean Vote), balcony framings, loggia

Streszczenie

Podczas analizy budynków wielkopłytowych bardzo rzadko uwzględniane są wymagania związane z ich przegrzewaniem. W artykule przedstawiono roczne symulacje komfortu cieplnego, przeprowadzone dla pojedynczego mieszkania w wielorodzinnym budynku wielkopłytowym w systemie W70. Na podstawie symulacji autorzy przeprowadzili analizę wpływu nocnego chłodzenia na komfort wewnątrz mieszkania. Analizie poddano różne warianty: okna z systemem zacienień zewnętrznych i wewnętrznych, otwierane w okresach nocnych w celu obniżenia temperatury.

Słowa kluczowe: budynki wielkopłytowe, komfort cieplny, PMV, loggia, balkon

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1. Description of problem

Overheating problems in buildings are very common and seem to be very important from occupants' point of view. Taking into consideration the fact that almost a quarter of Poles lives in large system panel buildings the issues related to this subject are very important and common. Occupants can control their thermal environment by means of clothing, operable windows, fans, heaters, internal and external sun shades.

Unfortunately at the simulation stage it is very difficult to predict the way the individual flat will be used. Looking globally at the multi-family building probably each flat should be analyzed separately after considering the requirements and expectations of inhabitants regarding temperature and humidity conditions. Many analyses were conducted by the authors and results were described in [1–4]. All of them under the assumption that all windows are closed during the entire day. For those unfavorable conditions there are problems with overheating of internal spaces even after using of internal and external shading systems. This assumption is however only theoretical as in practice the inhabitants open the windows when temperature inside exceeds uncomfortable values. Internal cooling through the windows makes sense especially during the night when external temperature is lower than internal. From the safety reasons sometimes opening of the windows during the night is impossible, especially at the lowest levels.

2. Description of analyzed building

The simulations were conducted for the W70 panel dwelling building, built in 1974. Plan area 21.5 m × 13.2 m; usage building area – 2279 m^2, 25 m high with 11 levels. Basement below the entire building, flat roof.

The building has natural ventilation and a central heating system with convection heaters. A communication area is located in the central part of the building. There are four flats at every single level. Exterior walls made of prefabricated panels in the W70 system, insulated with 15 cm of styrofoam with plasters at both sides: $U = 0.20$ W/m²K. Triple glazing windows: $U = 1.1$ W/m²K to keep current national requirements, SHGC (solar heat gain coefficient) equal to 0.63. SHGC is a description of windows used in United States, refers to the solar energy transmittance of the glass. In Europe the g value describes the same parameters of the glazing.

The simulations conducted for the Polish climatic conditions (building located in Cracow). The calculations were carried out in Design Builder v.3. The program has been specifically developed around Energy Plus, allowing the simulation of the building envelope and building interiors.

Analysis based on standard PN-EN ISO 7730, Ergonomics of the thermal environment. Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.

3. Simulation settings

Simulations were conducted for one flat, located at 7th floor with balcony at south elevation and windows at west side. The flat was analyzed as one thermal zone, an assumption that all internal doors are open was made. The main aim of simulations was to determine the temperature and PMV (Predicted Mean Vote) index during the summer months. The period of time between 15th May and 15th September was taken into consideration because at this time in Poland, there is a risk of overheating.

Fig. 2. Typical zones' visualization at every building level. Analyzed flat #2

The assumptions to the simulations:
- Heating system on from September to March (22°C), 7 days a week, 24 hours a day.
- Occupancy density: flats – about 1 person per 15 m^2.
- Operating schedule: flats – 100% occupancy density between 4 pm and 7 am, 5 days a week; at the weekends between 6 pm and 9 am; 50% reduced occupancy between 9 am and 6 pm.
- Metabolic activity: factor 1.2 met, winter clothing – clo = 1.0, summer clothing clo = 0.5.
- Ventilation requirements per Polish national standards PN-83/B-03430, in every flat 70 m^3/h for kitchen and 50 m^3/h for bathroom.
- Internal solar shadings (blinds with high reflexivity slats), and external shading panel (7 panels – louvre blades).

4. Test results

Six different simulation steps were analyzed and compared with one another.
1. All windows closed.
2. All windows closed, internal and external shading systems used.
3. Night cooling of the flat between 8 p.m. and 6 a.m. without shading systems.
4. Night cooling of the flat during the night until the internal temperature drops to 20°C, without shading systems.
5. Night cooling of the flat between 8 p.m. and 6 a.m. with shading systems.
6. Night cooling of the flat during the night until the internal temperature drops to 20°C, without shading systems.

4.1. Influence of shadings

In the first simulation step there is an assumption that all building windows are closed for the entire day. It affects the internal temperatures significantly. All simulation results have shown that during some days in the analyzed period of time the average interior air temperature exceeds 30°C and the PMV factor is even higher than 2. Those microclimate building conditions exceed the optimal internal summer temperature of 25°C and recommended value $-0.5 < PMV < +0.5$. In the second step, the internal and external shading systems were used at all windows. Those solutions affected the results significantly however did not eliminate the overheating temperatures entirely. Figures 3 and 4 present the number of overheating hours in the analyzed months. The number of discomfort hours, with the temperature above 25°C in the first simulation step is 2549, usage of shading systems reduces this number by about 35% to 1659.

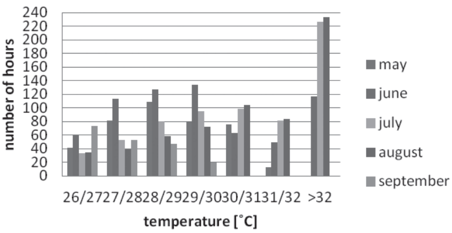

Fig. 3. Number of overheating hours in different months

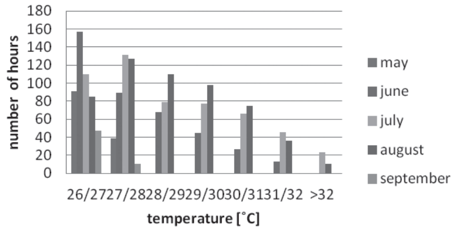

Fig. 4. Number of overheating hours, with internal and external shading systems, in different months

4.2. Influence of night cooling on thermal conditions

Simulation steps #3 through #6 assume night cooling of the flat which, in program, was modelled as additional ventilation rate. It represents the cooling of the flats by opened windows and was modelled as 5 air ventilation exchanges of the flat volume for a flat with and without shading systems. Night cooling itself was also analyzed in two different options. First case when the windows are opened between 8 p.m. and 6 a.m. (steps 3 and 5), second option – windows are opened until the internal temperature drops to 20°C, then windows are closed (steps 4 and 6).

Table 1 presents comparison of the number of discomfort hours in all analyzed cases.

Night cooling exerts significant influence on the internal thermal conditions. In all cases (3 thru 6), night cooling affected the number of discomfort hours significantly, decrease up to 80% can be observed comparing to the assumption when all windows are closed (steps 1 and 2). Temperatures above 30°C were almost entirely eliminated.

Using both shading systems and night cooling eliminated temperatures above 30°C entirely. From the overheating point of view the most favorable solution is using of night cooling together with internal and external shading systems (steps 5 and 6). However in those cases low temperatures even below 20°C can be observed. Figures 5 through 7 present the number of hours below 25°C and PMV factor in 6^{th} simulation step. Values are even lower than –2.0 and temperatures drops down to 15°C. Number of hours below 20°C is 433 and those are very unfavorable conditions for inhabitants.

Table 1

Number of overheating hours (above 25°C) in different simulation steps

Simulation step	Number of overheating hours	Temperatures above 30°C
Step 1	2549	1144
Step 2	1659	296
Step 3	591	71
Step 4	727	79
Step 5	229	0
Step 6	278	0

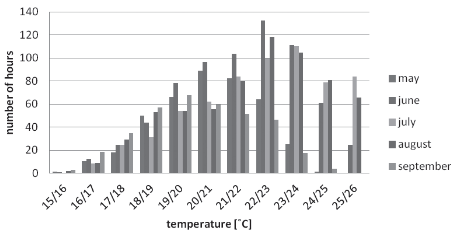

Fig. 5. Number of hours below 25°C in different months

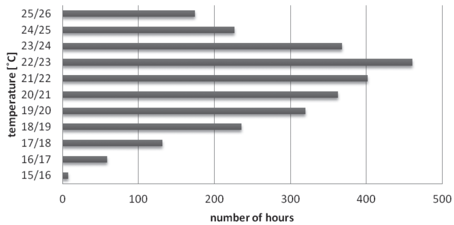

Fig. 6. Total number of hours below 25°C

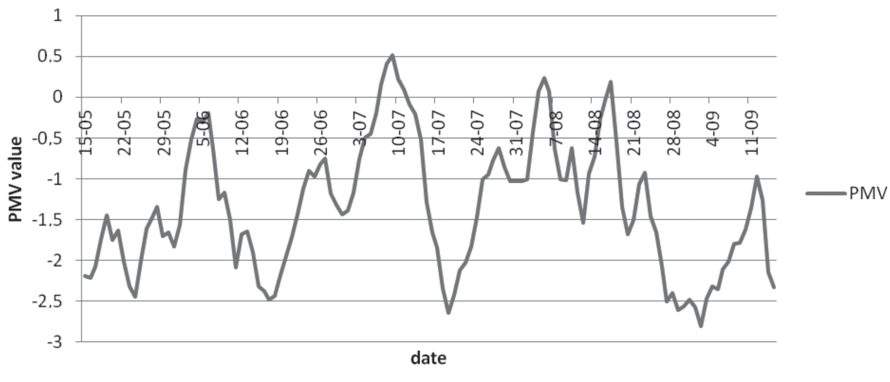

Fig. 7. PMV factor in 6^{th} simulation step (night cooling plus internal and external shading systems)

5. Conclusions

The results of the conducted analysis show that the overheating problem occurs in large panel buildings. Windows in the prefabricated panel buildings in most cases are poorly shaded from solar radiation. Glazing is the source of the excessive heat gains and results in the overheating of the dwellings. Using of internal and external shading systems reduces the number of discomfort hours however the most significant results are observed when internal spaces are cooled by opening the windows during the night. In practice this solution is commonly used by inhabitants. Modelling of this process is however complicated and difficult as it depends on the way separate flats are used. Cooling of the flats during every night would result in too low temperatures which affects the thermal conditions unfavorably. Simulations of night cooling by ventilation air exchanges is a simplification used for analyses purposes. Modelling of different air exchanges is the subject of authors' future works.

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JAN PORZUCZEK*

A NOVEL APPROACH TO THE DESIGN OF MODULAR CONTROLLERS FOR SOLAR THERMAL SYSTEMS

NOWE PODEJŚCIE DO PROJEKTOWANIA MODULARNYCH STEROWNIKÓW SYSTEMÓW SOLARNYCH

A b s t r a c t

The paper presents a new approach to the design of the solar thermal system controller which is characterized by modular arrangement. The proposed solution enables the integration of controller functions that significantly improve user comfort and the overall reliability of the system. These functions may include both security operations (control of blinds for solar collector, emergency power supply) as well as system monitoring (heat meter, data logger with memory card, Internet-based monitoring, weather station).

Keywords: solar thermal system, modular solar controller, plant monitoring

S t r e s z c z e n i e

W pracy przedstawiono koncepcję nowego, charakteryzującego się budową modułową, rozwiązania sterownika do systemów solarnych. Zaproponowane rozwiązanie umożliwia integrację w sterowniku solarnym funkcji znacząco poprawiających komfort i niezawodność eksploatacji układu. Do funkcji tych można zaliczyć zarówno zabezpieczenia (sterowanie roletami osłaniającymi kolektor, zasilanie awaryjne), jak również monitoring (ciepłomierz, rejestracja pracy układu na karcie pamięci, nadzór przez Internet, stacja pogodowa).

Słowa kluczowe: *kolektory słoneczne, modułowy sterownik solarny, monitoring instalacji*

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1. Introduction

Continuous increase in energy demand together with the emphasis on increase of participation of environment-friendly technologies foster the dissemination of the use of renewable energy sources. One of the most common ways to use this energy is the photothermal conversion in solar thermal systems [1, 2]. The need to provide appropriate operating parameters of the system enforces the use of properly selected and configured controllers. Solar thermal controllers are manufactured by many companies, both in Poland [3, 4] and abroad [5, 6]. Despite of the wide range of available solutions the controllers are still mostly closed-structure devices with virtually none expansion capabilities. On the other hand the flexible solutions, based on the programmable controllers (PLC Programmable Logic Controller), are applicable only in larger systems due to very high cost of PLC [7].

Simple controllers, representing the vast majority of the current market offer are dedicated to handle only basic types of solar installations. Usually their functionality is limited to controlling the pump charging the hot water tank. Depending on the category of the controller additional functions might be available: charging of the 2–3 hot water storage tanks, controlling the collectors located on different parts of the roof or controlling the hot water circulation pump. However, recently one may notice the growing demand for modular controllers, fully programmable that allow the integration of multiple systems into a complete operational system. Not less important for users appears to be implementing a number of additional functions such as control and monitoring system over the Internet [9] or utilize the power supply with the photovoltaic panels [10, 11]. Until now such systems implementations have relied only on PLCs, however, due to their high cost, they are rarely used in residential installations. Although the modularity and expandability are already offered by a few manufacturers of solar controllers, e.g. [5] however, software of these devices is still closed. With the spread of low-cost microcontroller platforms, such as Arduino [8], it became possible to design controllers in a small series and fit their software to the needs of a specific customer. It is also worth noting that such controllers can be easily upgraded when the supported system will be expanded. Regardless of design, solar controllers for custom, bespoke installations must meet the requirements defined by the standard PN-EN 12977 [12, 13].

2. Functionality of the solar thermal controller

The primary function of each solar controller is to control of the solar circuit pump based on temperature difference between a collector and a hot water tank [1]. In larger systems the groups of collectors that are located on different parts of the roof are supported. Such systems often support a group of hot water tanks, swimming pool or underfloor heating. Simple controllers only allow to generate on/off control signal for the pumps. More sophisticated controllers also allow the control of variable-speed pumps using PWM (Pulse Width Modulation) signal, which allows to improve the quality of control, as well as help to reduce electricity consumption. The efficiency of the differential thermostat has been studied in detail in the 80's and 90's of the twentieth century [14]. Several studies, e.g. [15] point out the significant relationship between energy yield and the differential thermostat setting. It has been shown that the use of variable hysteresis of the controller, adapted to current system conditions, allows to increase of solar energy yield and furthermore, the reduction of electricity consumption. However, virtually all commercially available solar thermal controllers provide the pump control based on a constant hysteresis. It may be noted that the introduction of a differential thermostat with variable hysteresis depending on the actual operating conditions of the solar system is easy to realize with programmable controller. A prototype of the controller described in this paper allows to both control of the pumps using on-off signal as well as variable speed utilizing the PWM signal.

An important addition to the differential thermostat is to provide the additional control and protective functions. The most common may include the following: control of the hot water circulation pump, anti-frost protection or periodic overheating of the hot water tank in order to prevent the Legionella growth. However, there are a number of functions which significantly support the solar system operation, that are rarely implemented in the solar controllers. For example, a rarity among controllers is the protection of solar collectors from excessive temperature increase in case of insufficient heat reception (eg. in the holiday season). Many providers offer blinds for obscuring collectors but very often they require a separate controller. The modular solar controller can implement such a function in the central unit or provide as an additional expansion module.

A reliable power supply is a basic requirement for the proper operation of all HVAC systems (Heating, Ventilation, Air Conditioning). A loss of power supply in solar thermal collectors causes interruption of the heat reception which consequently results in a very rapid increase of the collector temperature. An increase of fluid volume should be compensated by the expansion vessel in a well-designed system but design or realization weakness, as well as the expansion vessel defect may lead to system damage. For this reason, a considerable number of solar system users decide for the investment in emergency power source [10] or even a total power system using photovoltaic panels [11]. This all is more legitimate that the highest power demand, associated with the circulation pump at maximum capacity, coincides with the highest power generated from photovoltaic cells. As stated in the previously mentioned papers [10, 11], the power supply control should be connected with solar thermal system controller because it improves the overall system reliability.

A common feature of all solar controllers is to provide the information about the operation of the supported system. The basic controllers provide only readings from 3–4 temperature sensors in the hot water tanks and collectors. More sophisticated devices allow to use up to 5–7 temperature sensors. In many solar systems even this number of sensors may not be sufficient. Valuable information about the efficiency of the solar system can be provided by the use of the heat meter, especially in combination with solar radiation meter. Unfortunately, this feature is only available in very few controllers and the use of an external heat meter, designed for solar installations, is a substantial investment. Likewise, there may be other useful additional features to help the monitoring of solar thermal system operation, e.g.: data logger with memory card, solar system visualization over the Internet or the weather station.

3. Prototype of the modular controller for solar thermal system

As stated above, the controllers designed to control the solar thermal installations, in particular uncommon or complex ones, should be characterized by modular structure. This allows update of the controller functionality with further development of the installation. This chapter presents the exemplary prototype of the modular solar controller, based on the freely programmable Arduino platform [8]. A block diagram of the controller is shown in the the drawing (Fig. 1). The prototype of the controller consists of a central unit, implementing all the main control functions, and three major expansion modules: system monitoring, backup power supply and the weather station.

