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Problems of Determining of Wind Turbines Visual Impact Zones Size and Character on Lithuanian Landscape

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EXTENDED ABSTRACT

Landscape visual quality is one of the immaterial resources of living environment that makes an impact on the quality of life. Therefore, visual resources must be protected and increased by regulating their use.

Wind turbines become an inseparable part of the Western Lithuanian landscape. For example, in five wind farms in Kretinga region 51 wind turbines are located and 6 standalone wind turbines operate over there, too.

Wind turbines' visual impact depends on many qualities: wind turbine size, its color, form, observation distance, landscape richness, time of the day and other factors.

The paper aims at discussing factors, which determine wind turbine visibility, and giving directions for possible development of wind turbine visual impact evaluation methods by having compared theoretical wind turbine impact zone sizes, as well as visual impact importance degrees, with empirical survey results.

After the wind turbine visual impact zones in different countries have been analyzed and the situation in Lithuania taken in, the table of wind turbine visual impact hypothetical degrees has been made up.

The object of study *in situ* is the wind farm situated in the territory of villages Kiauleikiai, Kviečiai and Rūdaičiai (between the towns of Palanga and Kretinga, near the village Vydmantai). The park consists of 15 wind turbines. All the turbines are of the same type Enercon E-70 (2 MW). The hub height is 85 m, the length of their blades is 34 m, and the total diameter of the set of blades is 71 m; the total height of wind turbine with one of the blades at the top position is 120.5 m. All the wind turbines were installed in 2006.

After accomplishing the research and evaluating the results the following conclusions have been drawn:

1. As the total height of wind turbines is 120-160 m, these objects become dominating verticals. Under ideal weather conditions wind turbines can be seen at the distance of 20-25 km. Therefore, wind turbines have to be grouped into separate farms, laid out in the places aloof from residential areas, important territories under protection, as well as recreational zones.

2. The theoretical classification of wind turbine visual impact zones should be corrected by taking into account the visual character of Lithuanian landscape. When being at the distance of 0-7 km from the wind farm, 1-2 km interval is of great importance to the visual impact evaluation (visual impact varies from dominants to subdominants). Considering the above mentioned aspect there are proposed such intervals of zones of visual influence: 0-1 km; 1-3 km; 3-5 km; 5-7 km; 7-10 km; 10-13 km; 13-16 km; 16-20 km; >20 km.

3. It was noticed that forests, buildings and other vertical objects that are located near observation point change the visual impact significance very much. Weather conditions make significant influence as well, especially for the visibility of wind turbine wheel.

Keywords: wind turbines, wind farms, visual impact assessment, zones of visual impact.

REFERENCES

Environmental Resources Management. 2009. Ararat Wind Farm. Landscape and visual assessment report. Australia. 97 p.

Kamičaitytė-Virbašienė J. 2001. Landscape visual quality, the importance and problems of its regulation. Town Planing and Architecture 4, 202–209 p.

Jallouli J., Moreau G. 2009. An immersive path-based study of wind turbine landscape: A French case in Plouguin. Denmark, Renewable Energy 34 (2009), 597–607 p.

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Built Heritage Management Challenges in the Areas of Rural-Urban Interface

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EXTENDED ABSTRACT

Urban sprawl and management of rural-urban interface remains the relevant area of research of the last decades. In order to highlight the opportunities and challenges of management of built heritage in the areas of rural-urban interface, the paper presents the results of the literature review and sociological research on the state and preservation possibilities of rural relics in the urban settings.

The analysis of literature has demonstrated that developing and developed countries both encounter problems of urban expansion and of preservation of the rural heritage in the zones of rural-urban interface. The analysis has also revealed the diversities in urban-rural transition processes and character depending on the socioeconomic, sociocultural, geographical, and political contexts. The researchers analyzing the peculiarities of the urbanization in the post-communist transition countries and namely of Lithuania indicate the uneven, character of this process. This encourages analyzing ant considering separately the peculiarities of preservation of the rural heritage absorbed into the urban settings in the post-communist transition countries.

The results of the survey of architecture and heritage preservation professionals revealed that the rural heritage objects in the urban environment, while experiencing radical changes, nevertheless can be important as the cultural, economic, recreational, ecological resources for the newly emerging peri-urban and suburban areas and their positive effect can be felt even at the level of the city. Specialists had identified the potential of the rural heritage to contribute to the identity formation in the newly evolving urban areas; the rural heritage objects can become the public attraction centers of suburban and peri-urban areas. According to surveyed experts, the manor residencies possess a considerable potential in this regard. This suggests that the preservation of the rural heritage objects and the use of them in the urban development are important not only for the heritage protection, scientific knowledge, and public education, but also for the development of the urban environment in general.

