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# CONTENS

## Source Coding and Data Compression

- Olena Kapustian, Oleksandr Nakonechnyi*
1. Approximate Estimation of Functionals of the Solutions of Parabolic Equation under Nonlinearity in Output 16
- Oleksandr Yudin, Yuliia Boiko, Ruslana Ziubina, Serhii Buchyk, Vitaly Tverdokhle, Svitlana Beresina*
2. Data Compression Based on Coding Methods with a Controlled Level of Quality Loss 22
- Victoriya Himenko, Albert Lekakh, Victoria Dymchuk, Natalia Korolyova, Dmytro Zhuikov, Roman Puhachov*
3. Decoding Technology for Compressed Videodata in Infocommunication Systems 27
- Vladimir Barannik, Yuriy Ryabukha, Anton Sorokun, Anna Hahanova, Maksym Parkhomenko, Oleksandr Dodukh*
4. Developing a Method of Composing Key Components of a Video Image Based on the Integration of Their Code Structures 31
- Oleksandr Yudin, Ruslana Ziubina, Serhii Buchyk, Oleg Frolov, Olha Suprun, Natalia Barannik*
5. Efficiency Assessment of the Steganographic Coding Method with Indirect Integration of Critical Information 36
- Dmitry Barannik, Fustii Vadym, Vitaliy Tverdokhle, Oleksandr Slobodyanyuk, Dmytro Havrylov, Igor Shevchenko*
6. Evaluation the Potential Performance of the DCT- Transformants Non-Equilibrium Positional Encoding Method 41
- Victor Krasnobaev, Victoria Popenko, Tetiana Kuznetsova, Kateryna Kuznetsova*
7. Examples of Usage of Method of Data Errors Correction which are Presented by the Residual Classes 45
- Oleksandr Lefterov, Oleg Naguliak, Iryna Natreba, Serhii Radchenko, Oleksandr Sudakov, Yuri Suleimanov*
8. Processing Technique of Weighted Data to Improve Assessment of Latent Information 51
- Dmitriy Klyushin*
9. Randomness of Quantum Random Bit Generators 56
- Veda Kasianiuk, Petro Kuliabko, Vasyl Tereshchenko, Yaroslav Tereshchenko*
10. Refactoring as a Technique for Transformation IMS-Queries into SQL-Queries 62

- Hanna Ukhina, Valerii Sytnikov, Pavel Stupen, Oleh Strelcov, Iryna Yakovleva*
11. Signal Processing in the Restructuring of a Computer System Bandpass Frequency-Dependent Component to Eliminate the Internal Combustion Engine Detonation **66**
- Anatoly V. Anisimov, Igor O. Zavadskiy*
12. Splittable Data Compression Codes **71**
- Oleksandr Nakonechnyi, Anatoliy Pashko, Olena Kapustian, Taras Zinko, Iuliia Shevchuk*
13. Statistical Simulation of the Information Warfare **75**
- Victor Krasnobaev, Sergey Koshman, Anna Kononchenko, Kateryna Kuznetsova, Tetiana Kuznetsova*
14. The Formulation and Solution of the Task of the Optimum Reservation in the System of Residual Classes **81**
- Volodymyr Osadchyy, Yevgen Osadchyy, Vasyl Tereshchenko, Oleksandr Derevianchenko, Oleh Horbunov*
15. Transformer Timer Coding Technology **85**
- Vladimir Barannik, Ivan Tupitsya, Iryna Gurzhii, Valeriy Barannik, Sergiy Sidchenko, Oleg Kulitsa*
16. Two-Hierarchical Scheme of Statistical Coding of Information Resource Data with Quantitative Clustering **89**
- Anatoly V. Anisimov, Andrey Novokshonov*
17. Verifiable Arithmetic Computations Using Additively Homomorphic Tags **93**

## **Network Information Theory**

- Oleksandra Aleksandrova, Yevgen Bashkov*
1. 3D Face Model Reconstructing from its 2D Images Using Neural Networks **98**
- Andrii Sobchuk, Yurii Kravchenko, Maksym Tyshchenko, Piotr Gawliczek, Olesia Afanasyeva*
2. Analytical Aspects of Providing a Feature of the Functional Stability According to the Choice of Technology for Construction of Wireless Sensor Networks **102**
- R. Tovkach, Yu. Kharkevych, I. Kal'chuk*
3. Application of a Fourier Series for an Analysis of a Network Signals **107**
- Olena Starkova, Kostiantyn Herasymenko, Sergii M. Korotin, Volodymyr Afanasiev, Anastasiia Lisnyk*
4. Development of Recommendations for Ensuring Security in a Corporate Network **111**
- Olexandr Laptiev, German Shuklin, Spartak Hohonianc, Amina Zidan, Ivanna Salanda*
5. Dynamic Model of Cyber Defense Diagnostics of Information Systems with the Use of Fuzzy Technologies **116**



	<i>Yuri Kravchenko, Olga Leshchenko, Nataliia Dakhno, Oleksandr Trush, Oleksandr Makhovych</i>	
6.	Evaluating the Effectiveness of Cloud Services	120
	<i>Olena Verenysh, Sergiy Bezshapkin, Ihor Vasyliev, Danylo Verenysh</i>	
7.	GIS-technologies Using for Spatial Data Analyse of the Road Traffic Accidences on the Example of Kyiv	125
	<i>Galina Kirichek, Dmytro Kyrychek, Svitlana Hrushko, Artur Timenko</i>	
8.	Implementation the Protection Method of Data Transmission in Network	129
	<i>Volodymyr Saiko, Volodymyr Domrachev, Dmitry Gololobov</i>	
9.	Improving the Noise Immunity of the Inter-Satellite Communication Line of the Leo-System with the Architecture of the "Distributed Satellite"	133
	<i>Heorhii Loutskii, Artem Volokyta, Pavlo Rehida, Oleksandr Honcharenko, Bohdan Ivanishchev, Artem Kaplunov</i>	
10.	Increasing the Fault Tolerance of Distributed Systems for the Hyper De Bruijn Topology with Excess Code	137
	<i>Anatoliy Rokochinskiy, Pavlo Volk, Lyudmyla Kuzmych, Vasyl Turcheniuk, Liubov Volk, Andriy Dudnik</i>	
11.	Mathematical Model of Meteorological Software for Systematic Flood Control in The Carpathian Region	143
	<i>Kryvyi S. L., Pogorilyy S. D., Boyko Y.V.</i>	
12.	Network Model Of IT-Infrastructure Resource Management	149
	<i>Serhii Kovbasiuk, Mykhailo Rakushev, Oleksandr Permiakov, Oleksandr Lavrinchuk</i>	
13.	Outer Space Monitoring System: Purpose, Tasks, Structure and Approaches to Trajectory Processing	154
	<i>Vitalii Tkachov, Maksym Bondarenko, Oleg Ulyanov, Oleksandr Reznichenko</i>	
14.	Overlay Network Infrastructure for Remote Control of Radio Astronomy Observatory	161
	<i>Alexandr Kuznetsov, Kyril Shekhanin, Andrii Kolhatin, Diana Kovalchuk, Vitalina Babenko, Iryna Perevozova</i>	
15.	Performance of Hash Algorithms on GPUs for Use in Blockchain	166
	<i>Pavel V. Openko, Spartak Yu. Hohoniants, Olena V. Starkova, Kostiantyn V. Herasymenko, Mykola I. Yastrebov, Andrii O. Prudchenko</i>	
16.	Problem of Choosing a DBMS in Modern Information Systems	171