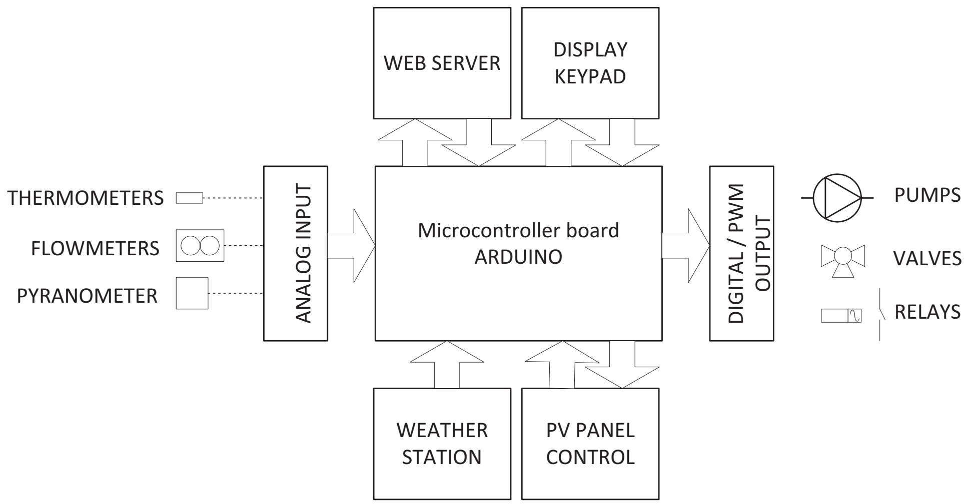

Fig. 1. The block diagram of the modular solar controller prototype

3.1. The central unit

The central unit of the solar controller is based on the Arduino Ethernet platform (Fig. 2). This system utilizes the Atmel ATmega328 microcontroller running at 16 MHz clock frequency. Equipped with communication interfaces such as SPI, I2C [16] and Ethernet allows to attach multiple additional modules. In order to provide the elementary local service, the controller is equipped with a small (1.8” diagonal, 160 × 128 pixel resolution) graphic display that communicates with the microcontroller through the SPI bus. In addition to communication interfaces, the central unit is equipped with 6 analog inputs (e.g. for temperature sensors) and 9 available digital inputs/outputs (including 4 PWM for pump speed control). This number of I/O channels allows the customization of the software for supported installation. The microcontroller is programmed in a language similar to C, using the development environment Arduino IDE software.

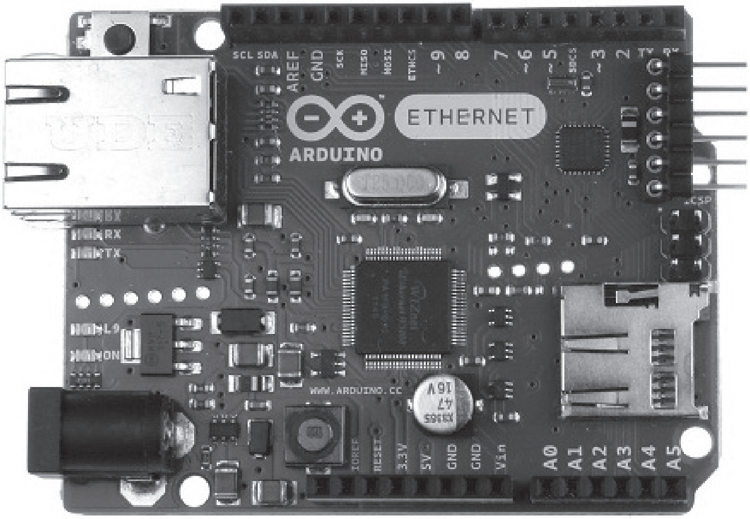

Fig. 2. The central unit board – Arduino Ethernet module

3.2. Solar thermal system monitoring

In the presented controller there are a number of monitoring features provided for solar installation. The use of a micro-SD memory card slot that is built-in Arduino system enables the implementation of a data logger recording selected data on plant operation. The diagram (Fig. 3) shows a sample logged data of the selected parameters of the solar installation operation.

A large number of measuring channels enables to add additional temperature sensors inlet end the outlet of solar collector as well as and the flowmeter. The use of these sensors makes it possible to implement a heat meter which can be used when analyzing the efficiency of solar energy. Common access to the Internet gives the opportunity for many contemporary systems to be monitored through the web [9]. The prototype controller provides a simple web server software that allows monitoring of the plant operation on the computer (or mobile devices such as smartphones) in a home network. For safety reasons those data should not be published on the Internet. The notification of events through SMS in the prototype system was not implemented, although it is a useful feature. However, it is possible to further expand the system using additional GSM communication module. For servicing a relatively small solar installations it appears to be unprofitable because it requires additional fees for data transfer. Notification by e-mail using the built-in Ethernet module seems to a better solution for such a system.

3.3. Control of photovoltaic power supply

Regardless of the method of use of photovoltaic panels (system powered only with PV panels or just a backup power supply) it is essential to control the voltage and load current

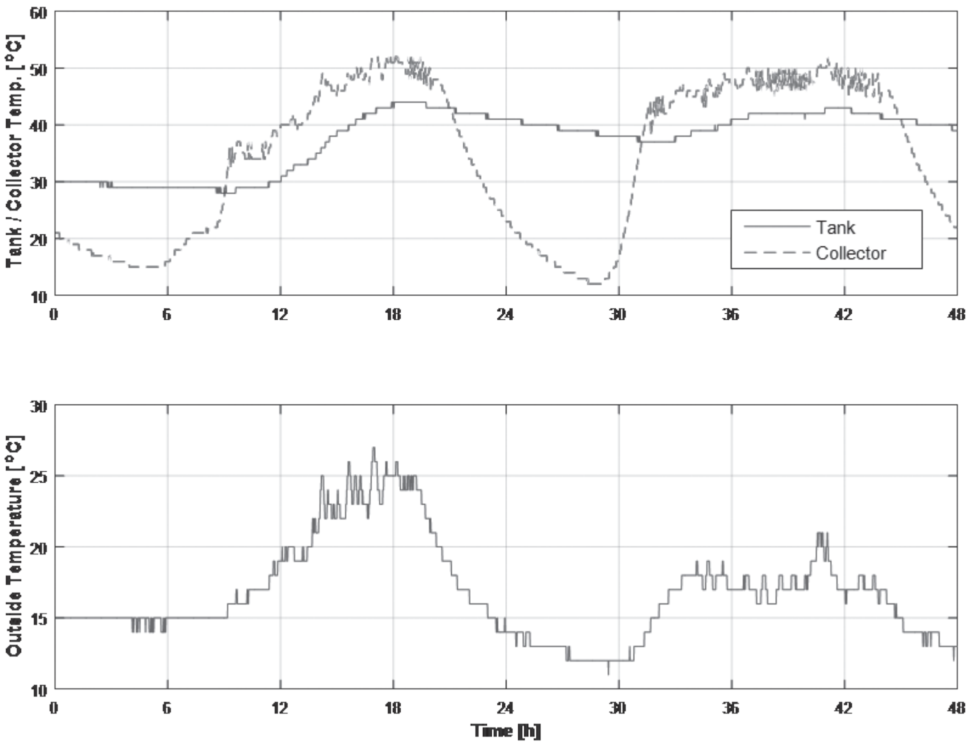

Fig. 3. The sample logged data of the selected parameters of the solar installation operation

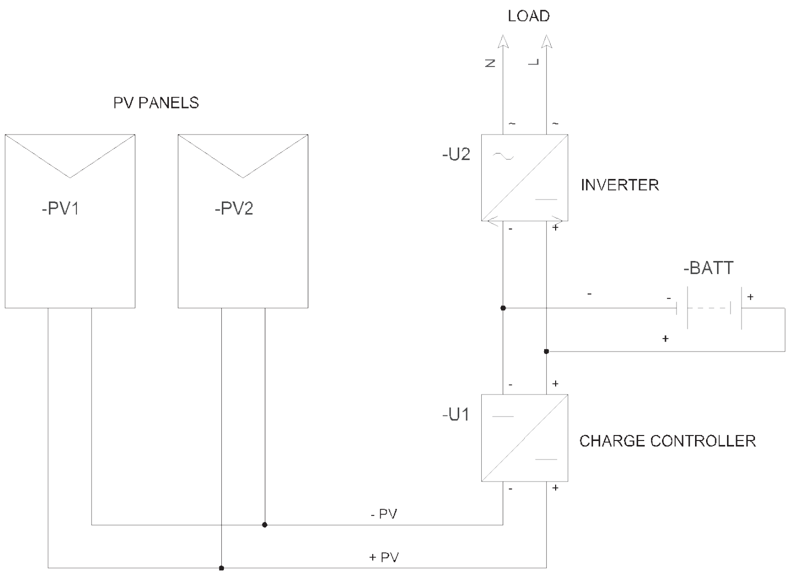

Fig. 4. Diagram of the photovoltaic power supply for the laboratory solar thermal installation

of the panels, as well as battery charging system (if used). The drawing (Fig. 4) shows a diagram of the photovoltaic power supply for the laboratory solar thermal installation. Further details of the applied solution and the experimental results of the obtained effectiveness are presented in [10].

3.4. The weather station

The module of the simple weather station is based on digital sensors: air temperature and humidity (Sensirion SHT11), as well as barometric pressure (Xtrinsic MPL3115A2). The sensors communicate with the microcontroller through an I2C serial bus [16]. Measurement of solar radiation in the presented prototype was carried out using LAB-EL LB-900 pyranometer [17]. This solution, although it provides high accuracy, may be disproportionately expensive compared to the needs. Probably a better solution would be to apply a small standard photovoltaic cell [5].

4. Conclusions

In this paper the limitations of a typical, commercially available, solar controllers were presented in detail. It has been shown that in unusual or complex solar systems the improved results can be achieved with the modular controllers. Such controllers can be better adapted for the plant through dedicated both the hardware modules and the software functionality. Obviously, the features listed above will not be necessary for every user, but with the further development of the installation (or an increase in customer needs) the controller functionality can be updated. Of course, preparing software for described controller (using language similar to C) is far more complicated than simple configuration of a typical, commercially available controller. However, the advantages of this solution in many cases may prevail outlay of work.

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ESTERA PRZENZAK*

RESEARCH ON TRANSPORT OF CONCENTRATED SOLAR RADIATION FOR LIGHTING PURPOSES

BADANIA NAD TRANSPORTEM SKONCENTROWANEGO PROMIENIOWANIA SŁONECZNEGO DO CELÓW OŚWIETLENIOWYCH

Abstract

This article presents the parameters of concentrated light, transmitted by optical fiber. A parabolic mirror was used for concentrating the solar radiation. An analysis of the spectrum of light reflected from the parabolic mirror and transmitted by using of variable length of the optical fibers is presented. The article also shows the simulations of the focused solar radiation with the transmitter in the form of fiber. This allowed to show the propagation of radiation inside the fiber and the distribution of the luminous flux on the important areas of the system. On the basis of this analysis, it is proved that the solar radiation concentrating system can be successfully used for lighting purposes.

Keywords: light transmission, optical fiber, concentrated solar radiation

Streszczenie

W artykule zaprezentowano parametry skupionego światła przetransmitowanego za pomocą światłowodów. Koncentrację promieniowania słonecznego osiągnięto za pomocą parabolicznego lustra. Zaprezentowano analizę widma światła odbitego od koncentratora i przetransmitowanego za pomocą światłowodu o zmiennej długości. Ponadto zaprezentowano wyniki symulacji komputerowych układu transportującego skupione światło za pomocą światłowodów. Dzięki temu możliwe było przedstawienie sposobu propagacji światła wewnątrz światłowodu, a także rozkładu natężenia promieniowania na istotnych powierzchniach systemu. W rezultacie wykazano, że skoncentrowane promieniowanie słoneczne może być z powodzeniem zastosowane do celów oświetleniowych.

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Słowa kluczowe: transmisja światła, światłowody, skoncentrowane promieniowanie słoneczne

1. Introduction

Aiming to reduce the energy consumption has nowadays become one of the most important priorities of the society. Lighting is one of the sectors of technology, which is most modernised and enjoys a great interest of the users. This is due to the fact that the standard lighting modernisation does not require a lot of work and financing. However, one should remember that the light is still the most expensive form of energy. Taking into account the process of production of electricity, its transmission and conversion to radiation, for lighting sources nowadays used as standard, the approximate energy efficiency of light production is as follows: a light bulb – 1.5%, a fluorescent – 3.5%, LED – 9% [1].

The fact is that the Sun provides the Earth's surface with light for several hours a day. Usually, this natural and free light source is to some extent used through the windows and partially glazed facades. However, often during daytime we use electric light due to insufficient amount of daylight reaching the deeper areas of rooms, or also in case of rooms without windows. In such situations, it would be very advantageous to provide light by using the lighting systems with the use of daylight. Another argument for the maximum use of the sunlight for lighting purposes is the fact that the spectrum of energy-efficient electric light is completely different from the spectrum of daylight (Fig. 1). It should be mentioned

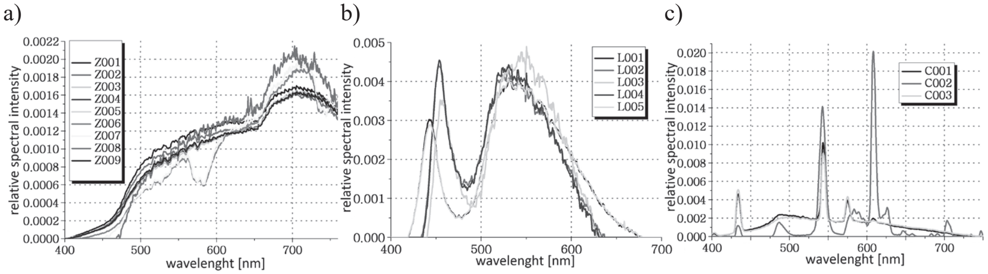

Fig. 1. Light spectrum: a) bulb, b) LED, c) fluorescent light [3]

here that it is the solar radiation that is the healthiest type of lighting for humans. The spectrum of light from the lamps is discontinuous, and white LED lamps emit too many short-waves [2]. Only the incandescent lighting emits a spectrum closest to daylight, but it is also the least efficient.

Thus, the lighting based on systems that use daylight from solar radiation is not only the healthiest, but also brings significant energy savings. There are many technological passive solutions, which are characterised by a cheap and simple construction, however, the main drawback is the inability to control their operation. This disadvantage is eliminated by active systems consisting of concentration and light transmission. Here, the difficulty is the fact that they are more expensive and have a more complex structure. Currently, in the Department of the Sustainable Development of Energy at AGH in Cracow, Poland a research connected to this topic takes place. Partial results and their analyses are presented in this article.

2. Description of the research position

In order to transmit more light than in the standard fibre system, the solar radiation concentrator has been used. The device consists of a parabolic mirror with a diameter of 1.2 m mounted on a plate with a diameter of 1.8 m filled with reflective foil (Fig. 2). For the concentrator to work properly, it has been integrated with the system tracking the location of the Sun based on the astronomical algorithm.

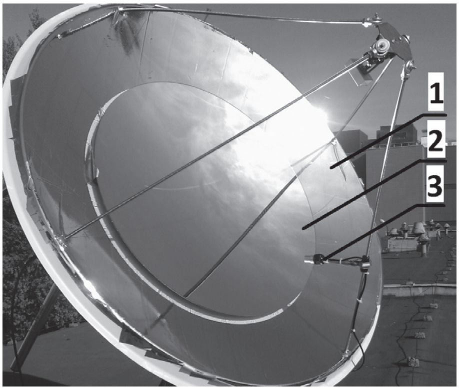

Fig. 2. One of the fibre head locations by the concentrator: 1 – reflective foil, 2 – parabolic mirror, 3 – head of the fibre optic cable

For the transmission of the concentrated light the fibre optic cable was used, with a length of 10 m consisting of 25 wires (each having a diameter of 0.75 mm). Near the focus of the concentrator, the head of the fibre optic cable was placed (Fig. 2), while the second end of the fibre was placed in the darkroom. Both on the roof and in the darkroom the light intensity sensors were placed, and were integrated with the programmable measurement and control PLC system. In addition to light intensity measurement, also the radiation spectrum study was performed transmitted using one fibre optic wire with the diameter of 0.85 mm and the optic spectrometer Science–Surplus with the detector Sony ILX511 linear CCD.

3. Examination of the concentrated light transport

One of the most important features in the studies on the light transmission is the transmission coefficient. It determines the amount of light that the given centre will let through. Knowledge of the value of this factor allowed the selection of the suitable location of the fibre optic cable head in relation to the concentrator's focus, as the right positioning of the fibre optic head has a significant impact on the quality of light that will reach the darkroom. The studies aimed to indicate the location, where the fibre optic end will get the highest possible amount of light, at the same time so that it will not be damaged as a result of high temperatures.

In order to compare the amount of transported light regardless of weather conditions the luminous flux was calculated for the external light falling on the fibre optic head φ_2 and emitted by the end of the fibre optic located in the darkroom φ_1. The calculations of the luminous flux falling on the head included the combined area of all wires of the fibre optic S, while the calculations of the flux inside the darkroom used the knowledge of the distance of the fibre optic end to the sensor d [1]:

$$\varphi_1 = I_{1,śr} \cdot d^2 \ [\text{lm}] \tag{1}$$

$$\varphi_2 = I_{2,śr} \cdot S \ [\text{lm}] \tag{2}$$

where:

- $I_{1śr}$ – the average light intensity measured in the darkroom lux,
- $I_{2śr}$ – the average light intensity measured outside lux,
- d – the distance of the optical fibre from the light intensity sensor m,
- S – the surface area of the fibre optic cable m^2.