The surveyed experts identify the potential uses of the rural heritage in new urban contexts. Part of these functions was identified as primary or close to primary, such as residential, representation, recreation, and farming; other functions were identified as new, such as cultural tourism, agro-tourism, creative industries etc. The conclusion and the starting point for a new discussion could be the observation that a new context presupposes new uses of rural heritage. Even the superficially authentic functions, such as residential or farming, are not actually historically authentic. Farming in the urban environment is quite different from farming in rural areas. Living and recreation, cultural activities are also affected by the urban context.

Keywords: urban sprawl, rural-urban interface, built heritage, sustainable development, Kaunas, Lithuania

REFERENCES

Antrop, M., Van Eetvelde, V. 2000. Holistic aspects of suburban landscape: visual image interpretation and landscape metrics. Landscape and urban planning, 50, 43-58.

Ažukaitė, L. 2011. Kaimo kraštovaizdyje susiformavusio statybinio paveldo panaudojimo galimybės urbanistinėje plėtroje [Possibilities of use of built heritage of rural origination in urban development]. Tyrimų vietose ataskaita. Kauno technologijos universitetas, Kaunas.

Bardauskienė, D., Pakalnis, M. 2012. Foresighted urban planning. Enivronmental Research, Engineering and Management, 59, 63-72.

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Building Information Modeling in Architectural Digital Design Education: Questions and Answers

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EXTENDED ABSTRACT

The paper includes the results of the research and the experience of teaching of the CAAD subject based on object-oriented building modeling. The problem was analyzed using the surveys of 59 postgraduate architecture students. The answers of the questionnaire were measured in ordered scale or in nominal scale. For the evaluating of the associations Cramer's V measure of associations and the test independence based on Chi-Square statistics were used.

The first part included three questions about the level of knowledge of information technology and knowledge of computer graphics. The second part comprises of three questions evaluating the complexity / simplicity, viability in the future and positive / negative influence of BIM to architectural creativity. Third part is about the use and viability of intelligent parametric AEC objects in comparison with 2D drawings and non-parametric 3D CAD objects. In the fourth part are evaluated the efficiency of the AEC objects and typical AEC modeling procedures. In the fifth part of survey are compared two programs Revit and AutoCAD Architecture.

More than a half of the respondents are only on the level less than average. Rather high activity in the fields of computer graphics is almost equally distributed. The knowledge and experience of CAD systems other than AutoCAD are not high enough. The absolutely dominating opinion is that the use of the BIM software demands the extensive efforts and time investment. Almost half of the architects are going to use BIM and the other half of them will definitely use BIM in the future. Significant generalization were two classifications of the efficiency classes of the types of AEC objects and typical AEC procedures what allowed to identify most efficient and most challenging elements of BIM. In some cases BIM will not be used in favour of simple 2D or especially 3D geometry. The comparison of the systems Revit Architecture and AutoCAD Architecture showed better votes for Revit. The analysis of correlations between answers to questions has revealed several statistically significant associations that can be interpreted that people with higher IT competence tend to accept easier BIM.

Evaluating general computing literacy of the students shows a lack of the basic expertise in information technology in the early years of studies what has negative influence for the BIM and digital design computing competence in the future.

The respondents took the factor of complexity of BIM software very seriously and that was not influenced by any other factors what is significant for wider adoption of BIM. In the same time optimistic attitudes are clearly visible evaluating the viability and the impact to creativity of BIM. Because of the various problems of graphical representation of the BIM architectural information still remains the relevance of traditional both 2D CAD drawings and non-parametric 3D models.

One of the essential results was the discovery of the most challenging and the most efficient AEC objects and typical AEC procedures using classifications based on the survey statistics.

The higher rates for Revit in comparison of BIM applications should not be simply extrapolated to the whole architectural community because of the limited real designing experience of students.

Keywords: Object-oriented modeling, building information modeling, computer-aided architectural design.

REFERENCES

Dokonal, W. 2008. What is the state of digital architectural design?, SIGraDi 2008 - [Proceedings of the 12th Iberoamerican Congress of Digital Graphics] La Habana - Cuba 1-5 December 2008.