- Volodymyr Andrushchak, Mykola Kaidan, Taras Maksymyuk, Mykhailo Klymash*
17. Smart Payload Management in Edge Nodes of Optical Label Switching Networks 175
- Vadym Mukhin, Yaroslav Kornaga, Valerii Zavgorodnii, Anna Zavgorodnya, Oksana Herasymenko, Oleg Mukhin*
18. Social Risk Assessment Mechanism Based on the Neural Networks 179
- Viktor Bondarenko*
19. Subjective-Probability Approach to Design an Expert System for Assessment of States of Complex Systems in Conditions of Non-Regular Destructive Influences 183
- Oleksandr Kurbatov, Pavel Kravchenko, Nikolay Poluyanenko, Oleksiy Shapoval, Tetiana Kuznetsova*
20. Using Ring Signatures for An Anonymous E-Voting System 187
- Oleksandr Pliushch, Viktor Vyshnivskiy, Serhii Toliupa, Anatolii Rybydajlo*
21. Utilization of Clipper Circuits to Improve Efficiency of the Gradient Signal Processing Algorithm for Adaptive Antenna Arrays 191

### **Information Theory and Technologies security**

- Ievgeniia Kuzminykh, Maryna Yevdokymenko*
1. Analyses of Security of Rootkit Detection Methods 196
- Serhey Lienkov, Genadiy Zhyrov, Ihor Pampukha, Ivan Chetverikov*
2. Block Encryption Algorithm for Digital Information Using Open Keys for Selfgeneration of Closed Random Private Keys 200
- Alexandr Kuznetsov, Anastasiia Kiian, Yurii Gorbenko, Oleksii Smirnov, Oleksandr Cherep, Liliia Bexhter*
3. Code-based Pseudorandom Generator for the Post-Quantum Period 204
- Oleksandr Lemeshko, Oleksandra Yeremenko, Maryna Yevdokymenko, Batoul Sleiman*
4. Enhanced Solution of the Disjoint Paths Set Calculation for Secure QoS Routing 210
- Yurii Sarychev*
5. Information Support is an Integral Part Public Administration Systems: Essence and Meaning 214
- Tamara Radivilova, Lyudmyla Kirichenko, Dmytro Ageyev, Maksym Tawalbeh, Vitalii Bulakh, Petro Zinchenko*
6. Intrusion Detection Based on Machine Learning Using Fractal Properties of Traffic Realizations 218
- Serhii Toliupa, Liudmyla Tereikovska, Oleksandr Korystin, Denys Chernyshev, Ihor Tereikovskiy*
7. Low-Resource Convolution Neural Network for Keyboard Recognition of the User 222

	<i>Ihor Tereikovskiy, Ihor Subach, Oleh Tereikovskiy, Liudmyla Tereikovska, Serhii Toliupa, Volodymyr Nakonechnyi</i>	
8.	Parameter Definition for Multilayer Perceptron Intended for Speaker Identification	227
	<i>Alexandr Kuznetsov, Anastasiia Kiian, Kateryna Kuznetsova, Mihael Zub, Yevhena Zaburmekha, Elena Lyshchenko</i>	
9.	Pseudorandom Sequences with Multi-Level Correlation Function for Direct Spectrum Spreading	232
	<i>D. Mogylevych, I. Kononova, B. Kredentser, O. Oksiuk</i>	
10.	Reliability of Redundant Telecommunications Equipment Advanced Model Considering Failures and Refusals of Structure Elements	238
	<i>Bogdan Korniyenko, Liliya Galata, Lesya Ladieva</i>	
11.	Research of Information Protection System of Corporate Network Based on GNS3	244
	<i>Valeriy Lakhno, Yurii Matus, Volodymyr Malyukov, Alyona Desyatko, Tetyana Hnatchenko</i>	
12.	Smart City Cybersecurity Projects Financing Model in Case of Description of Investors' Resources with Fuzzy Sets	249
	<i>Oleksii Bychkov, Kateryna Merkulova, Yelyzaveta Zhabska</i>	
13.	Software Application for Biometrical Person's Identification by Portrait Photograph Based on Wavelet Transform	253
	<i>Petro Snitsarenko, Volodymyr Nakonechnyi, Yurii Mikhieiev, Vitalii Hrytsiuk</i>	
14.	The Approach to Automated Internet Monitoring System Creation	257
	<i>Oleksandr Yudin, Yaroslav Symonychenko, Anna Symonychenko</i>	
15.	The Method of Detection of Hidden Information in A Digital Image Using Steganographic Methods of Analysis	262
	<i>Vladimir Barannik, Tatyana Belikova, Pavlo Gurzhii</i>	
16.	The Model of Threats to Information and Psychological Security, Taking into Account the Hidden Information Destructive Impact on the Subconscious of Adolescents	267
	<i>Lada Slipachuk, Volodymyr Nakonechnyi</i>	
17.	Typology of the Model of Integrated Sectoral Information System of the National Cyber Security Management	271
	<i>Svitlana Popereshniak</i>	
18.	The Testing of Pseudorandom Sequence of Small Length as a Component of the Internet of Things Security	277

## Information Theory in Computer Science

*Pursky Oleg, Selivanova Anna, Kharchenko Oleksandr, Demidov Pavlo, Kulazhenko Volodymyr*