Due to the lack of knowledge of the characteristics of the light distribution by the fibre optic the (1) expression is approximate. The adopted simplification means that the emission of light takes place with a constant intensity in a stable angle equal to one radian. Using the fluxes defined from the formulas (1) and (2) the light transmission through the fibre coefficient was determined [1]:

$$\alpha = \frac{\varphi_1}{\varphi_2} = \frac{I_{1,śr} \cdot d^2}{I_{2,śr} \cdot S} \tag{3}$$

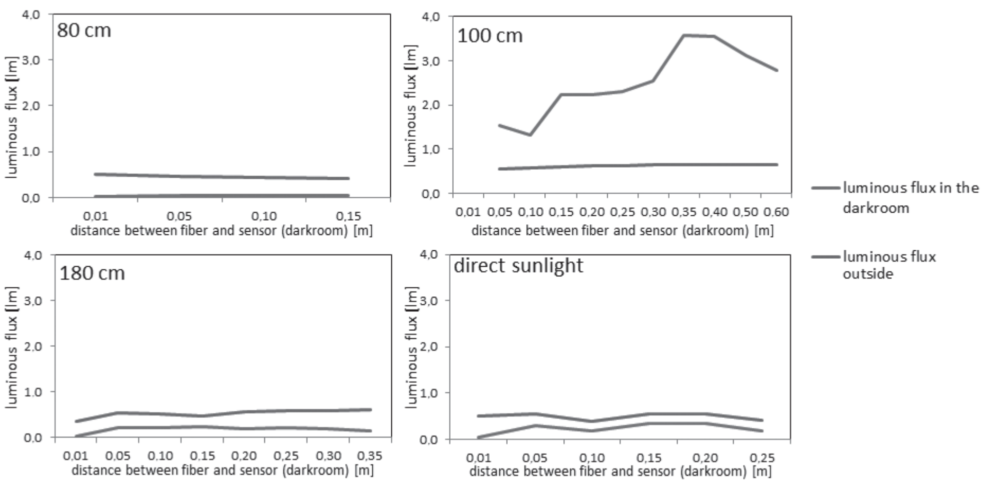

Fig. 3. Dependence of the luminous flux input to the darkroom and external (sensor lighted by direct solar radiation in a horizontal plane)

Values of the flux φ_1 and φ_2 are presented in Fig. 3, which shows flux values for different distances of the head from the concentrator surface. In addition, the flux values were presented for the fibre optic end in accordance to the orientation of the lighting intensity sensor outside. This allows the determination of the fibre optic quality – the higher the α coefficient, the better the fibre optic from the point of view of performance properties in the lighting system of rooms with daylight.

What results from chart 3 is that the location of the head at a distance of 100 cm from the mirror surface is the most effective solution. In this setting we have observed almost a 6-time higher flux of the transmitted light compared to the light falling on the external sensor in the horizontal plane ($\alpha > 100\%$). Therefore, the strengthening of the light – η created as a result of the use of the concentrated solar radiation took place.

In subsequent studies the spectral characteristics were performed on the assessment of the light quality. The first element that could affect the spectrum of the light radiation in the discussed system is the solar radiation concentrator. The performed measurements showed that the spectrum of the reflected light from the concentrator is continuous. Only minor deviations have been observed, which did not affect the qualitative features of the transmitted light (slight shift towards shorter wavelengths). Another element of the installation, which may cause distortion of the spectral characteristics is the transmitting medium. In Fig. 4 it can be seen that the spectrum of the transmitted light changes depending on the length of the used fibre. In order to test this feature, the analysis of the daylight transmission used the fibre optic with the diameter of 85 mm and lengths: 1, 4, 10 and 17 m. The studies calculated the degree of light passage in the wavelength for the selected lengths of the fibre. It can be seen in Fig. 4a, that for the length up to approx. 5 m the light loss is relatively small – approx.

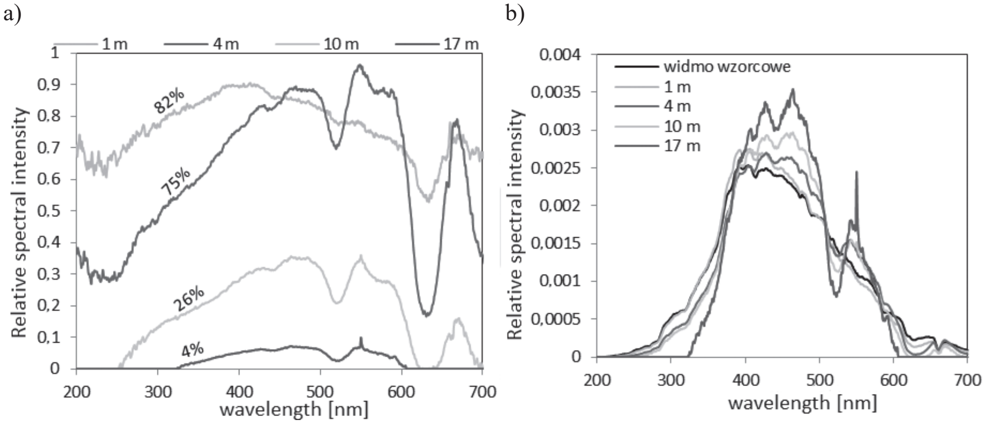

Fig. 4a) degree of light transmission, b) normalised spectrum for fibre

70% of light introduced to the fibre optic passes through. While for greater lengths – approx. 10 m, this loss is almost 3/4 of the introduced light, and for the length of 17 m only 4% of light was passed through the fibre optic. The conducted analysis and obtained results allow to conclude that the best length for this fibre optic type is approx. 5 m. Lengths between 5 and 10 m are still possible for use, while fibre optic with lengths of ca. 15 m are the border of the transportation of useful (for lighting purposes) amounts of light [PES].

The results listed in Fig. 4a clearly indicate that the light distortion increases with the length. The invisible ultraviolet light is poorly passed throughand the light with the length of approx. 630 nm, is damping, however, it includes a narrow scope, so it is not very relevant for lighting purposes. Though, an important feature is that for the fibre optic length over approx. 10 m the cutting of the red light is observed, what will result in the fact that the light after getting out of the fibre optic will give an impression of the cold light, with the colour slightly

Fig. 5. The propagation of radiation inside the fibre: a) flexion, b) a straight line

more bluish than the sunlight. In Fig. 4b (normalised spectrum) we can observe the distortions created as a result of light transmission. For waves with the length of approx. 600 nm we can observe absorption, yet, it is not a substantial distortion. The presented spectrum still has the character of the sunlight spectrum and it is continuous. The analysis of Fig. 4b confirms that good light parameters for the transmission to the distance up to 10 m and satisfactory to the maximum studied of 17 m [1].

Also computer simulations were performed as part of the research, which allowed to detect places of radiation loss in the waveguide. Below, in Fig. 5 we can see the way to propagate the rays inside the fibre. On a straight line (Fig. 5b) rays are reflected from the boundary of two materials having different refraction index. While on the bend the rays go to the shell, where some of them pass outside – they are lost. Based on the simulations it was calculated that in the case of the optical fibre bent by the 1cm ray, light losses were as high as 90%. They decreased with the growth of the bending ray: for r = 5 cm losses were 81%, and for r = 10 cm 71%. Thus, it can be seen that the bend of the fibre optic has a significant effect on the system efficiency. Other power degradations in the system are calculated via ray tracing simulations and described in [4].

4. Conclusions

The best way to reduce the demand for energy for illumination while retaining good qualitative light parameters is to maximally use the sunlight. High costs of optical fibres, however, force the search of new solutions, such as solar radiation concentrators. It has been proven that the light from the concentrator system has parameters close to the daylight, if the fibres cables not longer than 10 m are used – especially due to great quantitative losses in transmission. However, it is important to remember about the potentially smallest degree of fibre bending, as this has an adverse effect on the efficiency of the transmission.

The work has been completed as part of the statutory activities of the Faculty of Energy and Fuels at the AGH University "Studies concerning the conditions of sustainable energy development".

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MICHAŁ REPELEWICZ*, ANETA SZYMAŃSKA-STACHURA*, URSZULA GOIK**

A BUILDING MADE OF POLYSTYRENE PREFABRICATES FROM THE PERSPECTIVE OF NEW TECHNICAL CONDITIONS AND STANDARDS OF NF15 AND NF40

BUDYNEK Z PREFABRYKATÓW POLISTYRENOWYCH W ŚWIETLE NOWYCH WARUNKÓW TECHNICZNYCH ORAZ STANDARDÓW NF15 I NF40

A b s t r a c t

The article describes the results of performed calculations of heat transfer through the divisions of buildings designed in the technology of polystyrene prefabricates. All results were referred to the values contained in the new Technical Conditions. The article also contains the results of linear simulations of thermal bridges in the cited technology.

Keywords: *heat transfer coefficient, thermal bridges, technical conditions, polystyrene prefabricates*

S t r e s z c z e n i e

Artykuł opisuje wyniki przeprowadzonych obliczeń przenikania ciepła przez przegrody budynku zaprojektowanego w technologii prefabrykatów polistyrenowych. Wszystkie wyniki odniesiono do wartości zawartych w nowych Warunkach Technicznych. Artykuł zawiera również wyniki symulacji liniowych mostków termicznych w przytoczonej technologii.

Słowa kluczowe: *współczynnik przenikania ciepła, mostki termiczne, warunki techniczne, prefabrykaty polistyrenowe*

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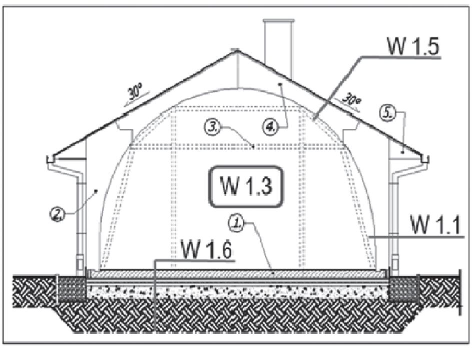
1. Introduction

New law regulation have been implemented in Europe. They improve energy efficiency of buildings and new initiatives are created to support low-energy and passive building engineering. Currently in Poland the new Technical Conditions are in force, which brings more changes in the years 2014, 2017 and 2021. Deciding to build a low-energy house, investors must take into account the higher cost of erecting these houses. However, the buildings meeting the relevant standards can be partially financed by the support from the National Fund for Environmental Protection and Water Management (NFOŚiGW). Subsidies are divided into two categories, closely linked to the categories of buildings: NF15 and NF40.

The technical Conditions adopted in 2014 and subsidies from the National Fund for Environmental Protection and Water Management steer the development of building engineering onto the area of Poland in the nearest years. The analysis of current technologies of erecting buildings designed to compare the ownership of the buildings with the requirements of the adopted changes in regulations becomes important. The article describes the analysis of meeting the chosen building parameters that were compared with the values required by the Technical Conditions and by the guidelines for subsidies to the standards of NF15 and NF40.The single-family house built in the technology of the M3 System was subjected to the analysis. Parameters included in the analysis are: heat transfer coefficients and coefficients for linear thermal bridges.

2. Short description of the M3 System technology



W 2.2

1.	Reiforced-concrete column 14cm x 24cm	

W 2.4

1.	Reiforced-concrete beam 16cm x 22cm	

W 1.1

1.	Mineral plaster+fiberglass mesh	1,0cm
2.	Self-supporting polystyrene monoblocks	30,0cm
3.	Cement-limestone plaster+fiberglass mesh	1,5cm

W 1.3

1.	Mineral plaster+fiberglass mesh	1,5cm
2.	Foamed polystytene	15,0cm
3.	Cellular concretet tile	24,0cm
4.	Cement-limestone plaster+fiberglass mesh	1,5cm

W 1.5

1.	Tin plate with glue	0,6cm
2.	Fiberglass meshand glue dedicated to polystyrene	1,0cm
3.	Self-supporting polystyrene monoblocks	30,0cm
4.	Cement-limestone plaster+fiberglass mesh	1,5cm

W 1.6

1.	Parquet	2,0cm
2.	Lean concrete	5,0cm
3.	Foamed polystytene	5,0cm
4.	Reiforced-concrete slab	18,0cm
5.	Foamed polystytene	15,0cm

Fig. 1. Constructional scheme. Description in the text

The examined technology is based on the use of foamed polystyrene monoblocks in form of large-scale prefabricates. Building elements are placed onto the foundation plate. They are attached to the foundation plate using a proper solution based on fiberglass mesh and glue dedicated to polystyrene. Polystyrene elements are constructed in the shape of arc which allows to perform a very thermally tight building envelope. Technology is complemented with gable ends made in any technology. In the analyzed building, there is a gable end made of cellular concrete with a thickness of 24 cm. More about the technology can be found on the website of the M3 System company and in the article [1]. Fig. 1 shows the scheme of prefabricated elements arrangement. Where: 1 is the floor on the ground, 2 – wall element of the monoblock, 3 – beam of the gable end, 4 – prefabricated roof component, 5 – finishing element.

3. The coefficient of heat transfer through the basic divisions in the building and the requirements contained in the Technical Conditions

Building divisions were marked and described in (Fig. 1). According to the Polish standards, the heat transfer coefficients for individual partitions were determined. It should be noted, that for the purpose of the calculation and subsequent simulation, the least favorable options of partitions were assumed. For partitions at the variable thickness, the narrowest variants of a constant thickness were assumed. The results of calculations combined with the requirements of the Technical Conditions are shown in (Table 1).

Table 1

Heat transfer coefficient

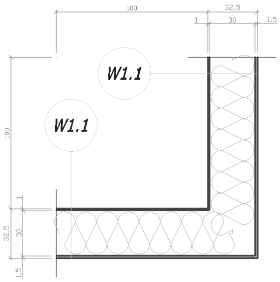
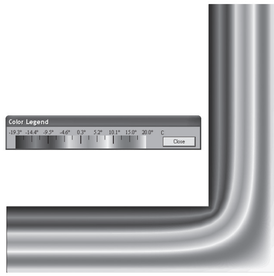
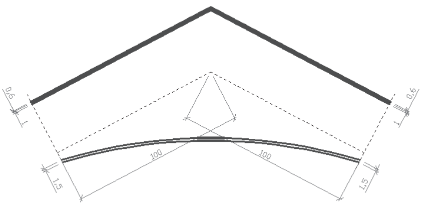
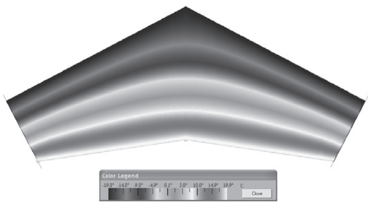
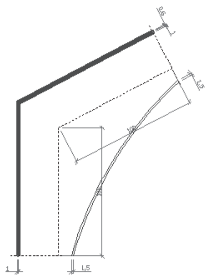
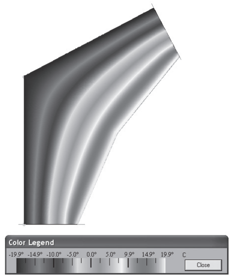
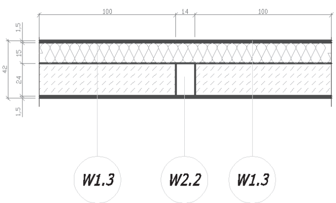
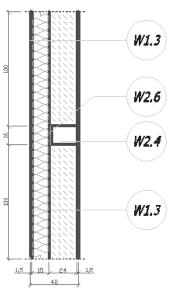
Division type	U [W/m²K]			
	Designated	Requirements of Technical Conditions		
		2014	2017	2021
Floor on the ground	0.184	0.30	0.30	0.30
Roofs	0.129	0.20	0.18	0.15
External walls – made of prefabricates	0.128	0.25	0.23	0.20
External walls – gable ends, cellular concrete	0.160	0.25	0.23	0.20

4. Thermal bridges

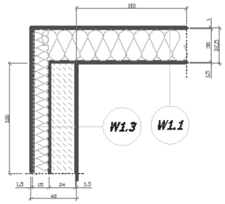
The article uses the method of simulating the flow of heat flux available in the Therm program. Bridges from a) to f) were determined using data from the Polish standards, and [2]. For bridges of g) and h), the requirements and calculation algorithms like in [3] were applied. Schemes of analyzed thermal bridges, and the distribution of heat flow is shown in (Tab. 2) and the values of linear coefficients of thermal bridges can be found in (Tab. 3).

Table 2

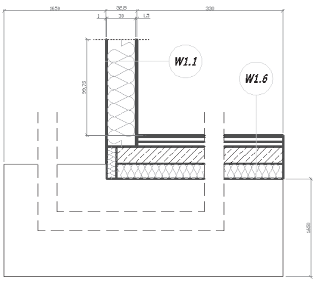
Distribution of heat flux flow

a) 	
b) 	
c) 	
d) 	
e) 	

f)



g)



h)

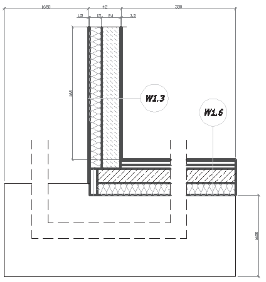


Table 3

Coefficients of the linear thermal bridges

Designation	Bridges presence location	Ψ_e [W/mK]
a)	Connection of two walls – M3 System	0.023
b)	Connection of system elements in the roof ridge	–0.105
c)	Connection of wall and roof system elements	–0.129
d)	Reinforcement of the gable end made with the reinforced concrete pole	0.115
e)	Reinforcement of the gable end made with the reinforced concrete beam	0.117
f)	Connection of the M3 System wall with the gable end made of cellular concrete	0.078
g)	Connection of the M3 System wall with the floor on the ground	–0.119
h)	Connection of the gable end with the floor on the ground	0.037

5. Conclusions

Simulations and comparative analysis indicate that the M3 System technology already meets the requirements of the Technical Conditions that will be in force from 2021 (in 2021 TC will best ricter than they are today).

The designated values of linear thermal bridges in the analyzed technology show that the M3 system technology fits in a NF15 standard. The only location that should be slightly improved are bridges in the gable end made of cellular concrete. Without changing anything in the solutions of divisions, the conditions of NF40 are met. It should be noted that the presented parameters constitute only a part of the requirements that must be met when seeking for the subsidies from the National Fund for Environmental Protection and Water Management.

M3 System is one of the few technologies in Poland which meet the conditions of NF15 and TC of 2021. The thermal insulation of these buildings is at the level of high energy-efficient constructions. Referring to the article [4] M3 System technology is prepared for the changes that the New Thermal Conditions will bring into Poland. This readiness can contribute to dominate the low-energy construction sector in Poland.

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KRZYSZTOF SORNEK*

POWER GENERATION IN SMALL HEAT SOURCES USING THERMOELECTRIC GENERATORS

WYTWARZANIE ENERGII ELEKTRYCZNEJ W MAŁYCH ŹRÓDŁACH CIEPŁA PRZEZ ZASTOSOWANIE GENERATORÓW TERMOELEKTRYCZNYCH

A b s t r a c t

This paper presents the results of studies conducted to determine the possibility of generating power using stove-fireplace with accumulation. During studies described in the paper, thermoelectric generator with the nominal power of 10 W and maximum operation temperature of 150°C was tested. Obtained results allowed to define real performance of the used generators. However, further tests are still needed to obtain better energy efficiency of the tested micro-scale cogeneration system.