Norušis M. J. 2008. IBM SPSS Statistics 19 Guide to Data Analysis. Prentice Hall, 672 p.

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Transport in a City – the Influence of the Organization of Transport on the Urban Pattern of Developing Cities. Searching for the Solutions that Can Stop the Transport from Becoming the Enemy of the Public Space

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Abstract. A part of the complex structure of a city is its transport system. It determines the possibilities of improving urban transport. At the same time the organization of urban transport defines the directions of the development of the infrastructure. This direct relation allows one to claim that, apart from regulating the residents' standards of living, the improvement of transport consequently shapes the cityscape. The present paper is aimed at showing the examples of cities whose development is based on a good organization of individual non-motorized transport and public transport, as well as the guidelines on shaping transport infrastructure which are included in theoretical papers.

Keywords: urban transport, public space, public transport, routes and trails for bicycles and pedestrians.

INTRODUCTION

One of the definitions of a city explains that it is a place for meetings, trade and communication. The cities developed striving to keep the ultimate harmony of the coexistence of these three elements that shape a city. All the components of a city were adapted to the scale and the needs of man. A traditional city had a clear division into the centre and the outskirts. The turn of the nineteenth and the twentieth centuries was a time of significant social changes caused by the industrial revolution. A new model of the society and the separation of the place of residence and the workplace brought the growth of motorized transport, which precipitated the abandonment of the urban planning system of that time. The full bloom of the rail transport, and later the popularization of cars contributed to the urban expansion especially that along the main routes leading to the city centre. It caused the growth of the suburbs. The distances between individual parts of the city became so long that travelling on foot was no longer possible. Residents were forced to use the city or car transport. The streets in the city centre that were formerly used by pedestrians, people travelling on horseback or by bike, were now roads for cars, and the meeting places and trade locations like city squares became car parks for these cars. Gradually the cities became less people friendly and turned into space for cars. Observing the following stages of the development of the city we can notice how closely it is connected with the accepted model of the transport infrastructure and its expansion.

METHODS

The descriptive analysis of the transport system and its urban context in the developing cities of Poland demonstrated by the example of the city of Rzeszów.

Defining selected premises of theoretical papers concerning urban transport.

The descriptive analysis of selected examples of transformation of urban transport and the description of how these changes influence the creation and functioning of the public space.

DISCUSSION

For the cities of Poland the statistic data concerning the level of motorization published by Eurostat is mostly disturbing. While in France motorization has increased slightly by almost 1%, in Germany it has decreased by 3%, in Poland between years 1999 and 2009 its level increased by 80%. What was also observed was that in case of Poland, the larger the city, the larger the number of cars per one thousand residents; whereas in the countries in Western Europe a greater number appears in rural areas due to the difficulties in providing public transport that would operate smoothly. Poles' prevalent desire to use cars as means of transport may be caused by many factors. The important one is undoubtedly the phenomenon described by urbanists as urban

sprawl. The term is explained as ex urbanization. The definition comprises a complex question of the spreading of buildings (beyond the city's boundaries or towards them), mostly to the agricultural areas and the consequent high segregation of functions. Recently urbanized areas that so far have been used for agricultural purposes, for obvious reasons have poorer access to various services and are not connected with the city centre. If they are included in the urban public transport system, the frequency of bus runs of the routes present in the area is mostly insufficient. This forces the residents to use private cars despite numerous difficulties such as traffic jams or the lack of parking places in the city centre.

The city of Rzeszów is an example of a city in need of a solution to the problem of transport and its negative impact on public spaces. At the moment the city lacks meeting places in individual districts, and the existing public places in the city centre are difficult to access, there are few of them, and they have poor aesthetic qualities. The region's capital is an important centre of industry, economy, commerce, services, culture and education due to its administrative function, location and size. It covers the area of 116.56 square kilometres and the population density is about 1,600 people per square kilometre. The capital of the Podkarpackie province is characterized by a low level of urbanization. Built-up areas constitute merely 32% of the city's general area and equal 36.92 square kilometres. The remaining areas which form the total of the city's area are as follows: agricultural areas (73.52 square kilometres), forested areas (4.59 square kilometers) and wasteland (0.22 square kilometres). The existing buildings show a compact feature only in the historic centre of the city. The remaining buildings, especially on the outskirts, create more random arrangements without a distinct model of transport connections.