1. Architecture Development for Web-based E-trade Management System 283

*Eduard Zharikov, Sergii Telenyk, Oleksandr Rolik, Yevhenii Serdiuk*

2. Cloud Resource Management with a Hybrid Virtual Machine Consolidation Approach 289

*Svitlana Popereshnyak, Anastasiya Vecherkovskaya*

3. Information Model Development by the Polypropylene Filtering Elements Forming Technological Process Description 395

*Valentyna Pleskach, Maria Pleskach, Olena Zelikovska*

4. Information Security Management System in Distributed Information Systems 300

*Tetiana Zatonatska, Olha Fedirko*

5. Modeling of the E-Commerce Impact on the Employment in EU 304

*Igor Panasiuk, Liudmyla Akimova, Olena Kuznietsova*

6. Modelling and Simulation of the Thermal Performance of Metal Framed Walls 309

*Dmytro Zatonatskiy, Tetiana Dluhopolska, Oleksandr Rozhko, Nataliia Tkachenko, Tetiana Stechyshyn, Olga Metlushko*

7. Modern Information Technologies in HRM: Concept of Personnel Security 313

*Oleksandr Rolik, Valerii Kolesnik, Volodymyr Samotyy*

8. Neural Network Approach to forecasting of IT Service Quality 317

*Mykhailo Strelbitskyi, Valentyn Mazur, Andrii Karpushyn*

9. Vessel Route Clustering in the Information and Telecommunication System of the Maritime Border Guard 321

*Anatoliy Melnyk, Viktor Melnyk*

10. Specialized Processors Automatic Design Tools – the Basis of Self-Configurable Computer and Cyber-Physical Systems 326

*Anastasiia Ivanytska, Liudmyla Zubyk, Dmitry Ivanov, Kateryna Domracheva*

11. Study of Methods of Complex Data Analysis that Based on Machine Learning Technologies 332

*Maksym Osiponok, Vasyl Tereshchenko*

12. The "Divide and Conquer" Technique to Solve the Minimum Area Polygonalization Problem 336

<i>Oleh A. Zaiarnyi, Inna S. Zaiarna</i>	
13.	The Application of Distributed Information Systems Based on Blockchain Technologies in Higher Education: Benefits and Challenges for Ukraine 340
<i>Iryna Vergunova</i>	
14.	The System Dynamic Control of the Water Erosion in a Hydrotechnical Rampart-Terrace 344
<i>Polianovskiy Hlib, Tetiana Zatonatska, Ihor Liutyi</i>	
15.	Utilization of Information Technologies in Higher Education 349
<i>Stig Ottosson, Vladimir Zaslavskiy</i>	
16.	Visualize what to be Coded Before Programming 355
<b>Special. Artificial Intelligence and Information Theory</b>	
<i>Oleksandr I. Provotar</i>	
1.	About the Calculation of Fuzzy Events Probabilities by Means of Interval Arithmetics 360
<i>Dmytro I. Cherniy, Yaroslav M. Linder, Volodymyr T. Matvienko, Volodymyr V. Pichkur</i>	
2.	An Algorithm for Finding Similar Objects in an Image 365
<i>Taras Lehinevych, Hlybovets Andii</i>	
3.	Analysis of Deep Metric Learning Approaches 369
<i>Anatolii O. Pashko, Olga V. Lukovych, Iryna V. Rozora, Olga I. Vasylyk</i>	
4.	Analysis of Simulation Methods for Fractional Brownian Motion in the Problems of Intelligent Systems Design 373
<i>Liliia Martynova, Galyna Kondratenko, Ievgen Sidenko, Yuriy Kondratenko</i>	
5.	Application of Fuzzy TOPSIS Method in Group Decision-Making for Ranking Political Parties 384
<i>Emil Nasirov</i>	
6.	Block-Diagonal Approach for Non-Negative Linguistic Matrix and Tensor Factorization 389
<i>Sergey Bushuyev, Igbal Babayev, Jahid Babayev, Boris Kozyr</i>	
7.	Complementary Neural Networks for Managing Innovation Projects 393
<i>Sergiy Pogorilyy, Artem Kramov</i>	
8.	Coreference Resolution Method Using a Convolutional Neural Network 397
<i>Victor Kulian, Olena Yunkova, Marina Korobova</i>	
9.	Digital Optimization of Portfolio with Market Restrictions 402

<i>Alexander Timinsky, Borys Lysytsin, Lyudmila Chernova, Liubava Chernova</i>	
10.	Digitalisation HR-management Used Bi-adaptive and Foresight Models 406
<i>Denys Khusainov, Josef Diblik, Andriy Shatyrko, Jaromir Bastinec</i>	
11.	Estimates of Solution Convergence Dynamical Processes in Neuronet with Time Delay 411
<i>Mykola Svirnevskyi, Sergiy Ivaschenko, Olexander Barmak, Iurii Krak</i>	
12.	Face Image Transformations for Correct Recognition Problems Solving 415
<i>Anatolij Tryhuba, Inna Tryhuba, Vitalij Boyarchuk, Oksana Ftoma</i>	
13.	Forecasting of a Lifecycle of the Projects of Production of Biofuel Raw Materials with Consideration of Risks 420
<i>Yuri Samokhvalov</i>	
14.	Forecasting Time and Cost of the Jobs in Network Models Based on Fuzzy Linguistic Estimates 426
<i>Vitalii Vrublevskyi, Oleksandr Marchenko</i>	
15.	Grammar Error Correcting by the Means of CFG Parser 430
<i>Ruslan Bahrii, Iurii Krak, Olexander Barmak, Veda Kasianiuk</i>	
16.	Implementing Alternative Communication Using a Limited Number of Simple Sign Language Gestures 435
<i>Anatolii O. Pashko, Iryna O. Pinchuk</i>	
17.	Intellectual Methods of Estimation of Intending Primary School Teachers' Foreign Language Communicative Competence 439
<i>Alexander Khimich, Volodymyr Sydoruk, Pavlo Yershov</i>	
18.	Intellectualization of Computation Based on Neural Networks for Mathematical Modeling 445
<i>Vasyl Gorbachuk, Maxym Dunaievskyi, Seit-Bekir Suleimanov</i>	
19.	Modeling of Agency Problems in Complex Decentralized Systems Under Information Asymmetry 449
<i>Kateryna Kolesnikova, Olga Mezentseva, Olena Savielieva</i>	
20.	Modeling of Decision Making Strategies in Management of Steelmaking Processes 455
<i>Vladyslav Hryhorenko, Dmitriy Klyushin, Sergey Lyashko</i>	
21.	Multiblock ADMM in Machine Learning 461
<i>Andriy Yaroshevskiy, Dmitry Klyushin</i>	
22.	Nonparametric Methods of Authorship Attribution in Classic and Modern Literature 465
<i>Hanna Livinska, Eugene Lebedev</i>	
23.	On Asymptotic Merging of Nodes Set for Stochastic Networks with General Service 470