Keywords: *microcogeneration, stove-fireplace with accumulator, thermoelectric generators, biomass*

S t r e s z c z e n i e

Artykuł prezentuje wyniki badań przeprowadzonych na potrzeby określenia możliwości wytwarzania energii elektrycznej z wykorzystaniem piecokominka. W czasie prowadzonych badań wykorzystany został moduł termoelektryczny o mocy 10 W, który charakteryzował się maksymalną temperaturą pracy równą 150°C. Otrzymane wyniki pozwoliły ocenić rzeczywistą wydajność zastosowanego generatora, a także wyciągnąć wniosek, że konieczne są dalsze testy dla uzyskania lepszej wydajności energetycznej stworzonego układu.

Słowa kluczowe: *mikrokogeneracja, piecokominek, generatory termoelektryczne, biomasa*

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1. Introduction

Micro-scale cogeneration systems, using heat generated in the boilers and other small heat sources, are going to be more and more popular in the near future. From currently recognized technologies (including Stirling engines, ORC based systems and thermoelectric generators), thermoelectric generators (TEG) were introduced to the tests.

The stove-fireplace with accumulation (SFA), which is a combination of fireplace and traditional accumulative stove, was used as a heat source. During typical operation, heat produced as a result of wood combustion is stored in the accumulative heat exchanger and dissipated up to 12 h after the fire has died out. As a result, the thermal efficiency of SFA can achieve a level of 90% [1].

The overall SFA efficiency can be further improved by the use of a dedicated power generating system. Such system may provide self-sufficient operation of the SFA and generate additional power used by home appliances or sold to the grid.

2. State of the art

The possibility of the use of thermoelectric generators in the small heat sources (including various types of stoves), is a subject of many worldwide studies. Nuwayhid et al. have presented the power generating system fitted to the side of a domestic woodstove and cooling by natural convection with maximum steady state matched load power 4.2 W (per single module) [2]. They have also studied the possibility of continuous generating 10–100 W electric power using of the heat from 20 to 50 kW wood stoves [3]. Lertsatitthanakorn investigated the similar prototype based on the biomass cook stove, getting a power output of 2.4 W [4]. As opposed to air cooling systems, Rinalde et al. [5] studied a forced water cooling system. In this case, an electric heater was used as a heat source and maximum power was obtained at the level of 10 W. In [6] there were compared a study of temperatures and electrical power measurements to a theoretical analysis using thermoelectric and heat transfer equations. More advanced studies were performed in [7], where TE modules manufactured with different materials have been tested. The power generator assembled with 96 TEG modules had an installed power of 500 W at a temperature difference of around 200°C, and an output power of about 160 W at a temperature difference of 80°C. Champier et al. has presented design and build a TE generator with Bi_2Te_3 modules which allows to operate with the maximum hot-side temperature at 230°C. TEG were fitted to the 10 kW cooking stove. Two cooling systems were tried: a heat fins exchanger placed on the cold side with a 10 W air fan and a water tank put directly on the cold side of the TE module. The maximum power reached between 1.7 W and 2.3 W per TE module for a temperature difference at a level of 160°C [8].

Analysis of the literature sources (above mentioned and other, connected e.g. with economic reasons) confirms the validity of the further studies in the area of the using thermoelectric generators in microcogeneration systems. This paper is related to the use of stove-fireplace with accumulation, but the proposed solution may be implemented also in the case of other heating appliances (e.g. biomass-fired boilers, fireplaces or stoves).

3. Test rig

The test rig used in the studies is equipped with a stove-fireplace with accumulation. The construction of SFA includes a furnace with a mass of 550 kg and the accumulation exchanger with a mass of 1050 kg. Based on the previously conducted tests, the starting version of dedicated heat exchanger dedicated for thermoelectric generators was located in the vicinity of the exhaust outlet from the furnace area [9]. The scheme of the studied system is shown in Fig. 1.

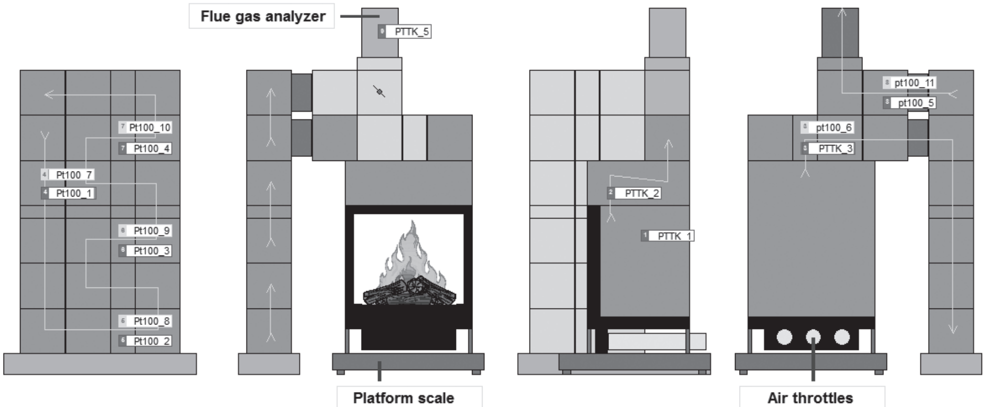

Fig. 1. The overview scheme of the studied system with marked heat exchanger for thermoelectric generators

Thermocouple and resistance sensors, monitoring temperature in the test rig, were located in the furnace area, in the flue gas channel, on the surface of the accumulation heat exchanger and on the surface of special heat exchanger designed for TEG. Besides temperature, there were performed the measurements of the flow rate of the air blown into the furnace area, the weight loss of fuel during the combustion process and concentration of the flue gas. The flue gas analyser uses the electrochemical methods for measuring the O_2 concentration (scope of 0–21%) and the NDIR method both for measuring CO (scope of 0–100 000 ppm), CO_2 (scope of 0–20%), NO (scope of 0–2500 ppm), NO_2 (scope of 0–500 ppm) and SO_2 concentrations (scope of 0–1000 ppm). Moreover, the NO_x concentration is calculated. Combustion process is regulated using three air throttles controlled by analogue signals 0–10 V and flue gas throttle targeting the gas either to the chimney or to the accumulator exchanger or to the exchanger area with TEG. Measurements are recorded by the control and measurement system with the PLC controller [10].

Power generating system is equipped with a single Bi_2Te_3 module with the dimensions of 40 × 40 × 3.2 mm and maximum operation temperature at a level of 150°C. The tested thermoelectric module was placed on the surface of the heat exchanger. Cooling down was carried out using the dedicated water cooler, supplied with water at temperature of 10°C. The generated electricity was used for charging the battery (using the voltage controller).

4. Experimental results

4.1. Optimization of structure of heat exchanger dedicated for TEG

The first part of the conducted tests was devoted to study the operation parameters of two variants of the heat exchanger structures. First, simple structure was made in the form of a rectangular channel with an uninterrupted gas flow (see Fig. 2a). The result of large cross-section of the channel and the lack of external isolation was relatively low temperature of the exchanger's surface. Due to mentioned disadvantages, the structure of the exchanger has been supplemented by a constriction and a radiator (see Fig. 2b). The constriction allowed to increase the gas flow in the boundary layer and the radiator allowed to intensify the heat exchange between exhaust gas and exchanger's wall. This way, the surface of the heat transfers through gas to the exchanger surface got increased. Moreover, the 5 cm layer of mineral wool thermal insulation was applied.

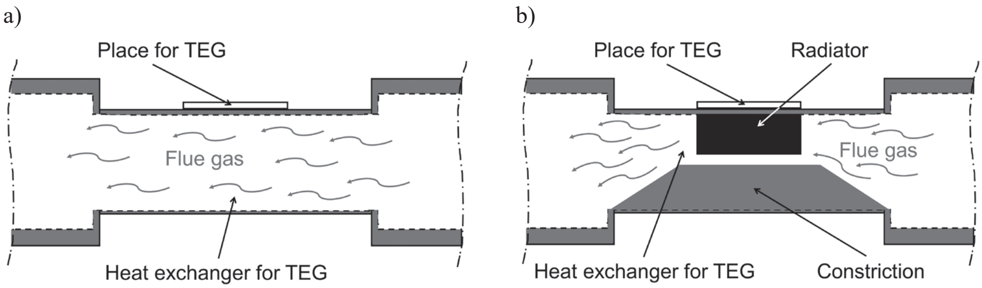

Fig. 2. Two variants of construction of the heat exchanger dedicated for TEG

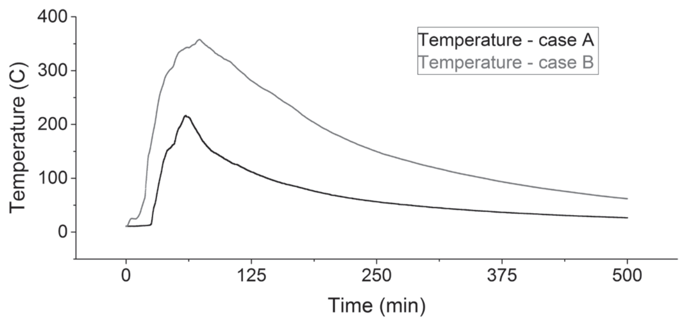

Fig. 3. Temperature variations on the exchanger's surface during combustion process

The temperature changes presented in the Fig. 3 were measured in the place of the destined assembly of the TEG (top wall of the exchanger) using a resistance temperature sensor Pt100. In each series 12 kg of dry pine wood was burned. To ensure identical process conditions, only one throttle of the supply air was fully opened, while the other dampers were closed.

The temperature variations on the exchanger's surface in each case tested is presented in Fig. 3. It can be concluded, that using additional elements (like constriction and radiator) allows to ensure significantly higher temperature on the exchanger's surface.

4.2. The study of TEG operation

The operation parameters of the thermoelectric generator (voltage, current and power), depend on the temperature of the hot and cold side. During conducted studies, the effect of the hot side temperature variations on the current-voltage characteristics and the obtained power has been experimentally determined. The increase of temperature of cooling water during TEG operation was less than 6 K (with the flow rate of 5 l/min). The studies were conducted using the artificial electronic load. The voltage-current characteristics, presented in Fig. 4, illustrates the increase of the open circuit voltage, short-circuit current as well as both of voltage and current with the increase of the exhaust gas temperature.

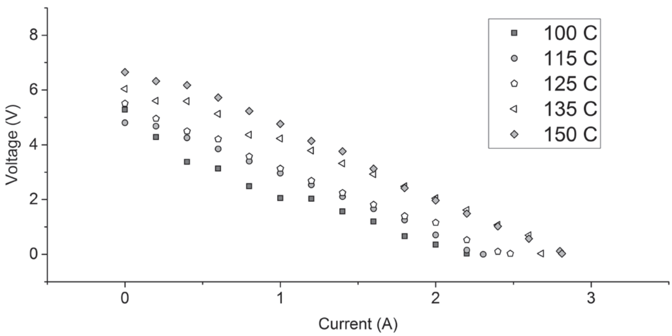

Fig. 4. Voltage-current characteristics of the tested thermoelectric generator

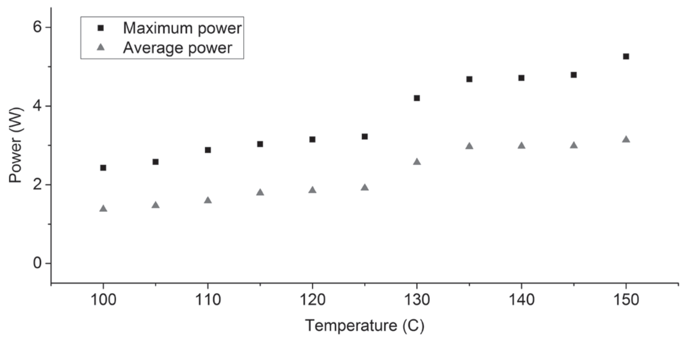

Fig. 5. Variations in the power value taken from TEG in the function of temperature

The high dependence on the temperature variations presents Fig. 5. This figure shows the variations in the power value taken from the thermoelectric generator in the function of the temperature (only the maximum power values were taken into account). The analysis of the presented data indicates the need to ensure the possibly constant parameters of exhaust (temperature, flow) during the combustion process.

5. Conclusions

Conducted tests confirm the possibility of using thermoelectric generators to generate power from the stove-fireplace with accumulation. During performed works only a single TE module was tested, however connecting few modules allows to achieve higher power and sufficient level of current and voltage. The proposed solution may be implemented also in the case of other heating appliances (e.g. biomass-fired boilers, fireplaces or stoves).

Analyzing results achieved during conducted tests we can conclude, that improvements in the power generating system construction are needed (e.g. in the area of intensification the heat transfer from flue gas to the hot side of TEG). When these changes are introduced to TEG operation, it will be possible to provide self-sufficient operation of stove-fireplaces with accumulation.

Supervisor: Ph.D. Mariusz Filipowicz, associate professor

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MARCELA SPIŠÁKOVÁ*, DANIELA MAČKOVÁ*

PERCEPTION OF WASTE MANAGEMENT BY CONSTRUCTION COMPANIES

POSTRZEGANIE GOSPODARKI ODPADAMI PRZEZ FIRMY BUDOWLANE

A b s t r a c t

The responsible waste management is an integral part of a sustainable construction process which is based on managing of waste stream on site, waste minimization, waste registry, waste disposal (reusing, recycling, landfilling, ...) on construction site, but also the policies and regulations in this field. Currently, many opportunities have arisen for the beneficial reduction and recovery of construction material that would otherwise be destined for the disposal as construction waste. The scope of use of these opportunities is related to the perception of waste management by construction companies, especially by contractors. The submitted paper presents the importance of on site waste management in terms of construction of buildings. The research was carried out through a questionnaire survey in Slovakia. It was focused on finding construction companies' approach to the issues of waste management on building sites and problems in the field of construction waste registry. The first part of the paper is focused on attitudes to waste disposal depending on company size (using chi-squared test) and the second part is focused on attitudes to meeting waste legislation.

Keywords: *waste management, waste disposal, construction industry, construction company, constructor, questionnaire*

S t r e s z c z e n i e

Odpowiedzialna gospodarka odpadami jest integralną częścią zrównoważonego procesu budowlanego, który opiera się na zarządzaniu strumieniem odpadów na miejscu, minimalizacją, rejestrem, utylizacją odpadów (ponowne wykorzystanie, recykling, składowanie...) na budowie, ale także polityki i przepisów w tej dziedzinie. Obecnie pojawiło się wiele możliwości korzystnych dla redukcji i odzysku materiałów budowlanych, które w przeciwnym razie byłyby przeznaczone do usunięcia jako odpady budowlane. Zakres wykorzystania tych możliwości jest związany z postrzeganiem gospodarki odpadami przez firmy budowlane, zwłaszcza przez wykonawców. Przedstawiono znaczenie gospodarki odpadami na miejscu w zakresie budowy budynków. Badania przeprowadzono za pomocą badań ankietowych na Słowacji. Koncentrują się na poszukiwaniu firm budowlanych zajmujących się kwestią gospodarowania odpadami na budowach i problemami w dziedzinie rejestru odpadów budowlanych. Pierwsza część artykułu koncentruje się na postawach unieszkodliwiania odpadów w zależności od wielkości firmy (za pomocą testu chi-kwadrat), a druga na podejściu do spełniania przepisów

Słowa kluczowe: *gospodarka odpadami, utylizacja odpadów, budownictwo, firma budowlana, konstruktor, kwestionariusz*

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1. Introduction

The construction industry affects our society not only at local but also at national and global level. The construction industry is considered one of the largest producers of solid wastes globally. The huge amount of construction and demolition wastes (CDW) has been generated from increasing the building of new structures, renovation, rebuilding, repair, demolition works and infrastructure development projects. Large quantities of construction and demolition waste harmfully affects the environment if it is not managed in a proper manner. As such, huge amounts of waste needs to be properly managed [1, 2].

The assessment of the local impact of the construction industry is based on the assessment of sustainability for particular building. The assessment of building sustainability is performed through the assessment systems (e.g. BREEAM, LEED, SBToolCZ, DGNB etc.). There economic, social and environmental criteria are assessed. The weight of importance for environmental criteria is usually more than 20% (e.g. assessment system DGNB – 22,5%) [3, 4]. The environmental criteria is divided into three groups – energy and emission, water and waste. The criterion "waste" is aimed on the assessment of the solid waste, hazardous waste to disposal and waste management which is presented in a part of the project documentation [5].

On the other hand, waste management of construction and demolition waste is also important to solve at national and global level. According to Eurostat, the construction and demolition waste, which is produced by the construction process, presents 33% of the total waste stream in the European Union (EU) [6]. CDW has been identified as a priority waste stream of the EU. However, CDW can be easily recycled through the existing technological methods and processes.

The issue of construction and demolition waste management needs to be solved not only at national but also local level. However, the initial step of waste management solution is the attitude of waste producer to this issue. The producers of construction and demolition are the constructors, usually construction companies.

2. Waste management in construction

Waste management is defined by legislative framework. The Directive 2008/98/EC on waste [7] (Waste Framework Directive) sets basic concepts and definitions related to waste management, such as definitions of waste, recycling, recovery. It explains when waste ceases to be waste and becomes a secondary raw material (so called end-of-waste criteria), and how to distinguish between waste and by-products. The Directive lays down some basic waste management principles.

Different definitions are applied throughout the EU. In Slovakia, the construction and demolition waste is defined by Act 223/2011 Coll. of Waste act as a waste from activities such as construction of buildings and civil infrastructure, total or partial demolition of buildings and civil infrastructure, road planning and maintenance. The construction and demolition waste consists of numerous materials, including concrete, bricks, gypsum, wood, glass, metals, plastic, solvents, asbestos and excavated soil, many of which can be recycled.