	<i>Maryna Antonevych, Anna Didyk, Vitaliy Snytyuk</i>	
24.	Optimization of Functions of Two Variables by Deformed Stars Method	475
	<i>Viktor Morozov, Olena Kalnichenko, Anna Kolomiets</i>	
25.	Research of the Impact of Changes Based on External Influences in Complex IT Projects	481
	<i>Yana Bondarenko</i>	
26.	Sequential A/B testing	488
	<i>Olexander Barmak, Oleg Kalyta, Eduard Manziuk, Iurii Krak</i>	
27.	Simplified Model for Recognition Facial Emotions	492
	<i>Olha Sherstiuk, Oleksii Kolesnikov, Dmytro Lukianov</i>	
28.	Team Behaviour Model as a Tool for Determining the Project Development Trajectory	496
	<i>Olga Romanko, Mariia Voronenko, Nataliia Savina, Iryna Zhorova, Waldemar Wójcik, Volodymyr Lytvynenko</i>	
29.	The Use of Static Bayesian Networks for Situational Modeling of National Economy Competitiveness	501
	<i>Dmytro Lukianov, Krystsina Mazhei, Viktor Gogunskii</i>	
30.	Transformation of the International Project Management Association Project Managers Individual Competencies Model	506
	<i>Oleksandr I. Provotar, Yaroslav M. Linder, Maksym M. Veres</i>	
31.	Unsupervised Anomaly Detection in Time Series Using LSTM-Based Autoencoders	513
	<i>Tetiana Olekh, Viktor Gogunskii</i>	
32.	Use of Discrete and Continuous Markov Chains for System Absorbing States	518
	<i>Miedviediev Vladimir, Tsololo Serhii, Dikova Yuliia</i>	
33.	Using a Neural Network Method to Solve the Problem of Automatic Generation of Vacations	522
	<i>Mariia Voronenko, Iryna Lurie, Oleg Boskin, Ulzhalgas Zhunissova, Roman Baranenko, Volodymyr Lytvynenko</i>	
34.	Using Bayesian Methods for Predicting the Development of Children Autism	525

# Modelling and Simulation of the Thermal Performance of Metal Framed Walls

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**Abstract**—Recently, in the building practice, steel framed walls have increasingly been used. Such wall structures have a lot of advantages. At the same time, such walls have some disadvantages, and the most important of them is the presence of metal elements which lead to the appearance of thermal bridges and, as a result, to an increase in the overall heat transfer coefficient of the wall structure. The objective of this work was to evaluate and compare the thermal insulation properties of metal framed walls. To achieve the objectives of the study, several configurations of metal framed walls with different levels of thermal insulation and the distances between vertical steel studs were modeled. The heat transfer coefficient of the simulated steel framed walls was determined using the THERM 7.6 software. The simulation results showed that the use of an additional external insulation layer is an effective way to mitigate the adverse effects of thermal bridges caused by the presence of metal frames. Changing the distance between the metal studs also leads to heat losses reduction by almost 15% for a wall without an external expanded polystyrene layer. However, the effectiveness of this reduction is slightly less for walls equipped with additional external insulation. The novelty of the work is that the impact of geometric and thermophysical parameters of steel framed walls on their resistance to heat transfer was established and the ways to increase the thermal performance of such wall structures were outlined.

**Keywords** — *thermal simulation software, energy consumption, light steel framed wall, thermal transmittance, heat transfer coefficient*

## I. INTRODUCTION

Residential and non-residential buildings are significant energy consumers [1]. So, there is an urgent need to reduce the energy consumption of buildings, especially in their operational stage, since this accounts for 80%–85% [2] of the total amount of energy consumed during their life cycle. Therefore, it is very important to find solutions and elaborate methods that offer advantages in reducing buildings energy needs.

For Ukraine, the benefits of energy saving are of particular importance in view of its high energy dependence and energy consumption. The domestic economy is energy deficient, meeting its energy needs at the expense of its own production by only 45%. Its fuel and energy balance is dominated by natural gas, which accounts for more than 40%, far exceeding the corresponding indicators of countries such as the United States, the United Kingdom and so on. One of the largest consumers of energy resources is the housing sector - more than 30% of the total energy consumption in the country. The available housing stock of Ukraine, according to the energy classification, belongs to the most energy-intensive class F, which is characterized by energy consumption greater than 250 kWh/m<sup>2</sup> per year. At the same time, in European countries, the energy efficient buildings belong to class A and A+, which means very low energy consumption (from 15 to 45 kWh/m<sup>2</sup> per year).

When designing an energy efficient building such architectural and building principles of enhancement energy efficiency must be followed: optimization of architectural forms of the building with taking into account the possible impact of wind; optimal location of the building relative to the sun, which provides the opportunity for maximum use of solar radiation; increase of thermal resistance of building enclosures (exterior walls, coverings, etc.); minimizing the harmful effect of thermal bridges; increase of thermal resistance of translucent structures; creating an energy efficient ventilation system.

One of the most important factors that affect the energy performance of a building is the value of the heat transfer coefficient of the outer envelope of the building. Various types of thermal insulation may be used to reduce the heat transfer coefficient value.

There are many types of thermal insulation. Their effectiveness is estimated by the degree of thermal resistance. The higher the thermal resistance, the more effective the insulation.

Thermal insulation foams include extruded polystyrene, expanded polystyrene and polyurethane foam.

Granular insulation includes perlite (expanded volcanic rock), vermiculite (expanded mica) and polystyrene foam in granules. Usually they fill cavities, for example, in concrete slabs.

Foamy insulation is mineral wool and fiberglass. Fiberglass products are obtained from molten glass, and mineral wool is produced from molten rocks.

Filling insulation can be made of mineral wool, glass wool or cellulose.

Reflective insulation consists of one or more layers of aluminum foil.

Foam is a mixture of chemicals that are pumped into the cavity, where the foam is formed, filling them.

Over the last few years, alternatives to the traditional constructive methods have been developed. The so-called frame buildings began to gain more and more popularity. Nowadays, in the construction of frame houses, two types of frames are used - wooden and metal ones. Metal frames are made of lightweight galvanized metal in the form of profiles. Such structures are called lightweight steel framing (LSF) systems. They are made in various shapes and thicknesses. When assembling the frame, they are connected using screws, rivets or bolts, which eliminate welding work. Metal structures are dimensionally stable, do not shrink, and thanks to this, one can immediately order and put doors and windows, and perform any finishing work.

The strength of steel structures allows making openings located between the load-bearing elements wider and use any siding and roofing materials. The service life of such structures, thanks to galvanization, is about a hundred years. But there are also limitations that must be taken into account: metals have thermal conductivities higher than wood, therefore, the correct thermal insulation of the frame is needed, which does not allow the occurrence of so called thermal bridges and gaps in the envelope of the building. And the elements, if any, extending beyond the envelope, need an additional insulation. But all these shortcomings are covered by one biggest plus - the low price per square meter.

Structurally LSF system is a building construction system consisting of dry materials [3]. This system includes three major materials: metals, sheathing panel materials and insulation [4]. Other materials are also needed for fastening and joining. The system must also include air tightness and waterproof membranes and as well as finishing layers. In order to avoid problems related with ground moisture, a frame building needs a ground floor, commonly a concrete slab [5].

As mentioned above, steel framing creates notable thermal bridges and reduces overall thermal performance of steel framed walls. In relation to wood framing steel is much more thermally conductive than wood [6].

Taking into account the disadvantages discussed above, more and more attention has been paid recently to the development of methods that would improve the thermal efficiency of walls with metal frames [7].

The purpose of the work was to determine the thermal properties of the walls with metal frames. To achieve this, three types of walls were considered. The walls differed in the distance between the frame studs as well as the depth of the metal studs. At the same time, three levels of thermal insulation were varied for each type of wall, namely: only with internal insulation as well as with additional layers of external insulation (1.2 cm and 2.5 cm layers of expanded polystyrene). As a result of computer simulation, the thermal

characteristics of these walls were determined and proposals were made to improve the thermal performance of such walls.

## II. MATERIALS AND METHODS

The general view of steel frames is depicted in Fig. 1.

Commonly, thermal insulation is filled between steel studs and covered with sheathing, for an example, with oriented strand board and layers of external and internal plaster boards. Additional layer of external insulation may also be used.



Fig. 1. Steel frames

The steel framed wall fragment to be simulated is shown in Fig. 2. This structure contains metal studs with a “U” cross-sectional shape. The depth and distance between adjacent metal studs were varied during the simulation.

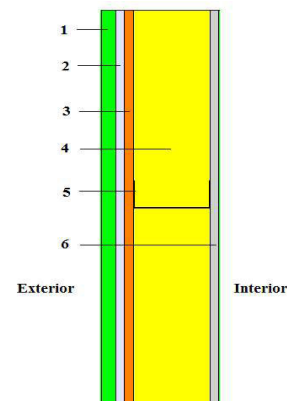


Fig. 2. The scheme of the steel framed wall geometrical model. Materials: 1—external plaster; 2—external insulation (optional); 3—oriented strand board (OSB); 4—internal insulation; 5—steel stud; 6—internal plasterboard

The characteristics of steel framed walls, the thermal properties of which were determined during the simulation, are given in Table 1. And for each type, the level of thermal insulation were varied.

The thermal properties of the materials the walls consisted of were as follows. The thermal conductivity of plaster board, mineral wool, OSB, EPS and steel were assumed to be 0.21; 0.04; 0.13; 0.038 and 50 W/(m·K), correspondingly.

The convective surface heat transfer coefficients were taken according to EN ISO 6946 [8] for a horizontal heat flow. According to this standard, the convective surface heat transfer coefficient between the outer surface of the wall and the external environment was assumed to be  $h_e=25$  W/(m<sup>2</sup>·K), and it was taken as  $h_i=7.69$  W/(m<sup>2</sup>·K) between the inner surface of the wall and the interior environment.

The rest of the boundary conditions were as follows: the external temperature assumed to be 0 °C and the internal temperature was defined at 20 °C.

The boundary conditions taken for computer modeling are summarized in Table 2.

TABLE 1. Characteristics of walls with metal frames

Wall symbol	Geometrical characteristics of steel studs; distance between adjacent studs	Material used for insulation of wall cavity	Exterior/interior plaster boards	External insulation
Ia	8.9 mm depth, 4.1 cm flange, 1.2 mm thickness, 40 cm distance between adjacent studs	Mineral wool (MW)	2 cm external plaster; 1.25 cm internal plasterboard; optional external insulation	no
Ib				1.2 cm of expanded polystyrene (EPS)
Ic				2.5 cm of EPS
IIa	8.9 cm depth, 4.1 cm flange, 1.2 mm thickness, 60 cm between adjacent studs	MW	2 cm external plaster; 1.25 cm internal plasterboard; optional external insulation	no
IIb				1.2 cm of EPS
IIc				2.5 cm of EPS
IIIa	10.2 cm depth, 4.1 cm flange, 1.2 mm thickness, 60 cm between adjacent studs	MW	2 cm external plaster; 1.25 cm internal plasterboard; optional external insulation	no
IIIb				1.2 cm of EPS
IIIc				2.5 cm of EPS

TABLE 2. Boundary conditions

No	Parameter	Value
1	Internal temperature	20 °C
2	External temperature	0 °C
3	External convective heat transfer coefficient	25 W/(m <sup>2</sup> ·K)
4	Internal convective heat transfer coefficient	7.69 W/(m <sup>2</sup> ·K)

The next task was to determine the limiting dimensions of the geometric model of the wall fragment. For a wall with a single layer of vertical metal studs and a distance of 400 mm (or 600 mm) between adjacent studs, standard ISO EN 10211 [9] recommends to take advantage of its symmetry to locate the adiabatic plans.

So, a cross-section of the wall measuring 600 mm (or 400 mm), with a metal stud in the centre, was taken as a geometric model.

Thermal simulation was carried out with THERM 7.6 software [10].

THERM's two-dimensional conduction heat-transfer analysis is based on the finite-element method.

The advantages of the presented program include a convenient graphical interface that allows building models of complex geometry with high accuracy.

### III. RESULTS AND ANALYSIS

The results of the thermal simulation (temperature maps) are shown in Fig. 3.

These temperature profiles were used to evaluate average surface heat flux passing through each type of the analyzed walls. This allowed performing calculations of overall heat transfer coefficients (U-values). Fig. 4 represents the values of all overall heat transfer coefficients calculated as a result of the simulation.