Waste legislation and policy of the EU member states shall apply as a priority order the following waste management hierarchy within the waste management. The waste management hierarchy is divided into five levels – prevention, preparing for re-use, recycling, recovery and disposal. There is a high potential for recycling and re-use of CDW, since some of its components have high resource value. In particular, there is a re-use market for aggregates derived from CDW waste in roads, drainage and other construction projects. Technology for separation and recovery of construction and demolition waste is well established, easily accessible and, in general, inexpensive.

One of the objectives of the Waste Framework Directive is to provide a framework for high level of resource efficiency. In particular, member states shall take the necessary measures designed to achieve that by 2020 a minimum of 70% (by weight) of non-hazardous construction and demolition waste shall be prepared for re-use, recycled or undergo other material recovery.

According the Enviroportal [8], the current situation in the waste management on national level in Slovakia is worse. In the analysed period (years 2005–2013), the amount of waste generated by the construction sector in Slovakia amounted to average 2.776 million tonnes, what presents 26.2% of the total amount of waste which is lower than the EU average (33%). The relatively lower waste level can be related to lower construction intensity than in other European countries. The lower waste level is not a signal of more effective construction waste management. This is also confirmed by the level of waste disposal. In the analysed period (years 2005–2013), the amount of construction waste disposal presents 57.8% and construction waste recovery 42.2%. Some European countries (the Netherlands, Denmark, and Belgium) have their reuse and recycling rates higher than 80%, but Malta, Romania and Bulgaria present these rates at lower than 10%.

In this context of target volume of waste recovery (70%) by 2020, it is important to deploy initiatives that contribute to an effective waste management scenario reaching high CDW recovery rates. It can be achieved only through active and appropriate attitude of each constructor, at particular construction site, to waste management.

3. Approaches of constructors to waste management

The perception of construction waste management by constructors (construction companies) can be divided into two groups:

- attitudes to waste disposal,
- attitudes to meet waste legislation regulations.

Both aspects are interconnected. The positive approach to waste disposal (recovery preference) means positive approach to meet waste legislation regulations (legislative rates target).

The level of waste management perception by construction companies was found out by a questionnaire survey performed by Institute of Construction Technology and Management at the Faculty of Civil Engineering, Technical University in Kosice in 2014. The basic method of research is a questionnaire. Respondents (experts) were asked by personal questioning to answer questions relating to waste management perception in Slovak construction companies.

Thirty-seven respondents from small-sized, thirty-six respondents from medium-sized and twenty-nine respondents from large-sized companies were interviewed.

The aim of this paper is to present partial results from the above mentioned research. The first part is focused on attitudes to waste disposal depending on each company size and the second part is focused on attitudes to meet waste legislation regulations.

Respondents were asked three questions to find out attitudes to waste disposal:

– Q1: How is the construction waste disposal used at particular building site?
– Q2: To whom is the construction waste given?
– Q3: Is the recycling of construction waste significant in financial terms?

The respondents had a scale of possible answers and the share of answers (in percent) for all three questions depending on company size as shown in Figure 1.

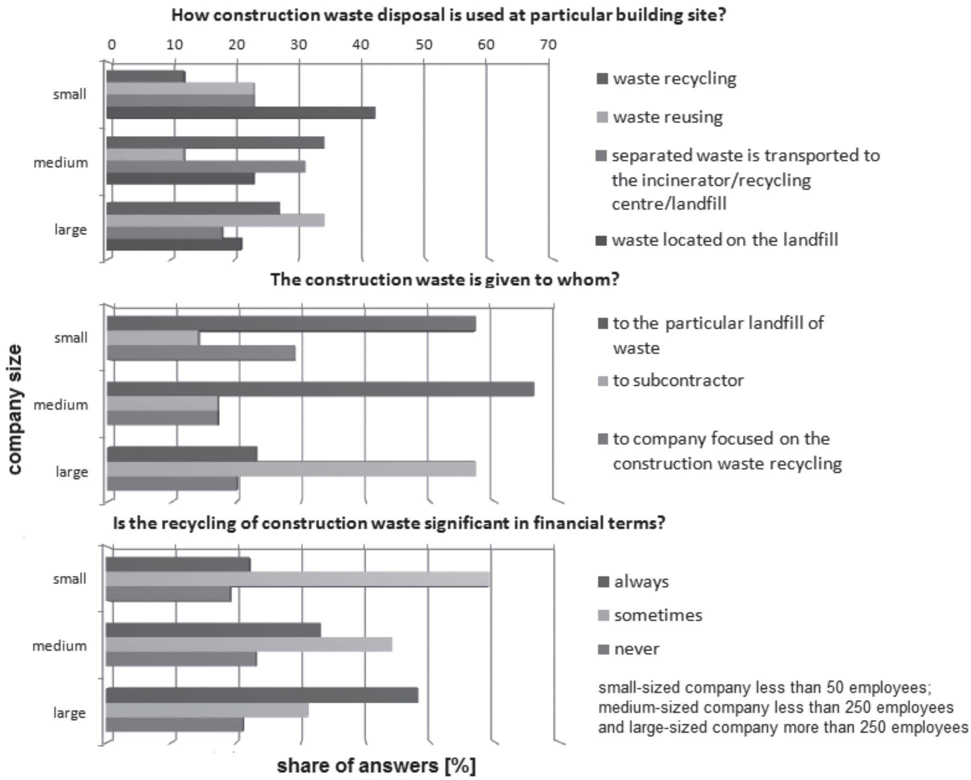

Fig. 1. Share of answers for questions Q1, Q2, Q3 depending on company size

Using chi-squared test (significance level α = 0.05) there influence of the company size to attitudes to waste disposal was investigated. A null hypothesis was: The attitude of constructor to waste disposal is independent on the company size. The share of answers (in percent) for all three questions depending on company size is shown in Table 1. Consequently chi-squared test was performed and the results are shown in Table 2.

Table 1

Shares of answers for questions Q1, Q2, Q3 [%]

Company size	Q1 [%]				Q2 [%]			Q3 [%]		
	Ans1	Ans2	Ans3	Ans4	Ans1	Ans2	Ans3	Ans1	Ans2	Ans3
Small	12	23	23	42	57	14	29	22	59	19
Medium	34	12	31	23	66	17	17	33	44	23
Large	27	34	18	21	23	57	20	48	31	21

Table 2

Results of chi-squared test

	p-value
Q1	< 0.0001
Q2	< 0.0001
Q3	0.00753

As we can see in Table 2, p-value of chi-squared test is significantly lower than significance level $\alpha = 0.05$, therefore we reject null hypothesis and accept alternative hypothesis: The attitude of constructor to waste disposal is dependent on the company size. The large-sized construction companies prefer waste reusing while small-sized companies locate the construction waste mainly on landfills. This approach is understandable, because large-sized companies declare the financial significance of recycling and reusing

The second part of a questionnaire survey was focused on the attitudes of companies to meet waste legislation regulations. One of the legislation requirements is keeping the waste registry. The producer, as well as the waste holder, is legally obligated to keep the construction and demolition waste registry. All information about the waste type, the amounts and disposal ways has to be reported to the authority of waste management. The initial step of the registry presents identification of the generated waste type according to European waste list in Notice of the Ministry of the Environment No. 283/2001. The next step is the quantification of waste producer during the construction works. This step can be considered as the most critical point of the whole waste registry process since there is no uniform and simple method for the registry of CDW volume. The final step is the determination of CDW disposal waste considering the waste characteristics, economic and transport possibilities of waste producers and the principles of waste management hierarchy.

We assumed that the declared volume of originated waste was not identical to the real waste volume. The respondents confirm this assumption (68%) and identified potential causes: common additional changes in the constructions projects, the inability to quantify waste in the preparation phase of the construction project, unforeseen waste especially during reconstruction work. The construction companies expressed their willingness to comply with the legal requirements, but due to the difficulties in quantifying waste that is not always possible. They emphasize the need of legislative support in the field of waste quantification.

4. Conclusions

The proper approach to waste management by construction companies is essential for solving the construction waste issues at local, national and global level. The submitted paper presented the partial results of a questionnaire survey focused on attitudes to waste disposal and attitudes to meet waste legislation regulations by construction companies. The research confirmed that the attitude of constructor to waste disposal is dependent on the company size. The large-sized construction companies prefer waste reusing while small-sized companies prefer waste landfilling. At the same time, the construction companies see the need of legislative support in the field of waste quantification which identified as the most critical point of the whole waste registry process.

The article presents a partial research result of project VEGA – 1/0677/14 Research of construction efficiency improvement through MMC technologies.

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WIND TUNNEL STUDIES OF COOLING TOWER SURFACE IN TERMS OF AERODYNAMIC INTERFERENCE

BADANIA MODELOWE WPŁYWU INTERFERENCJI AERODYNAMICZNEJ NA POWŁOKĘ CHŁODNI KOMINOWEJ

Abstract

The cooling tower can be classified as a special structure, both in terms of reliability and size. The collapse of such a large tower, located closely to other buildings, may result in very serious consequences. It seems that special attention should be paid during design process of this kind of structures. Despite the increase in cost, the additional analysis and studies are indicated and also may raise reliability. The article presents the influence of wind action on the cooling tower. It consists of the studies on the issue of aerodynamic interference performed in the wind tunnel. The attention was particularly focused on the influence of the wind pressure on the shell of cooling tower, and on variability of these pressures on the surrounding objects. Making an adequate scale model, configuration of measuring equipment and an execution of wind tunnel tests will be described in this paper. The research was concentrated on measuring the pressure coefficients on the cooling tower surface in single situation and interference situations.

Keywords: *cooling tower, wind tunnel, aerodynamic interference, power plant*

Streszczenie

Chłodnię kominową można zakwalifikować do grupy konstrukcji specjalnych zarówno pod względem niezawodności jak i rozmiaru. Zniszczenie tak wielkiego obiektu zlokalizowanego w sąsiedztwie budynków elektrowni może skutkować poważnymi konsekwencjami. Projektowanie wymaga szczególnej uwagi. Pomimo większych kosztów, dodatkowe badania i analiza są zalecone ze względu na niezawodność. Artykuł zawiera informacje o badaniach przeprowadzonych w tunelu wiatrowym nad zagadnieniem działania wiatru na chłodnię kominową oraz zjawiska interferencji aerodynamicznej. Szczególną uwagę zwrócono na wpływ zmiennego ciśnienia wiatru, na powierzchnię chłodni kominowej. Poniżej opisano proces wykonania modelu w odpowiedniej skali, konfigurację aparatury pomiarowej i wykonanie badań w tunelu wiatrowym. Badania były skupione na pomiarze współczynników ciśnienia wiatru na powierzchni chłodni kominowej w sytuacji z otoczeniem i bez niego.

Słowa kluczowe: *chłodnia kominowa, tunel wiatrowy, interferencja aerodynamiczna, elektrownia*

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1. Wind tunnel studies

1.1. Model of cooling tower and its surrounding

The model of a cooling tower and surrounding objects are inspired by the new power plant unit in Kozienice, Poland. All the objects are not an accurate representation of this unit, however during the execution of models, similarity to the original was one of the most important goals.

Studies focused on the cooling tower – the biggest object in a new part of the power house. The cooling tower is 185 m height. The meridian located on the tower surface can be described by a hyperbolical equation:

$$\frac{x^2}{35^2} - \frac{(y-140)^2}{100^2} = 1$$

where:

$0 \le y \le 185$,

x – diameter.

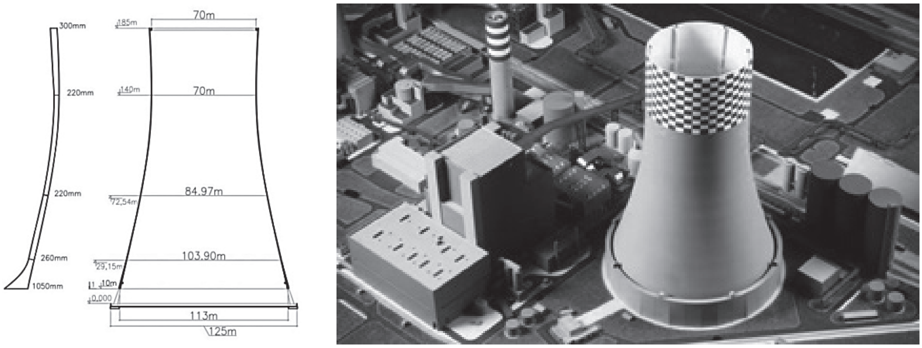


Fig. 1. Dimensions of the cooling tower (left), model of a new power plant unit in Kozienice (right)

Buildings located in a distance of 400 m from the cooling tower were taken into consideration. The second highest object in the area is a steam generator building with a height of 107 meter and it is situated 124 meters from the center of the tower. Surrounding consists of 20 different types of structures (see Table 1).

The scale of models is 1:400. It is equivalent to 46.3 cm height for the tower and 25 cm for steam generator building.

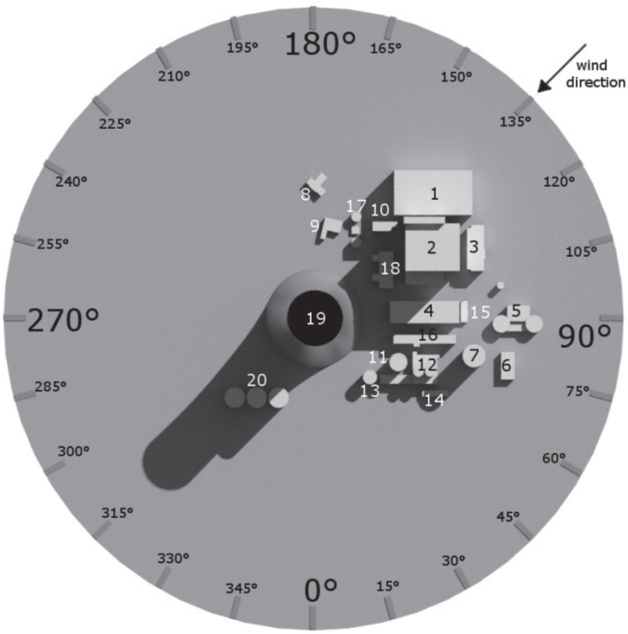
1.2. Measuring points

To achieve the assumed level of accuracy and due to limited number of measuring sensors available in the wind tunnel, the measuring points were located on 4 meridians of the cooling tower (0°, 90°, 180°, 270°). There are 13 sensors on each meridian located along its length. Willed total number of points is 312 (24 meridians). Taking advantages of the fact that geometry of the cooling tower is rotationally symmetrical, it is possible to rotate the cooling tower to reach the desired number of points. Due to, the predicted lower variability of internal pressure, the measuring points located on internal surface of the cooling tower are spaced more rarely. The total number of internal measuring points is equal to 65.

Table 1

List of surrounding objects with location from center of the cooling tower [1]

#	Height [m]	Distance [m]
1	42.6	165
2	107	124
3	22.9	201
4	29.25	96
5	14.65	230
6	10	242
7	57.45	194
8	9.15	156
9	7	100
10	38.77	134
11	37.7	108
12	33.6	107
13	23.4	93
14	7.8	163
15	7.6	187
16	20	105
17	11.4	103
18	60	97
19	185	–
20	66.6	95



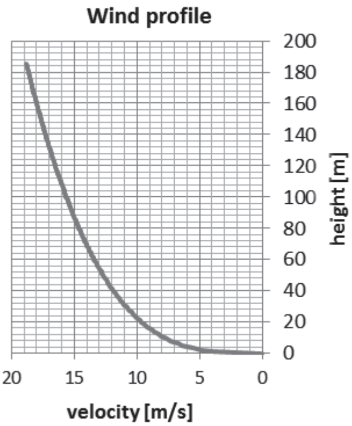
1.3. Wind tunnel properties

Reynolds number is a dimensionless quantity that is used to help predict similar flow patterns in different fluid flow situations. For the model of the cooling tower the value of Reynolds number for $u = V_{ref} = 18.8$ m/s lies between $2.2 \cdot 10^5$ and $3.76 \cdot 10^5$ (for the smallest and the biggest diameter). As a result, the critical and supercritical regime $R_e \in (10^5; 3.5 \cdot 10^5)$ is achieved for the small and medium velocity of flow. In this range, the flow in front of the tower is unsettled, turbulent, vertical and asymmetrical. The number and size of vortexes behind the tower is random and unpredictable. For the real structure of the cooling tower the R_e value is between $8.8 \cdot 10^7$ and $1.5 \cdot 10^8$ which gives transcritical regime. Taking into account that the purpose of the studies was to look into the changes of the wind pressure acting on cooling tower in case of aerodynamic interference, this kind of simplification is possible, because precise values of wind pressure are not the most important but the changes of those [2, 3].

All of the wind tunnel properties such as: configuration of adjustable ceiling, ejection of floor blocks, RPM of the fan, type of circulation, settings of barrier and spires had been optimized for the size of the model, its scale, external shape, roughness of the terrain and type of performance. Experience gained during previous studies executed at Cracow University of Technology wind tunnel, was taken into consideration during adjustment of wind tunnel properties.

Table 2

Vertical wind profile and wind tunnel properties



(Wind profile chart)	Reference velocity	$V_{ref} = 18.8 \frac{m}{s}$
	Reference pressure	$q_{ref} = 220$ Pa
	Intensity of wind turbulence	$I_v = 20\%$
	Kinematic viscosity of air	$\mu = 10 \cdot 10^{-6}$

1.4. Execution of results

The first part of the experiment was focused on measuring the wind pressure acting on cooling tower without any influence of facilities located in the neighborhood of the tower. This situation is called single.

The second part of the experiment measured the change of wind pressure acting on the cooling tower, which was caused by the influence of power plant facilities. This part is much more complex. Occurrence of surrounding buildings significantly complicated the studies. Direction of wind is not the only one variation. Location of surrounding buildings must have been additionally taken into consideration. This part is called an interference situation. Also the wind pressure acting on internal surface of the cooling tower was measured in the third part of the experiment.

2. Results of internal pressure

2.1. Introduction

The results are submitted in matrix form, where the columns represent the meridians, and the rows represent the height. Data is arranged in such a way, that the windward meridian is always in 1st column (and 25th – which is always the copy of 1st one). 25th column is placed only to achieve visualization of symmetry of results. The 13th column always represents the leeward meridian. The change of wind direction is counterclockwise (see Table 1).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0,3	0,24	0,04	-0,23	-0,5	-0,67	-0,73	-0,67	-0,51	-0,4	-0,4	-0,33	-0,3	-0,33	-0,4	-0,4	-0,51	-0,67	-0,73	-0,67	-0,5	-0,23	0,04	0,24	0,3
2	0,36	0,29	0,03	-0,31	-0,66	-0,9	-0,97	-0,88	-0,52	-0,37	-0,39	-0,36	-0,36	-0,36	-0,39	-0,37	-0,52	-0,88	-0,97	-0,9	-0,66	-0,31	0,03	0,29	0,36
3	0,4	0,3	0	-0,4	-0,82	-1,09	-1,14	-0,91	-0,51	-0,36	-0,37	-0,35	-0,37	-0,35	-0,37	-0,36	-0,51	-0,91	-1,14	-1,09	-0,82	-0,4	0	0,3	0,4
4	0,44	0,33	-0,01	-0,47	-0,95	-1,25	-1,32	-1,05	-0,55	-0,4	-0,4	-0,38	-0,37	-0,38	-0,4	-0,4	-0,55	-1,05	-1,32	-1,25	-0,95	-0,47	-0,01	0,33	0,44
5	0,49	0,35	-0,03	-0,54	-1,07	-1,4	-1,47	-1,13	-0,59	-0,42	-0,41	-0,4	-0,39	-0,4	-0,41	-0,42	-0,59	-1,13	-1,47	-1,4	-1,07	-0,54	-0,03	0,35	0,49
6	0,55	0,39	-0,04	-0,61	-1,21	-1,56	-1,61	-1,23	-0,63	-0,45	-0,44	-0,42	-0,41	-0,42	-0,44	-0,45	-0,63	-1,23	-1,61	-1,56	-1,21	-0,61	-0,04	0,39	0,55
7	0,6	0,41	-0,08	-0,72	-1,38	-1,75	-1,78	-1,3	-0,63	-0,44	-0,43	-0,42	-0,41	-0,42	-0,43	-0,44	-0,63	-1,3	-1,78	-1,75	-1,38	-0,72	-0,08	0,41	0,6
8	0,64	0,45	-0,04	-0,7	-1,37	-1,77	-1,86	-1,43	-0,71	-0,48	-0,46	-0,45	-0,44	-0,45	-0,46	-0,48	-0,71	-1,43	-1,86	-1,77	-1,37	-0,7	-0,04	0,45	0,64
9	0,68	0,47	-0,04	-0,73	-1,43	-1,84	-1,88	-1,55	-0,8	-0,51	-0,49	-0,47	-0,48	-0,47	-0,49	-0,51	-0,8	-1,55	-1,88	-1,84	-1,43	-0,73	-0,04	0,47	0,68
10	0,71	0,54	0,05	-0,63	-1,31	-1,73	-1,87	-1,53	-0,85	-0,55	-0,52	-0,49	-0,5	-0,49	-0,52	-0,55	-0,85	-1,53	-1,87	-1,73	-1,31	-0,63	0,05	0,54	0,71
11	0,75	0,58	0,12	-0,54	-1,19	-1,6	-1,73	-1,41	-0,86	-0,62	-0,58	-0,52	-0,51	-0,52	-0,58	-0,62	-0,86	-1,41	-1,73	-1,6	-1,19	-0,54	0,12	0,58	0,75
12	0,8	0,63	0,2	-0,4	-0,98	-1,32	-1,43	-1,13	-0,85	-0,72	-0,64	-0,54	-0,5	-0,54	-0,64	-0,72	-0,85	-1,13	-1,43	-1,32	-0,98	-0,4	0,2	0,63	0,8
13	0,76	0,64	0,27	-0,25	-0,75	-1,03	-1,13	-0,97	-0,82	-0,72	-0,65	-0,54	-0,51	-0,54	-0,65	-0,72	-0,82	-0,97	-1,13	-1,03	-0,75	-0,25	0,27	0,64	0,76

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	-0,2	-0,21	-0,15	-0,16	-0,25	-0,4	-0,49	-0,49	-0,37	-0,26	-0,22	-0,19	-0,18	-0,2	-0,22	-0,3	-0,35	-0,41	-0,4	-0,36	-0,28	-0,29	-0,2	-0,2	-0,2
2	-0,2	-0,19	-0,1	-0,18	-0,32	-0,55	-0,68	-0,66	-0,42	-0,24	-0,23	-0,2	-0,2	-0,21	-0,24	-0,35	-0,43	-0,52	-0,5	-0,42	-0,26	-0,2	-0,18	-0,2	-0,2
3	-0,16	-0,14	-0,05	-0,2	-0,42	-0,71	-0,83	-0,8	-0,55	-0,24	-0,25	-0,21	-0,23	-0,23	-0,27	-0,38	-0,51	-0,61	-0,57	-0,46	-0,27	-0,19	-0,15	-0,16	-0,16
4	-0,1	-0,08	-0,03	-0,15	-0,42	-0,73	-0,91	-0,89	-0,59	-0,27	-0,27	-0,24	-0,25	-0,26	-0,31	-0,43	-0,62	-0,77	-0,73	-0,58	-0,34	-0,21	-0,11	-0,1	-0,1
5	0	-0,01	-0,01	-0,15	-0,51	-0,85	-1,07	-1,03	-0,72	-0,39	-0,32	-0,32	-0,31	-0,36	-0,36	-0,47	-0,72	-0,96	-0,95	-0,78	-0,45	-0,22	-0,05	0,01	0
6	0,15	0,12	0,07	0	-0,61	-1,02	-1,29	-1,22	-0,83	-0,44	-0,39	-0,36	-0,35	-0,38	-0,42	-0,5	-0,79	-1,16	-1,21	-1,04	-0,64	-0,29	0,01	0,14	0,15
7	0,31	0,27	0,11	-0,15	-0,78	-1,23	-1,48	-1,39	-0,91	-0,51	-0,43	-0,43	-0,4	-0,45	-0,44	-0,5	-0,81	-1,35	-1,5	-1,36	-0,9	-0,35	0,05	0,26	0,31
8	0,44	0,37	0,1	-0,21	-0,91	-1,4	-1,66	-1,55	-0,95	-0,55	-0,47	-0,49	-0,45	-0,49	-0,46	-0,49	-0,8	-1,43	-1,65	-1,54	-1,06	-0,45	0,05	0,34	0,44
9	0,55	0,44	0,1	-0,41	-1,05	-1,56	-1,8	-1,64	-0,95	-0,54	-0,46	-0,48	-0,45	-0,48	-0,45	-0,49	-0,8	-1,44	-1,7	-1,6	-1,13	-0,54	0,04	0,41	0,55
10	0,64	0,5	0,12	-0,43	-1,08	-1,57	-1,79	-1,6	-0,95	-0,58	-0,5	-0,5	-0,48	-0,5	-0,48	-0,52	-0,78	-1,36	-1,61	-1,52	-1,07	-0,55	0,06	0,47	0,64
11	0,7	0,55	0,15	-0,36	-1	-1,46	-1,65	-1,48	-0,93	-0,64	-0,58	-0,53	-0,5	-0,52	-0,55	-0,6	-0,78	-1,28	-1,52	-1,45	-1,01	-0,45	0,14	0,54	0,7
12	0,78	0,65	0,26	-0,26	-0,8	-1,21	-1,34	-1,13	-0,79	-0,7	-0,65	-0,55	-0,49	-0,54	-0,6	-0,67	-0,74	-1	-1,24	-1,22	-0,85	-0,37	0,21	0,62	0,78
13	0,77	0,64	0,3	-0,15	-0,64	-0,99	-1,1	-0,98	-0,79	-0,72	-0,64	-0,55	-0,49	-0,55	-0,6	-0,68	-0,73	-0,91	-1,06	-1,02	-0,7	-0,24	0,28	0,63	0,77

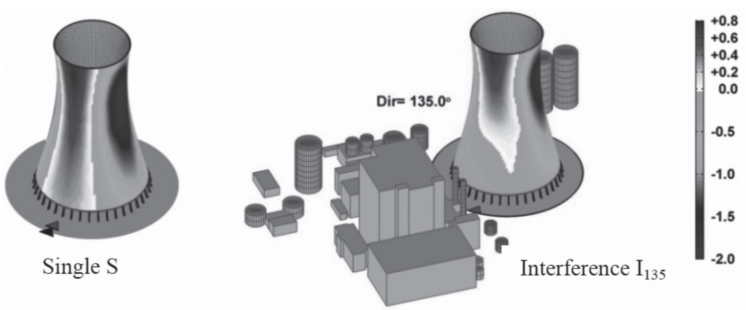
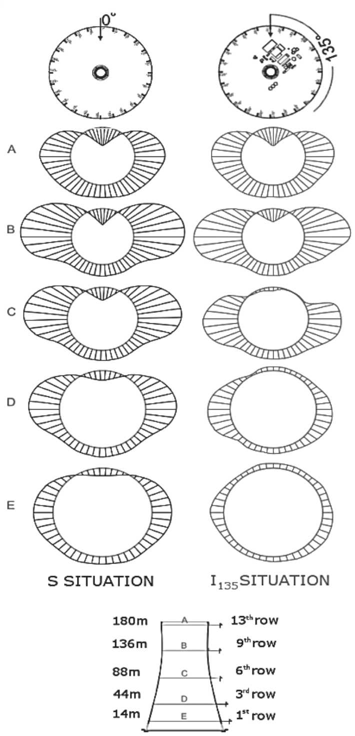
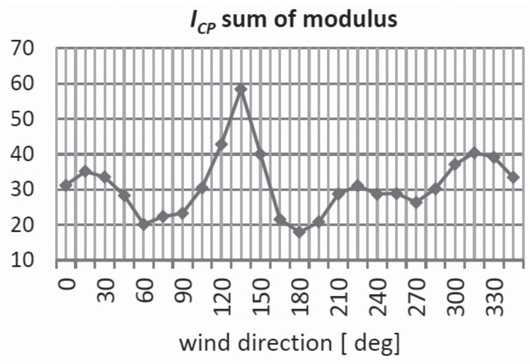


Fig. 2. Results of external pressure coefficient C_{Pe} for single situation S (above) and interference situation I_{135} (below)

a)



b)



$$I_{Cp} = C_{Pe}(\mathrm{S}) - C_{Pe}(\mathrm{I}_{135}) \quad (1)$$

c)

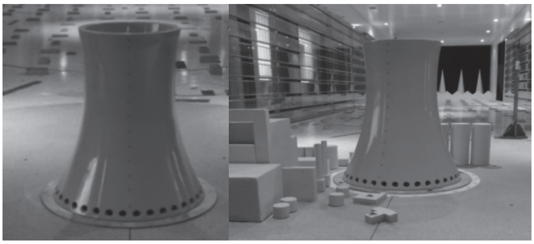


Fig. 3. a) Distribution of external pressure coefficient C_{Pe} in cross sections; b) Diagram of sum of modulus; c) Pictures of cooling tower in wind tunnel

The numeration of meridians is also counterclockwise. The following data show the $C_{Pe}{}^{\mathrm{I}}$ (interferences situation) and $C_{Pe}{}^{\mathrm{S}}$ (single situation) coefficients (according to EC1-4). The coefficients are not the values of the pressure on the surface; they only show the distribution of the pressure.

Due to the amount of data, only the single situation S (wind acting one the cooling tower without surroundings) and Interference situation I_{135} (wind acting on the cooling tower with surroundings from the angle 135°; see Table 1) are presented.

2.2. Comparison between single S and interference I_{135} situation

In single situation the distribution of pressure is line-symmetric with respect to 13th meridian. In the area starting from meridian 4th up to 22nd only negative wind pressure appears with maximum values reached for the sides of tower. The biggest values of positive pressure are located on the 1st windward meridian, near the top of the tower.

When it comes to the I_{135} situation, significant changes in comparision to the single situation are visble. The most observable phenomen is a change of sign from positive to negative pressure. It results in occurance of negative pressure on the whole lower part of circumference otower.

2.3. Conclusions

The main aim of the issue was concerned with interference of wind load acting on a surface of the cooling tower. Disorder of distribution of pressure was affected by power plant facilities located in the surroundings of cooling tower. The greatest differences are related with angle 135°, at which the structure of the tower is obstructed by adjacent power generator building. Detailed results are released in [1] written by the same authors.

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JOZEF ŠVAJLENKA*, MÁRIA KOZLOVSKÁ*

TRANSPORT COSTS OF PREFAB WOOD AND BRICK CONSTRUCTION – COMPARATIVE STUDY

KOSZTY TRANSPORTU PREFABRYKATÓW Z DREWNA I CEGŁY – STUDIUM PORÓWNAWCZE

Abstract

Construction industry has a large share in environmental pollution. In the context of building industry, it is also the transport of building materials and products, which largely contributes to environmental degradation. Construction increasingly promotes wood-based construction systems, thanks to faster construction, better environmental, energy and economic parameters. Prefabricated wood-based panel construction system fully utilizes construction, manufacturing and assembly advantages of the production to the efficiency of the entire construction process. The key moment to increase the efficiency and degree of prefabrication is panel's finishing. Creation of structural elements in the factories allows a reduction in rides to the site. The paper analyzes the transport costs of the model house constructed by the system of traditional brick and panel system based on wood in the context of transport and manipulation of materials in both bearing systems.

Keywords: *wood construction, brick construction, costs analysis*

Streszczenie

Duży udział w zanieczyszczeniu środowiska naturalnego ma przemysł i budownictwo. Produkcja budowlana, jak również transport materiałów i produktów budowlanych, w dużym stopniu przyczyniają się do degradacji środowiska naturalnego. Do budowy obiektów coraz częściej stosuje się prefabrykowane systemy oparte na drewnie strukturalnym. Systemy te charakteryzują się krótszym czasem budowy, mniejszym zużyciem energii i lepszymi parametrami ekonomicznymi. System ściany prefabrykowanej to budownictwo wykorzystujące drewno. Kluczowymi elementami procesu są: zwiększenie wydajności, skrócenie czasu prefabrykacji elementów oraz ich transportu. Tworzenie komponentów konstrukcyjnych w zakładach pozwala na skrócenie czasu transportu na miejsce w stosunku do pojedynczych elementów. W artykule analizowane są koszty transportu i materiałów domów modelowych z drewna i cegły.

Słowa kluczowe: *konstrukcje z drewna, budynek z cegły, analiza kosztów*

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1. Introduction

The growth in freight transport increases the demand for non-renewable sources of energy and increases the production of greenhouse gases. According to the Statistical institute of the Slovak Republic the largest share in emissions and polluting substances within the transport operation in Slovakia is road transport. Individual automobile transport and road freight transport makes up 87% of total emissions.

The building industry has a large proportion in the environmental pollution. Especially it is the transportation of building materials and products which is largely involved in damaging the environment within the building industry. In accordance to the European Directive No. 2010/31 EU, which establishes a common goal to reduce by 2020 the production of greenhouse gases by 20%, the construction sector is highly promising in terms of potential energy savings and greenhouse gas emissions reduction.

In Slovak Republic and in the whole Central Europe as well we are observing an increasing interest in the construction of environmentally friendly materials. These materials certainly include wood, wood-based products and wood-based composites. Besides the fact that wood is one of the so-called renewable raw materials, environmental benefits of modern wood versus heavy ceramic and silicate structure also save the total costs of construction and related production and transport.

2. Wood-based panel construction system

Building constructions based on wood are capable of becoming economically interesting also in our regions, if they effectively manage design, technology, logistics, quality management system in manufacturing and construction. According to Stefko [1] the wooden buildings can be divided into: prefabricated panel constructions, columnar constructions, timbered constructions, skeleton and half-timbered constructions. According to the Association of Wood Processors of Slovak Republic, the most widely used structural systems of prefabricated wooden buildings constructed in Slovakia include panel constructions and columnar construction systems. Therefore, the contribution deals with the panel construction system.

Structural elements – panels (wall, ceil, roof, gable, partition wall) are produced in different stages of completion in the production hall (Fig. 1, Fig. 2) and subsequently transported to the construction site where they are assembled to the structure. Build-up process is characterized by speed and precision. The panel generally consists of a wooden frame of profiled timber, covered on both sides with large-scale plates, filled with thermal insulation material. During the manufacturing of the panels the preparation for installations is incorporated.

Prefabricated construction panel system fully utilizes construction, manufacturing and assembly advantages of the production to the efficiency of the entire construction process. The key moment to increase the efficiency and degree of prefabrication is panel's finishing.

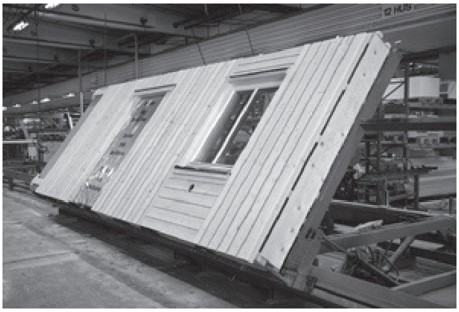

Fig. 1. Production hall of sandwich wall panels (La Vardera)

Fig. 2. Loading wall panels onto a vehicle (Nesbau)

Panel system has enormous potential for increasing efficiency in the design, production and construction phase. Manufacturing can be automated, however to increase the quality of production and to re-implement the construction workmanship is necessary. Bearing system of prefabricated wooden houses is completed within a few days. Other finishing and plumbing work is performed after the assembly of individual elements.

2.1. The proportion of transport costs of panel construction system based on wood

In Slovakia, contribution to the total cost is presented within 1–4% in the low and 2–6% in a high level of completion of design elements. A low level of construction elements completion is a panel without surface treatment, doors and windows with pre-treatments for the installations. The high level of completion is a panel with doors and windows and pre-treatments for the installations and surface treatment. The percentage also depends on the energy standard. The higher mass elements have greater demands on carrying capacity transport mechanisms or need multiple rides to the site. The percentage increases in proportion to the distance of transportation of components.