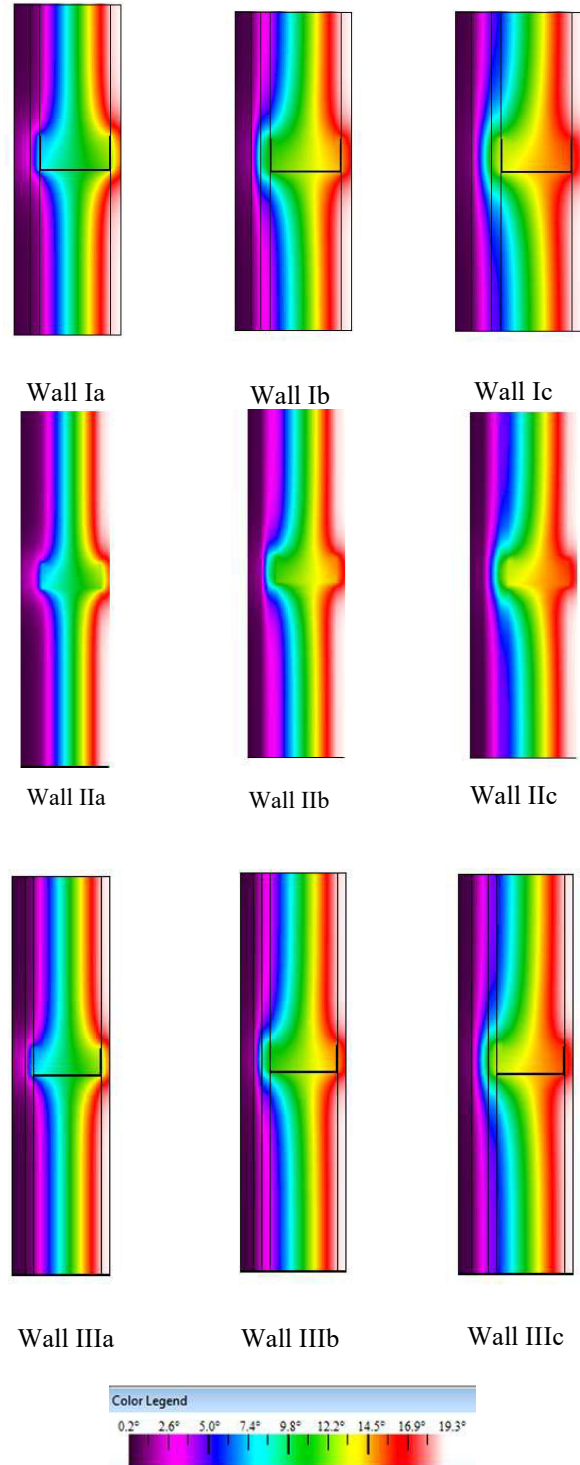


Fig. 3. Temperature maps

For walls without external insulation overall heat transfer coefficients between 0.55 and 0.69 W/(m<sup>2</sup>·K) were obtained as a result of simulation. It can be noticed that installation of additional external layer of thermal insulation results in considerable overall heat transfer coefficient decrease. The values of overall heat transfer coefficients for the walls with additional 1.2 cm layer of external insulation range from about 0.42 to about 0.5 W/(m<sup>2</sup>·K), whereas for walls with 2.5 cm of EPS the U-values are within 0.38 and 0.42 W/(m<sup>2</sup>·K).

The heat transfer coefficient decreases with distance increase between the metal studs. Moreover, the most noticeable decrease in the heat transfer coefficient was obtained for walls without an additional layer of external thermal insulation. When applying an additional outer layer of thermal insulation, an increase in the distance between the adjacent studs causes less noticeable decrease in the heat transfer coefficient, namely, the decrease is only 9.5% for walls with an additional 2.5 cm layer of thermal insulation and about 11% for walls with a 1.2 cm layer of thermal insulation.

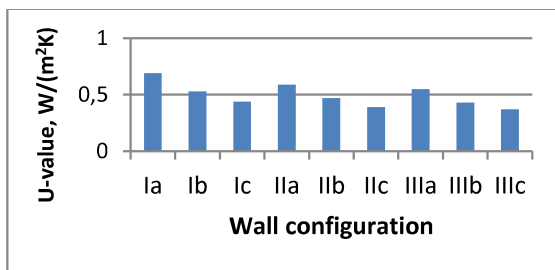


Fig. 4. U-values of simulated metal stud framed walls

It is known that the overall heat transfer coefficient for walls with metal inclusions can be significantly higher than for similar walls if the negative impact of thermal bridges is not taking into account. The data represented in Fig. 5 depict the influence of metal framed wall configuration and level of insulation on the magnitude of so called framing effect.

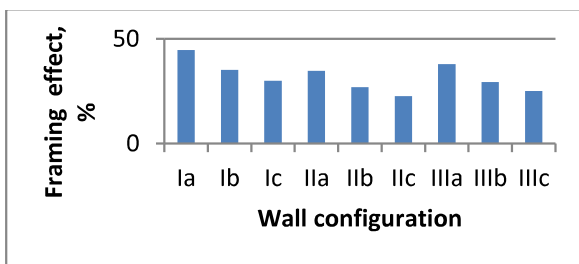


Fig. 5. - The magnitude of framing effect f

The *framing effect*, (*f*) takes into account the increase of wall overall heat transfer coefficient due to the impact of thermal bridges. It can be calculated using the following expression:

$$f = \left(1 - \frac{U_{ideal}}{U_{simulated}}\right) \cdot 100\%$$

where  $U_{simulated}$  - simulated overall heat transfer coefficient (all thermal bridges are taken into account) and  $U_{ideal}$  - "ideal" overall heat transfer coefficient (thermal bridges are not taken into account).

For the wall structure with 8.9 cm depth metal studs, 1.2 mm thick, and distances between them of 40 cm, without external insulation, the framing effect reaches about 44 %. The magnitude of the framing effect may be lowered with the increase in external insulation layer thickness as well as distances between adjacent studs.

## CONCLUSIONS

This work was devoted to the study of thermal efficiency of walls with metal frames. To obtain the thermal characteristics of such walls, a computer simulation was performed. In the analysis, the walls were considered to have different levels of thermal insulation, different distances between the adjacent metal studs, as well as different geometric characteristics of these studs. The results of computer simulation allow us to draw the following conclusions. The use of an additional layer of external thermal insulation results in a significant reduction in the overall heat transfer coefficient of such walls. To some extent, the overall heat transfer coefficient also decreases as the distance between adjacent metal studs increases. As a result of modeling, the relationship between the level of thermal insulation of the walls, their geometrical parameters and the framing effect is also revealed. This framing effect is also greatly reduced when an additional outer layer of thermal insulation is applied.