2.2. Comparative analysis of costs of transporting panel construction system based on wood and traditional brick system

This part of the paper presents a comparative analysis of the two alternatives: constructional and technological systems, applied to the house model. The comparison consisted of a prefabricated panel system and traditional brick system. For this purpose a real project of prefabricated wooden houses was used, on which alternatively the traditional brick system of ceramic fittings was created. The difference between the systems is in vertical and horizontal structures and the thickness of the external insulation. Build-up areas, the finishing work and technical equipment including energy standard were the same.

Building model is designed as a semi-detached house. It has a simple shape with two floors and a flat roof. Building area is in the shape of a square 12 × 12 m floor area of one flat 144 m^2 and a building space of all building 864 m^3. The house is based on the foundation strips. In a brick building a more massive foundation strips are intended. External wooden walls are 270 mm width and a thickness of masonry construction is 440 mm. Contact insulation system is chosen on the wall for both variants, on wooden house at 120 mm thick and 180 mm on masonry construction. The ceiling structure of wooden system consists of a wooden beam ceiling; the brick ceiling structure is reinforced with concrete slab. Roof structure in both variants is a flat roof with a slope of 5%. The roof has a wooden structure with thermal insulation, which guarantees the required thermal resistance. In both variants there is waterproofing on reinforced concrete floor slabs, 100 mm insulation and 70 mm concrete screed. Windows and entrance doors are glazed with insulating triple glazing. The house has electric underfloor heating.

The analysis focuses on the cost of the machine for transport and installation of materials and products needed for construction of buildings implemented by the assembled construction of a traditional brick construction system. On the basis of calculations derived from the weight of materials and structural elements necessary for the rough construction Fig. 3 is compiled. Comparison between the weight of the materials needed to construct rough construction is disaggregated down in vertical structures, horizontal structures and roofing.

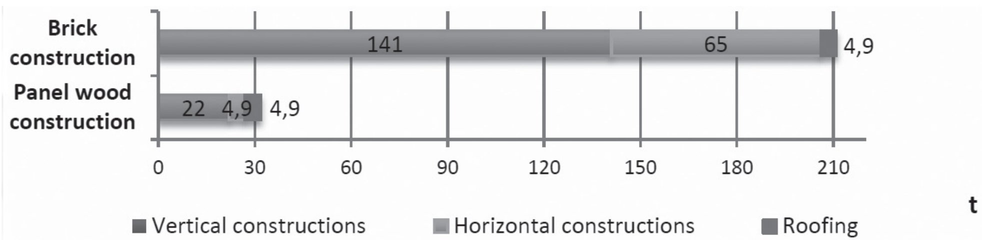

Fig. 3. Compare the weight of construction materials and products

Fig. 3 shows lower weight of wood rough construction in comparison with classic wooden brick by up to 85%. Significantly lower weight of wood construction is favourably reflected in the transport, in decreasing of harmful emissions and energy consumption. Also, lower weight wood construction reduces complexity of foundation and thus the financial cost.

Table 1 presents the costs of transporting of building materials and products, calculated per 1 km and rent mechanisms necessary for landing and incorporation of materials and components in construction.

Comparison of transport costs involved in the foundation structures and rough construction, the implementation of prefabricated wooden and brick buildings shown in Table 1 presents the 44% difference between structural variants calculated per 1 km of transport in favour of wooden houses. Other (fixed) costs independent of the number of km, the design of these systems at almost the same. Number of rides of mechanisms for wooden variation is reduced by 37%. In both scenarios a concrete mixer is needed, as well as a concrete pump, truck with hydraulic boom to manipulation with reinforcements and timber for foundation and roofing. The main differences are the transport and manipulation with masonry materials and wall panels.

Table 1

Comparative analysis of costs of transporting panel construction system based on wood and traditional brick system

Specification of mechanism				UM	Vo-lume	The number of rides (the quantity transported)	Costs of UM (EUR)	Costs of wood construction (EUR)		Costs of brick construction (EUR)	
								to 1 [km]	others (fixed) costs	to 1 [km]	others (fixed) costs
Foundations, vertical constructions	Concrete	Transport	mobile concrete mixer	[m³]	110	19	7,2	×	792	×	×
					145	25		×	×	×	1044
		Car delivery		[km]	1	–	2	38	×	×	×
					1	–		×	×	50	×
		Assembly	putzmeister	[hour]	4	–	80	×	320*	×	×
					10	–		×	×	×	800*
		Car delivery		[km]	1	1	2	2	×	–	×
					1	3		×	×	6	×
	Armature	Transport	truck with hydraulic boom	[km]	1	1 (5,5 [t])	5	5	×	×	×
					1	1 (9 [t])		×	×	5	×
		Unloading		number of unloading	1	–	30	×	30	×	×
					1	–		×	×	×	30
	Shuttering	Transport	truck with hydraulic boom	[km]	–	–	5	×	×	×	×
					1	1 (165 [m²])		×	×	5	×
		Unloading		number of unloading	–	–	30	×	×	×	×
					1	–		×	×	×	30
	Ceiling panels of wood con-struction	Transport	truck	[km]	**	** (4,9 [t])	–	**	×	×	×
					–	–		×	×	×	×
		Unloading, manipula-tion	lifting me-chanism	[hour]	***	–	–	***	×	×	×
					–	–		×	×	×	×
Vertical constructions	Wall panels of wood construc-tion	Transport	truck	[km]	1	2 (22 [t])	5	10	×	×	×
					–	–		×	×	×	×
		Unloading, manipula-tion	lifting me-chanism	[hour]	16	–	60	×	960*	×	×
					–	–		×	×	×	×
	Masonry material	Transport	truck with hydraulic boom	[km]	–	–	5	×	×	×	×
					1	7 (141 [t])		×	×	35	×
		Unloading		number of unloading	–	–	30	×	×	×	×
					7	–		×	×	×	210
Roofing	Timber	Transport	truck with hydraulic boom	[km]	1	1 (4,9 [t])	5	5	×	×	×
					1	1 (4,9 [t])		×	×	5	×
		Unloading		number of unloading	–	–	30	×	***	×	×
					1	–		×	×	×	30
Total transport costs to 1 km and others (fixed) costs								**60**	**2102**	**106**	**2144**
The number of rides								24		38	

Note: UM – unit of measure, * lease, ** transported together with wall panels, *** unloading with wall panels

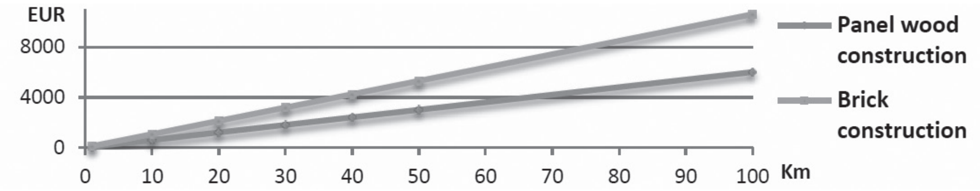

Fig. 4. Effect of distance on transport costs of wooden panel and brick construction

Fig. 4 shows a significant difference between variants depending on transport distance. For example, in this case, at a distance of 100 km, the difference is 4600 EUR.

3. Conclusions

The presented comparative case study has revealed differences between prefabricated wooden buildings made of prefabricated wall panels and classic brick building in the context of the cost of transport of building materials and structures, including their installation. Significant advantages of the prefabricated wooden houses are lower weight compared to traditional masonry construction by about 85% in favor of the wood construction. Significantly lower weight of wood construction is very favourably reflected in transport, decrease of harmful emissions and energy consumption. Also, lower weight wood construction reduces complexity foundation and thus the financial cost. Prefabrication of structural components can reduce the number of rides to the construction site by 37%. The share of transport costs of construction elements in the context of the total cost of wooden houses is not significant for smaller transport distances, but at larger distances, this proportion increases proportionally and is reflected in the total cost of construction.

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MATEUSZ SZUBEL*

IMPACT OF THE AIR NOZZLES CONFIGURATION IN THE BIOMASS BOILER ON THE CARBON MONOXIE EMISSION

WPŁYW KONFIGURACJI DYSZ POWIETRZNYCH KOTŁA NA BIOMASĘ NA EMISJĘ TLENKU WĘGLA

A b s t r a c t

The aim of the research was to evaluate possibility to reduce the emission of the carbon monoxide (CO) in the biomass boiler, by application of a newly-designed secondary air supply system. The approach implied the practical tests of the real biomass boiler installation and numerical analyses of chosen optimizing solutions of the secondary air distribution system. Promising modifications have been implemented in the current design and tested. Results of the numerical and experimental studies have been compared and discussed.

Keywords: *straw combustion, CO emission, CFD*

S t r e s z c z e n i e

Celem badań była ocena możliwości redukcji emisji tlenku węgla (CO) w czasie spalania słomy w dedykowanym kotle wsadowym, poprzez modyfikację systemu dystrybucji powietrza wtórnego. Wykonano serię eksperymentów z wykorzystaniem instalacji doświadczalnej kotła, a także analizy numeryczne uwzględniające wybrane rozwiązania optymalizacyjne w zakresie dystrybucji powietrza wtórnego. Rozwiązanie dające obiecujące wyniki obliczeń zaimplementowano w rzeczywistej jednostce. Wyniki analizy numerycznej i prac doświadczalnych zostały porównane i przedyskutowane.

Słowa kluczowe: *spalanie słomy, emisja CO, CFD*

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1. Introduction

The process of lignin-containing cellulosic fuels gasification is similar to classic combustion, but it occurs in case of insufficient amount of oxygen (less than enough for the stoichiometric combustion) [1]. For equivalence ratios below 0.1, the pyrolysis occurs. In such case only a modest fraction of the biomass energy is found in the gaseous product – the rest being in char and oily residues. If the equivalence ratio is between 0.2 and 0.4, the process is called a proper "gasification". Such process is characterised by the highest level of energy transfer to the gas [2].

In case of the biomass boilers, products of the gasification are burned in separated area of the combustion chamber, often called a secondary combustion chamber. Inefficient process of the post-combustion leads to high incomplete combustion losses and high emission of the CO to the atmosphere. It is possible to improve the combustion process by providing efficient mixing of the gas fuel and the oxidant, preventing rapid decrease of the temperature in the secondary combustion chamber and extending the time of the fuel presence in the combustion area.

2. Dynamics of changes of the CO emission during combustion proces in the biomass batch boiler

In case of the batch biomass boilers characterised by the simple construction, high emission of carbon monoxide is a significant problem, which currently is the goal of studies described in many papers. In [3], authors describe works devoted to the optimisation of the air manifold, which provides the primary and the secondary air to the gasification process, which occurs in the primary chamber of the boiler and post-combustion of the flammable products in the secondary chamber. Specifics of the combustion in the biomass batch boilers has been shown in [4]. Moreover, the process of the biomass combustion strongly depends on the type and size of fuel, specifics of device and the process conditions, which is described in [5, 6].

Fig. 1 presents the example result of the experimental test, performed on the installation of the 180 kW straw-fired boiler (1/4th of the nominal fuel load – about 40 kg). In the first 5 minutes the air fan efficiency was increased to 100% (0.18 m^3/s) and it was decreased to 0 after 70 minutes of the boiler operation. The water flow through the water jacket was constant (about 8 m^3/h). Temperature on water inlet to the water jacket was about 323K. Temperature distribution in the selected points of the primary and secondary combustion chamber, as well as the CO emission analyses have been performed.

The symbols of the sensors included on the chart legend correspond to the given locations of the measurements: DR2 – central point of the boiler door region, PR3 – the top of the secondary combustion chamber (outlet of the exhaust to the ash separator), TY – the bottom of the secondary combustion chamber (inlet of the CO to the region of the post-combustion). Through the first 5 minutes, the process of ignition occurs, in which the reactions are random. After the rapid growth of the temperature, the nominal process of the gasification (and combustion) takes a place to about 30th minute. Then the stage of the smoldering of the solid residues in the primary combustion chamber occurs till the end of the fuel burning cycle.

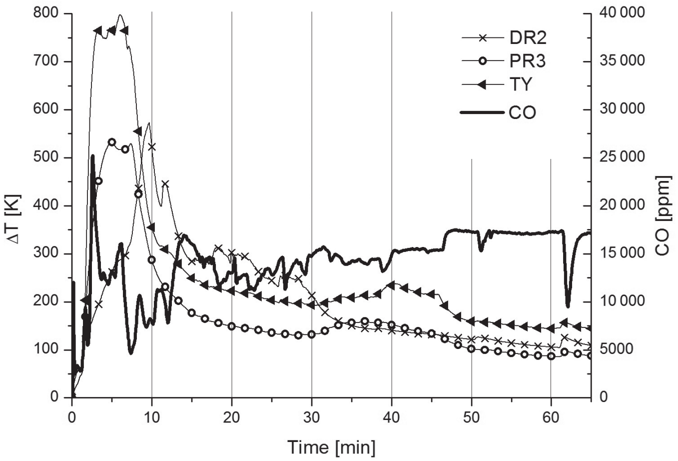

Fig. 1. Dynamics of the temperature variation in the primary and the secondary combustion chambers and the CO emission, recalculated to the 13% of the oxygen in the exhaust

To investigate the possibility of the reduction of CO emission during the whole process of the straw combustion, the numerical and experimental methods have been used simultaneously, to find a simple method of the post-combustion improvement and to evaluate usefulness of the numerical computations results in the optimisation process of the heating unit.

3. Optimization of the combustion process in the small biomass-fired boiler

Based on the result of the experimental tests partially presented in the previous chapter, the secondary air feeding system has been identified as ineffective. As a first step of the optimisation process, the numerical CFD (computational fluid dynamics) model of the CO post-combustion in the current state of the biomass boiler (Fig. 2a) has been developed.

To analyse the process of the CO post-combustion in cases of the current and modified design of the air feeding system, the commercial software ANSYS Workbench 15 has been applied. Spatial geometry of the secondary chamber has been developed in Autodesk Inventor 2015 software. It was decided, that it is justified to ignore the primary chamber, because the moment when the chamber is almost full of straw in the form of compressed blocks was considered. The geometry has been exported through the ANSYS DesignModeler to the ANSYS Meshing, where the discretization of the computational domain has been carried out. Total number of the elements was $1.3 \cdot 10^6$.

Because of non-homogeneous air distribution along the pipes of the air manifold, the primary and secondary air inlets have been set as an individual boundary conditions. The highest value of the mass flow was set for the central pipe, located on the symmetry plane of the geometry (Fig. 2b) and for the secondary air nozzles, 0.0237 kg/s and 0.0239 kg/s, respectively. The mass flow for other ducts oscillate around 0.0235 kg/s. The boundary conditions assumed for the CFD model are presented in Fig. 2.b, where the SAN is "secondary air nozzle" and PAN are "primary air nozzles".

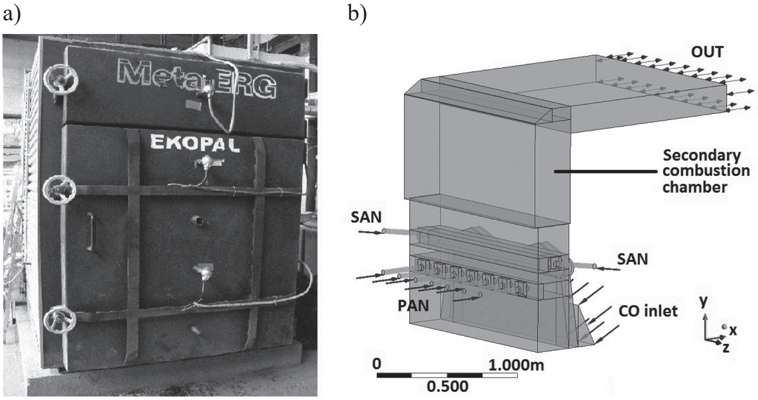

Fig. 2. Straw-fired boiler on the measurement stand (a) and the domain of the secondary combustion chamber (modified case) defined in the numerical model (b)

To simulate the chemical reaction of the O_2 and CO, the eddy dissipation model of combustion has been applied, which is based on the Arrenius equation. The *k*–ε model of turbulence has been applied, due to the lack of the inflation layer. ANSYS CFX solver, which is based on the finite volumes technique has been applied to perform the computations.

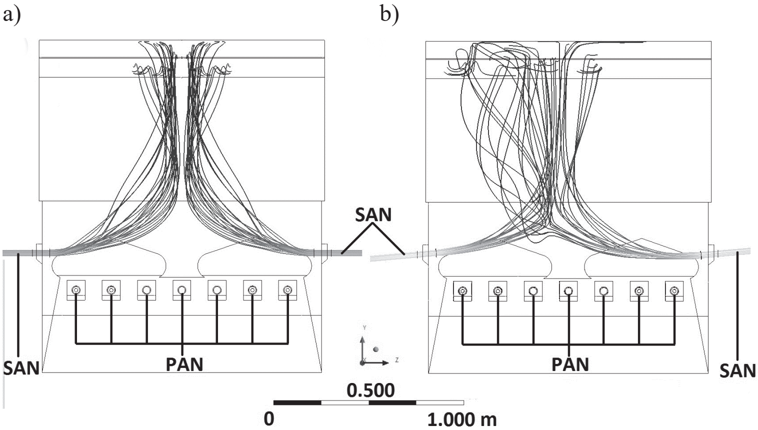

Fig. 3. Result of the numerical simulation of the secondary air fluxes in the secondary combustion chamber: a) current state of the heating unit, b) proposed modification of the secondary air nozzles

Due to the goal of study – comparison of the CO post-combustion in case of two different methods of the secondary air feeding, the steady state CFD model has been applied. Constant mass flux of the CO as an inlet boundary condition has been assumed (Fig. 2b). Fig. 3a presents the result of the computation in range of the secondary air fluxes in current state of the studied device. Due to the location of the nozzles opposite each other and moderate mass flow rates, the flow in the centre of the combustion chamber is laminar, which results in high concentration of the oxygen and CO in the exhaust.