Obviously, other strategies can be used to mitigate the adverse influence of thermal bridges and enhance thermal performance of walls with metal frames. For example, perforated metal profiles are currently used to reduce the negative effects of thermal bridges. So, further research is needed to optimize the configuration and improve thermal performance of such walls.

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## INDEX

<b>A</b>		Diblik, Josef	411
Afanasiev, Volodymyr	111	Didyk, Anna	475
Afanasieva, Olesia	102	Dikova, Yuliia	522
Ageyev, Dmytro	218	Dluhopolska, Tetiana	313
Akimova, Liudmyla	309	Dodukh, Oleksandr	31
Aleksandrova, Oleksandra	98	Domrachev, Volodymyr	133
Andrushchak, Volodymyr	175	Domracheva, Kateryna	332
Anisimov, Anatoly	71, 93	Dudnik Andriy	143
Antonevych, Maryna	475	Dunaievskiy, Maxym	449
<b>B</b>		Dymchuk, Victoria	27
Babayev, Igbal	393	<b>F</b>	
Babayev, Jahid	393	Fedirko, Olha	304
Babenko, Vitalina	166	Frolov, Oleg	36
Bahrii, Ruslan	435	Ftoma, Oksana	420
Baranenko, Roman	525	Fustii, Vadym	41
Barannik, Dmitry	41	<b>G</b>	
Barannik, Natalia	36	Galata, Liliya	244
Barannik, Valeriy	89	Gawliczek, Piotr	102
Barannik, Vladimir	31, 89, 267	Gogunskii, Viktor	506, 518
Barmak, Olexander	415, 435, 492	Gololobov, Dmitry	133
Bashkov, Yevgen	98	Gorbachuk, Vasyl	449
Bastinec, Jaromir	411	Gorbenko, Yurii	204
Belikova, Tatyana	267	Gurzhii, Iryna	89
Beresina, Svitlana	22	Gurzhii, Pavlo	267
Bexhter, Liliia	204	<b>H</b>	
Bezshapkin, Sergiy	125	Hahanova, Anna	31
Boiko, Yuliia	22	Havrylov, Dmytro	41
Bondarenko, Maksym	161	Herasymenko, Kostiantyn	111, 171
Bondarenko, Viktor	183	Herasymenko, Oksana	179
Bondarenko, Yana	488	Himenko, Victoriya	27
Boskin, Oleg	525	Hlybovets, Andii	369
Boyarchuk, Vitalij	420	Hnatchenko, Tetyana	249
Boyko, Y.	149	Hohonianc, Spartak	116, 171
Buchyuk, Serhii	22, 36	Honcharenko, Oleksandr	137
Bulakh, Vitalii	218	Horbunov, Oleh	85
Bushuyev, Sergey	393	Hrushko, Svitlana	129
Bychkov, Oleksii	253	Hryhorenko, Vladyslav	461
<b>C</b>		Hrytsiuk, Vitalii	257
Cherep, Oleksandr	204	<b>I</b>	
Cherniy, Dmytro	371	Ivanishchev, Bohdan	137
Chernova, Liubava	406	Ivanov, Dmitry	332
Chernyshev, Denys	222	Ivanytska, Anastasiia	332
Chetverikov, Ivan	200	Ivaschenko, Sergiy	415
Chernova, Lyudmila	406	<b>K</b>	
<b>D</b>		Kaidan, Mykola	175
Dakhno, Nataliia	120	Kal'chuk, I.	107
Demidov, Pavlo	283	Kalnichenko, Olena	481
Derevianchenko, Oleksandr	85	Kalyta, Oleg	492



## INDEX

Kapustian, Olena	16, 75	Kaplunov, Artem	137
Karpushyn Andrii	321	Kyrychek, Dmytro	129
Kasianiuk, Veda	62, 435	<b>L</b>	
Kharchenko, Oleksandr	283	Ladieva, Lesya	244
Kharkevych, Yu.	107	Lakhno, Valeriy	249
Khimich, Alexander	445	Laptiev, Olexandr	116
Khusainov, Denys	411	Lavrinchuk Oleksandr	154
Kiiian, Anastasiia	204, 232	Lebedev, Eugene	470
Kirichek, Galina	129	Lefterov, Oleksandr	51
Kirichenko, Lyudmyla	218	Lehinevych, Taras	369
Klymash Mykhailo	175	Lekakh, Albert	27
Klyushin, Dmitriy	56, 461, 465	Lemeshko, Oleksandr	210
Kolesnik, Valerii	317	Leshchenko, Olga	120
Kolesnikov, Oleksii	496	Lienkov, Serhey	200
Kolesnikova, Kateryna	455	Linder, Yaroslav	365, 513
Kolhatin, Andrii	166	Lisnyk Anastasiia	111
Kolomiets, Anna	481	Liutyi, Ihor	349
Kondratenko, Galyna	384	Livinska, Hanna	470
Kondratenko, Yuriy	384	Loutskii, Heorhii	137
Kononchenko, Anna	81	Lukianov, Dmytro	496, 506
Kononova, I.	238	Lukovych, Olga	373
Kornaga, Yaroslav	179	Lurie, Iryna	525
Korniienko, Bogdan	244	Lyashko, Sergey	461
Korobova, Marina	402	Lyshchenko, Elena	232
Korolyova, Natalia	27	Lysytsin, Borys	406
Korotin, Sergii	111	Lytvynenko, Volodymyr	501, 525
Korystin, Oleksandr	222	<b>M</b>	
Koshman, Sergey	81	Makhovych, Oleksandr	120
Kovalchuk, Diana	166	Maksymyuk, Taras	175
Kovbasiuk, Serhii	154	Malyukov, Volodymyr	249
Kozyr, Boris	393	Manziuk, Eduard	492
Krak, Iurii	415, 435, 492	Marchenko, Oleksandr	430
Kramov, Artem	398	Martynova, Liliia	384
Krasnobaev, Victor	45, 81	Matus, Yurii	249
Kravchenko, Pavel	187	Matvienko, Volodymyr	365
Kravchenko, Yurii	102, 120	Mazhei, Krystsina	506
Kredentser, B.	238	Mazur, Valentyn	321
Kryvyi, S.	149	Melnyk, Anatoliy	326
Kulazhenko, Volodymyr	283	Melnyk, Viktor	326
Kuliabko, Petro	62	Merkulova, Kateryna	253
Kulian, Victor	402	Metlushko, Olga	313,
Kulitsa, Oleg	89	Mezentseva, Olga	455
Kurbatov, Oleksandr	187	Miedviediev, Vladimir	522
Kuzminykh, Ievgeniia	196	Mikhieiev, Yurii	257
Kuzmych, Lyudmyla	143	Mogylevych, D.	238
Kuznetsov, Alexandr	166, 204, 232	Morozov, Viktor	481
Kuznetsova, Kateryna	45, 81, 232	Mukhin, Oleg	179
Kuznetsova, Tetiana	45, 81, 187	Mukhin, Vadym	179
Kuznietsova, Olena	309	<b>N</b>	
		Naguliak, Oleg	51