It was found, that for the better degree of the O_2 and CO mixing, it is necessary to change the direction of the secondary air fluxes. It was decided, that the simplest solution to achieve higher efficiency of the reactants mixing and consequently of the post-combustion is to deflect nozzles. CFD simulation with deflection of the nozzles by 5° in horizontal and vertical axis has been carried out. The result of the modification is shown in Fig. 3b.

a) b) c) d)

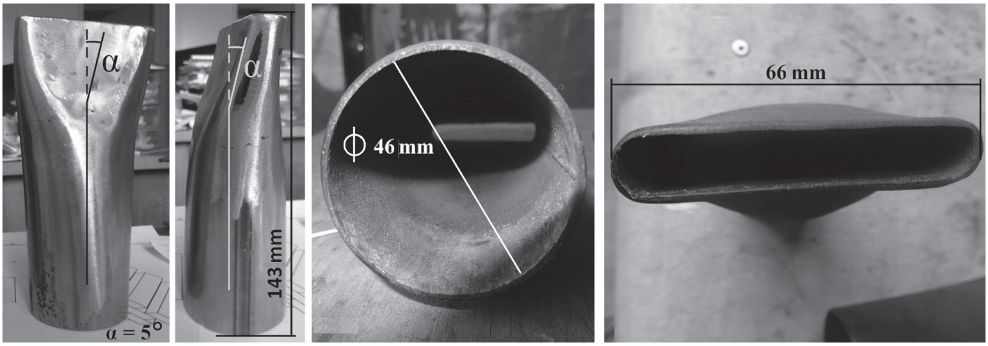

Fig. 4. Nozzles, which are responsible for deflection of the secondary air fluxes in the experiment

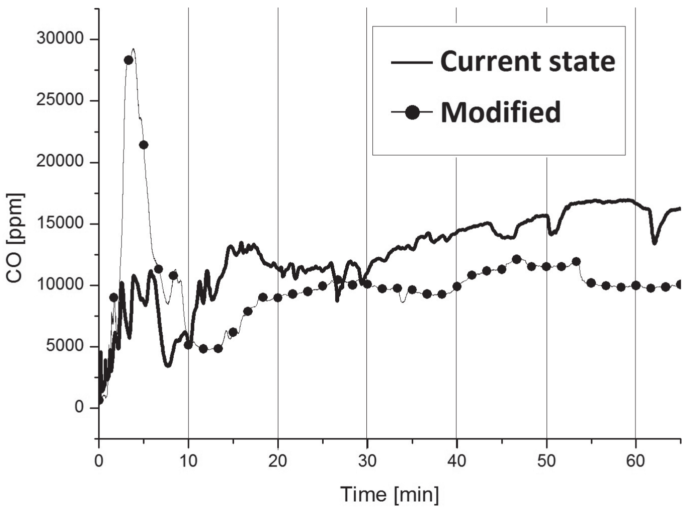

Fig. 5. Comparison of the averaged dynamics of the CO emission changes in case of the current state of the heating unit and after modification of the secondary air nozzles

In result of the nozzles deflection, 3.8% points of O_2 reduction and 2.3% points of CO_2 increase in the exhaust (with equal inlet CO mass flux) have been achieved in case of the CFD simulations. Based on the promising results of the computations, the deflected nozzles presented in Fig. 4 has been developed and applied as caps for the current secondary air ducts. Three series of the experimental tests have been carried out both for the base state of the boiler and for the deflected nozzles. Each series consisted of the preliminary combustion (warming up of the boiler) and proper experiment and they were conducted in the same conditions (fan efficiency, mass of the fuel etc.). The emission levels from experimental series for the first and second case of the secondary air feeding have been averaged and presented in Fig. 5. After the stage of ignition (to the 5th min. of the experiment), permanent effect of the CO emission reduction has been achieved, which was possible by intensification of the turbulences in the area of the post-combustion.

4. Conclusions

The process of biomass combustion in the batch boiler requires to provide efficient mixing of the gasification products and the oxidant. To achieve satisfying levels of the CO concentration in exhaust it is reasonable to apply deflected secondary air nozzles, which improve the flow turbulences, resulting in the higher efficiency of the chemical reactions. Designed configuration of the nozzles can be applied in form of the air ducts, instaled in the new-designed units, as well as in form of the caps, implemented in the existing heating units. In the second of the mentioned cases, modification is efficient and economically reasonable (cheap solution). The optimal angle of the deflection, as well as shape of the diffusors have to be determined, which will be achieved using CFD modeling as the next stage of the studies. Results of the computations will be compared with data from experiments, performed on the boiler with implemented solutions.

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TECHNOLOGICAL AND ECONOMICAL ANALYSIS OF SELECTED WOOD-BASED CONSTRUCTION SYSTEMS

ANALIZA TECHNOLOGICZNYCH I EKONOMICZNYCH WYBRANYCH SYSTEMÓW NA BAZIE DREWNA

Abstract

The aim of the paper is to present the results of a comprehensive analysis of three selected wood-based construction systems from design, technological and economical point of view. The selected construction systems imply the stick frame construction system, the structural insulated panels and the standard panel construction system. The optimal construction system from the perspective of a customer is evaluated on the basis of the multi-criteria optimization method. The typified design of the family house Largo 85 served as a model to present and analyze the parameters such as construction cost, construction time, heat transfer coefficient of external walls and air soundproof of walls. The mentioned criteria are the most significant for a customer when making a decision about the most suitable wood-based construction system.

Keywords: *wood-based buildings, construction cost, construction time, structural insulated panels, frame construction system*

Streszczenie

Celem pracy jest przedstawienie wyników kompleksowej analizy trzech wybranych systemów budowlanych na bazie drewna z projektowego, technologicznego i ekonomicznego punktu widzenia. Wybrane systemy konstrukcyjne oznaczają: system konstrukcji szkieletowej, izolowane panele strukturalne oraz standardowy system konstrukcji paneli. Optymalny system konstrukcji z punktu widzenia klienta jest oceniany na podstawie wielokryterialnej metody optymalizacji. Charakterystyczna konstrukcja rodzinnego domu Largo 85 służyła jako model do przedstawienia i analizy parametrów takich jak: koszt budowy, czas budowy, współczynnik przenikania ciepła ścian zewnętrznych i dźwiękoszczelne powietrza ścian. Wymienione kryteria są najbardziej znaczące dla klienta przy podejmowaniu decyzji o systemie budowy na bazie drewna.

Słowa kluczowe: *budynki na bazie drewna, koszt budowy, czas budowy, strukturalne panele izolowane, system konstrukcji szkieletowy*

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1. Introduction

Nowadays, the public interest in healthy living, healthy housing, fast construction and low operating cost housing increases. Current trends in construction reflect it and natural construction materials as wood and materials from natural sources are being used more often. Application of wood into construction has a long tradition in all European countries. Much attention has been paid to development and improvement of wooden construction [1]. Currently, there are available and preferred several wood-based construction systems. The systems differ by structure, composition of materials as well as by appearance [2].

Given the stability, durability and renewability of wooden materials, as well as the targets for a greener, sustainable and low-carbon construction industry, a big potential to increase the use of wood in house construction has been identified [3]. Wood as a building material is seen to have low impacts from the perspective of low water pollution, low green house gas emissions, low air pollution and low solid waste compared to concrete and steel [4]. Several building industry professionals has described industrialized wood building methods as promising for various reasons as dry pre-fabrication increased quality, speed of on-site assembly, requiring less personnel on site [5, 6]. In Slovakia, prefabricated wood-based building systems are the most preferred and expanded from all the modern methods of construction. The constant expansion of wood construction in architecture coincides with the development of new building materials and new building systems. One of the advantages of wood houses is the variability of structures and composition of the walls, which can be designed as a low cost, low energy and passive models.

2. Materials and Methodology

In the study, presented in the paper, three wood based construction systems were compared with one another. The systems include:
– the panel construction system – variant 1
– the structural insulated panels (SIPs) – variant 2
– the stick frame construction system – variant 3

2.1. The panel construction system and the stick frame construction system

The wooden house is built of large panels, manufactured in a factory and assembled on site. The wall sections in the stick frame construction system are identical with the panels of the panel construction system. The thermo-technical and acoustic characteristics of the structures are also identical. The panel construction system is characterized by the factory production and assembly on site, the stick frame construction system is characterized by necessary on-site carpentry work. This is reflected in the construction time, construction cost and in demands of machines and equipment. Three selected construction systems were compared by the mentioned parameters (construction time, construction cost, and demands of mechanization) point of view. The external panels provided with basalt thermal insulation are faced by fibre gypsum boards Fermacell and have windows installed in the factory.

2.2. SIPs – The structural insulated panels

The construction system SIPs is characterized by modern sandwich panel provided with the hardened polystyrene in the core and faced by oriented strand boards (OSB). Unlike the conventional wooden construction, the panel does not involve any wooden frame.

2.3. Characteristics of the family house and selection of wood based construction systems

The typified family house Largo 85 (Fig. 1) served as the reference house for comparison of selected construction systems. In order to reveal an optimal variant for the potential customer, the three variants of the reference house, characterized by the three construction systems, were designed. The reference house Largo 85 is a single-storey house with sloping gabled roof. The dimensions of the house are: 11 m (length) and 7.7 m (width) and the usable area is 70.73 m^2. In the next part of the paper the thermo-technical and acoustic parameters of the house are presented, as well as the total construction cost, the time schedule and the total construction time of the house in three selected (above mentioned) construction systems. Based on the multi-criteria optimizing method, the optimal construction system for the potential customer has been determined. The results of the study are presented in the next parts of the paper.

Fig. 1. The reference family house Largo 85

3. Results and Discussion

3.1. The thermo-technical parameters

The thermo-technical assessment of the building involves the course of isotherm, the course of temperature and assessment of water vapour diffusion. Moreover, the thermal resistance and the heat transfer coefficient of the structure were estimated. The estimation, based on the standards STN EN ISO 6946 and STN 73040, was made by the software Area 2010 and Teplo 2010. The external temperature is –15°C and the internal temperature is +20°C.

The boundary conditions R_{si} = 0.13 $m^2 \cdot K/W$; R_{se} = 0.04 $m^2 \cdot K/W$. The calculation value of the thermal resistance R = 7.67 $m^2 \cdot K/W$. The calculation value of the heat transfer coefficient U = 0,127 $W/m^2 \cdot K$, and the amount of diffusing water vapour $Gd = 2.861 \cdot 10^{-9}$ kg/m^2s (Table 1). From the estimation it is clear that there is no water vapour condensation of the structure in the specified design temperature. The calculation value of the thermal resistance of the SIPs construction system R = 7.500 $m^2 \cdot K/W$. The calculation value of the heat transfer coefficient U = 0.130 $W/m^2 \cdot K$ and the amount of diffusing water vapour $Gd = 2.6 \cdot 10^{-9}$ kg/m^2s (Table 2). From the estimation it is clear that there is no water vapour condensation of the structure in the specified design temperature.

Table 1

The composition of the external wall of panel and stick frame construction system

No.	Type of the layer *from interior to exterior*	Thickness *d* [m]	λ [W/m·K]
1	Fibre gypsum board Fermacell	0.015	0.320
2	Wood frame + insulation Isover	0.060	0.036
3	Vapour barrier – Tyvek sheet	0.0002	0.350
4	Wood frame + insulation Isover	0.120	0.036
5	Fibre gypsum board Fermacell	0.015	0.130
6	Bonding mortar Baumit	0.003	0.800
7	Polystyrene EPS	0.100	0.040
8	Bonding mortar Baumit + glass fibre mesh lep. malta+sk.sieťka	0.003	0.800
9	Silicone plaster Baumit	0.002	0.700

Table 2

The composition of the external wall of SIPs construction system (EUROPANEL manufactory)

No.	Type of the layer *from interior to exterior*	Thickness *d* [m]	λ [W/m·K]
1	Fibre gypsum board Fermacell	0.015	0.320
2	Air space + CD profile	0.030	0.147
3	Vapour barrier – Tyvek sheet	0.0002	0.350
4	Oriented strand board – Europanel	0.015	0.130
5	Polystyrene EPS – Europanel	0.180	0.040
6	Oriented strand board – Europanel	0.015	0.130
7	Bonding mortar Baumit	0.003	0.800
8	Polystyrene EPS	0.100	0.040
9	Bonding mortar Baumit + glass fibre mesh	0.003	0.800
10	Silicone plaster Baumit	0.002	0.700

3.2. The acoustic characteristics

The value of theoretical airborne sound insulation of external wall is 47.6 dB in both, panel and stick frame construction system. In SIPs construction system it is 38.8 dB.

3.3. The construction time

The construction time is also one of important parameters in selecting an optimal construction system. The time schedules of all three variants were prepared, the results of the schedules are presented in Fig. 2. The construction time of the house (only framework structure, without finishing processes) in the variant of the panel construction system is 11 days. The construction time of the house (only framework structure, without finishing processes) in the variant of the stick frame construction system is 32 days. The construction time of the house (only framework structure, without finishing processes) in case of the SIPs construction system is 26 days.

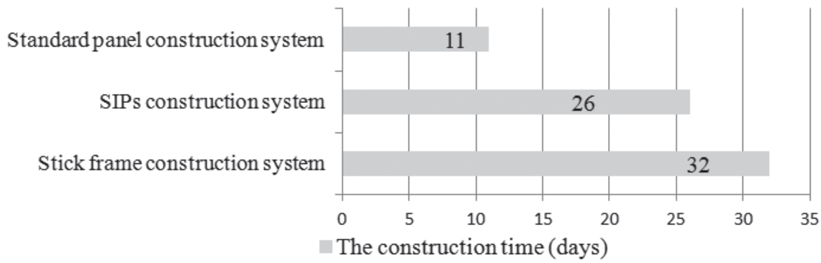

Fig. 2. The construction time of the house in three different construction systems

3.4. The cost analysis

In order to compare the construction cost of the house in three different variants, the cost calculations were prepared. The construction cost involves the cost of the frame structure, facade and windows installation. The cost of three different variants (panel construction system, SIPs construction system and stick frame construction system) are similar. The construction of external and indoor walls is different due to different construction systems. The roof structure and the facade are the same. The construction costs of the house include: a) material cost, b) labour cost, c) site equipments cost and d) cost of material transport into site. The results are presented in Fig. 3.

The stick frame construction system – the main items in the cost calculation of external and indoor walls are: timber, insulation material and fibre gypsum boards Fermacell as the cost of material and the cost of wood-based frame structure erecting and facing. The different items in the cost calculation, divided into material cost, labour cost, site equipments renting cost and transport cost are in Fig. 3 presented in percentages. In the stick frame construction system, the material cost is 66.8% of the total construction cost and the labour cost is 30.39% of the total construction cost. The remaining 2.81% of the total construction cost responds to material transport cost and cost of site equipments renting. The total construction cost of the house (without finishing processes) is 31.505 Eur.

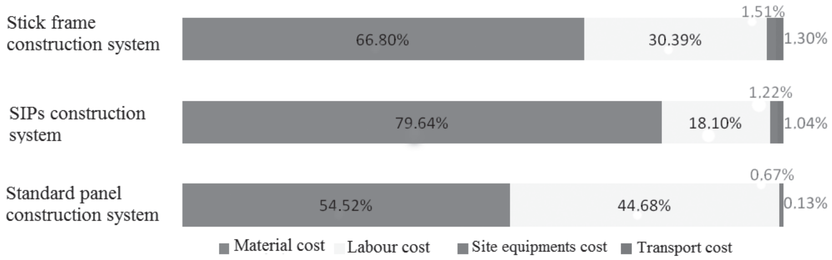

Fig. 3. Comparison of the construction cost of three different construction systems

The standard panel construction system – it is surprising that the labour cost is almost 45% of the total construction cost**.** That is because the cost includes the operating cost of manufacturer (automatic production line, rental cost etc.). The cost of material is 55% of the total construction cost. The total construction cost of the house in this variant of construction system is 33.568 Eur.

The SIPs construction system – the main items of the external walls and indoor walls are represented by the structural insulated panels (SIPs), manufactured by Europanel Manufactory. The cost of material is almost 80% of the total construction cost and the labour cost is a little more than 18% of the total construction cost. While the labour capacity of this construction system is low, the cost of material (Structural Insulated Panels) is excessively high. The total construction cost of the house in the variant of the SIPs construction system is 34.379 Eur.

Table 3

The values of the total utility of three different variants

Conjunction of nominal scale of optimising criteria and corresponding index coefficient K_{ij}								Total utility
	C1	C2	C3	C4	C5	C6	C7	
Stick frame construction system	0.1400	0,20515	0.05974	0.00136	0.00095	0.00074	0.4000	0.80794
SIPs construction system	0.11412	0.2100	0.07396	0.00169	0.00108	0.00086	0.36656	0.76827
Standard panel construction system	0.1400	0.20515	0.1750	0.0025	0.0025	0.0025	0.37541	0.90307

Based on the multi-criteria optimization method, the optimal wood-based construction system for a potential customer is defined and the order of the construction system variants is determined. The scales of the criteria of decision making method: the designing criteria 35%

(i.e. C1 – acoustic characteristics 40% and C2 – thermo-technical characteristics 60%), the technological criteria 25% (i.e. C3 – construction time 70%, C4 – total labour capacity 10%, C5 – demands on site equipments 10%, C6 – transport of materials 10%) and the cost criteria 40% (i.e. C7 – the total construction cost of the house without finishing processes 100%). In Table 3 the results of determining the total utility of three different construction systems are presented (stick frame, SIPs and standard panels). The method of index coefficients was applied. Based on the results, the optimal variant is the one with the highest value of the total utility.

Based on the results, the highest rate of the total utility of the construction system from the presented criteria point of view is in the variant of the standard panel construction system (0.90307). Under these conditions, the standard panel construction system presents the optimal variant of the wood-based house for a potential customer. The SIPs construction system is the system with the lowest total utility (0.76827).

4. Conclusions

The three selected wood-based construction systems are analyzed in the paper from technological, design and economic point of view. Based on the multi-criteria optimising method, the optimal variant of wood-based house from the perspective of a potential customer is determined. The three different variants were assessed and compared in terms of construction cost, construction time, thermo-technical parameters and acoustic characteristics. These construction parameters play an important role in deciding for the most suitable type of the construction system of the house. Based on the results, the standard panel construction system, with the highest total utility, was determined as the optimal one.

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