## INDEX

Nakonechnyi, Oleksandr	16, 75	Salanda, Ivanna	116
Nakonechnyi, Volodymyr	227, 257, 271	Samokhvalov, Yuri	426
Nasirov, Emil	389	Samotyy Volodymyr	317
Netreba, Iryna	51	Sarychev, Yurii	214
Novokshonov, Andrey	93	Savielieva, Olena	455
<b>O</b>			
Oksiiuk, O.	238	Savina, Nataliia	501
Olekh, Tetiana	518	Selivanova, Anna	283
Openko, Pavel V.	171	Serdiuk, Yevhenii	289
Osadchyy, Volodymyr	85	Shapoval, Oleksi	187
Osadchyy, Yevgen	85	Shatyrko, Andriy	411
Osiponok, Maksym	336	Shekhanin, Kyryl	166
Ottosson, Stig	355	Sherstiuk, Olha	496
<b>P</b>			
Pampukha, Ihor	200	Shevchenko, Igor	41
Panasiuk, Igor	309	Shevchuk, Iuliia	75
Parkhomenko, Maksym	31	Shuklin, German	116
Pashko, Anatolii	373, 439, 75	Sidchenko, Sergy	89
Perevozova, Iryna	166	Sidenko, Ievgen	384
Permiakov, Oleksandr	154	Sleiman, Batoul	210
Pichkur, Volodymyr	365	Slipachuk, Lada	271
Pinchuk, Iryna	439	Slobodyanyuk, Oleksandr	41
Pleskach, Maria	300	Smirnov, Oleksii	204
Pleskach, Valentyna	300	Snitsarenko, Petro	257
Pliushch, Oleksandr	191	Snytyuk, Vitaliy	475
Pogorilyy, S.	149	Sobchuk, Andrii	102
Pogorilyy, Sergiy	397	Sorokun, Anton	31
Polianovskyi, Hlib	349	Starkova, Olena	111, 171
Poluyanenko, Nikolay	187	Stechyshyn, Tetiana	313
Popenko, Victoria	45	Strelbitskyi, Mykhailo	321
Popereshnyak, Svitlana	300	Strelcov, Oleh	66
Provotar, Oleksandr	360, 513	Stupen, Pavel	66
Prudchenko, Andrii O.	171	Subach, Ihor	227
Puhachov, Roman	27	Sudakov, Oleksandr	51
Pursky, Oleg	283	Suleimanov Seit-Bekir	449
Popereshniak, Svitlana	277, 295	Suleimanov, Yuri	51
Radchenko, Serhii	51	Suprun, Olha	36
Radivilova, Tamara	218	Svirnevskyi, Mykola	415
Rakushev, Mykhailo	154	Sydoruk, Volodymyr	445
Rehida, Pavlo	137	Symonychenko, Anna	262
Reznichenko Oleksandr	161	Symonychenko, Yaroslav	262
Rokochinskiy, Anatolii	143	Sytnikov, Valerii	66
Rolik, Oleksandr	289, 317	<b>T</b>	
Romanko, Olga	501	Tawalbeh, Maksym	218
Rozhko, Oleksandr	313	Telenyk, Sergii	289
Rozora, Iryna	373	Tereikovska, Liudmyla	222, 227
Ryabukha, Yuriy	31	Tereikovskyi, Ihor	222, 227
Rybydajlo, Anatolii	191	Tereikovskyi, Oleh	227
<b>S</b>			
Saiko, Volodymyr	133	Tereshchenko, Vasyl	62, 85, 336
		Tereshchenko, Yaroslav	62
		Timenko, Artur	129
		Timinsky, Alexander	406

## INDEX

Tkachenko, Nataliia	313		
Tkachov, Vitalii	161		
Toliupa, Serhii	191, 222, 227		
Tovkach, R.	107		
Trush, Oleksandr	120		
Tryhuba, Anatoliy	420		
Tryhuba, Inna	420		
Tsololo, Serhii	522		
Tupitsya, Ivan	89		
Turcheniuk, Vasyl	143		
Tverdokhlebl, Vitaliy	22, 41		
Tyshchenko, Maksym	102		
<b>U</b>			
Ukhina, Hanna	66		
Ulyanov, Oleg	161		
<b>V</b>			
Vasyliiev, Ihor	125		
Vasylyk, Olga	373		
Vecherkovskaya, Anastasiya	295		
Verenych, Danylo	125		
Verenych, Olena	125		
Veres, Maksym	513		
Vergunova, Iryna	344		
Volk, Liubov	143		
Volk, Pavlo	143		
Volokyta, Artem	137		
Voronenko, Mariia	501, 525		
Vrublevskiy, Vitalii	430		
Vyshnivskiy, Viktor	191		
<b>W</b>			
Wójcik, Waldemar	501		
<b>Y</b>			
Yakovleva Iryna	66		
Yaroshevskiy, Andriy	465		
Yastrebov, Mykola I.	171		
Yeremenko, Oleksandra	210		
Yershov, Pavlo	445		
Yevdokymenko, Maryna	196, 210		
Yudin, Oleksandr	22, 36, 262		
Yunkova, Olena	402		
		<b>Z</b>	
Zaburmekha, Yevhena			232
Zaiarna, Inna			340
Zaiarnyi, Oleh			340
Zaslavskiy, Vladimir			361
Zatonatska, Tetiana			304, 349
Zatonatskiy, Dmytro			313
Zavadskiy, Igor			71
Zavgorodnii, Valerii			179
Zavgorodnya, Anna			179
Zelikovska, Olena			300
Zhabska, Yelyzaveta			253
Zharikov, Eduard			289
Zhorova, Iryna			501
Zhuikov, Dmytro			27
Zhunissova, Ulzhalgas			525
Zhyrov, Genadiy			200
Zidan, Amina			116
Zinchenko, Petro			218
Zinko, Taras			75
Ziubina, Ruslana			22, 36
Zub, Mihael			232
Zubyk, Liudmyla			332