The road system in Rzeszow does not work properly due to the fact that maximum traffic capacity has been exceeded. There are several causes of the street congestion. The constantly growing number of cars is an important cause here. In 2008 there were 431 vehicles per one thousand residents. By comparison, in the capital city of Germany – Berlin, which covers the area of 890 square kilometres, thus seven times the area of Rzeszow, the number was 318. Another cause of street congestion is the insufficient connection between individual districts. The city of Rzeszow is divided by the River Wislok, as well as railway lines that come together in the centre, coming from the east, the south and the north (outside the centre ramifying to the north and the south). There are not enough bridge connections (there are 5 including 2 with single lane alternating traffic) and overcrossings with railway lines (there are 8 including 2 with single lane alternating traffic). Another aspect affecting the traffic capacity is the overlapping of transit traffic and the local traffic, which results from the lack of ring roads.

The system of public transport is mostly based on bus lines. They belong to different shipping companies that care neither about coordinating regional connections with local ones nor about coordinating the inner city connections. It results in the increased time and arduousness of travel. Consequently, the residents are reluctant to travel this way. The fact that the routes have not been marked out properly may be another cause of aversion to public transport. The bus lines overlap in some parts of the city, and other parts are served insufficiently. There is no division into fast buses running on greater distances and buses running in individual districts. The lack of punctuality is caused by road congestion and the technical conditions of buses. As much as 40% of transportation consists of buses over 15 years old. Due to the low quality of service the number of passengers of public transport decreased from about 43 million to 36 million a year, from 2004 to 2010.

In the province capital city non-motorized transport has been pushed to the background. Currently it constitutes merely 20% of all travel that takes place in the city. Travel by bicycle makes less than 2% of this number. Although cycling is considered the most efficient on average and short distances, in Rzeszów this means of transport is inconvenient and dangerous in some places. In the city centre only a few streets give priority to pedestrian and bicycle traffic. Pedestrians' discomfort is caused by the fact that streets are too narrow and damaged. In many places they are separated from busy streets and car parks with high acoustic screens. This solution creates additional barriers, and the scale of the acoustic screens is overwhelming for the pedestrians. The sense of security is also diminished. What is also worth mentioning is that the roads that one has to cross without traffic lights are too wide. The basic inconvenience for cyclists is the poor infrastructure. Trails for bicycles were constructed along the ring roads and there are no cross-town connectors leading bicycle traffic into the centre. Although officially the total length of the bicycle trails is about 90 kilometres, these are actually mostly routes for cyclists and pedestrians, without designated lanes, inconvenient for the former and dangerous for the latter. The fact that the existing trails are not connected is a serious impediment. Travelling on the roads alongside cars is dangerous, which is proved by the statistics concerning accidents involving cyclists. Another problem is that the bicycle routes have been constructed and equipped with traffic signs in a wrong way. It results from the lack of regulation and detailed guidelines on projects. The consequence of light bicycle traffic is the shortage of special racks for parking bicycles.

Jan Chmielewski (Chmielewski J.M., 2001) in his thesis titled "The Theory of Urban Planning" describes an urban transport system that operates smoothly. It is characterized by fully integrated network of various transport systems. The author names three main components of an exemplary system. They include road systems used mainly by private car transport, the systems of community transport connections (bus routes, tram routes, railway lines and the Underground) as well as the systems of routes and trails for bikes and pedestrians.

The transport system proposed by the author operates effectively only when individual car transport does not dominate. It is exclusively a necessary complement of individual non-motorised transport and community transport. Chmielewski stresses that "Private car traffic is the most area and cost consuming and the least environmentally friendly one […] the authorities should, therefore, strive to "elevate the standard of community transport, increase its accessibility and the speed of travel".

Creating a transport system whose components complement one another and form a vast network of connections is described by Christopher Alexander in "A Pattern Language" (Christopher A., 2008). The author proposes concentrating different means of transport on the points of change and designating stops on these routes no more than 200 metres away from one another, so that the distance can be covered on foot. It is aimed at minimizing the waiting time and creating a possibility for a swift change.

Due to the fact that trams, trains and buses run on strictly designated routes, Alexander suggests enriching the system of public transport with a service of minibus on demand where the order is made over the phone. A computer-operated system combines the qualities of a bus and a taxi. For a low fee a minibus delivers its passengers to the places of their choice within a given zone. The stops of minibuses should be located about 200 metres away from one another and be equipped with a device for calling the bus. This system works in an exemplary way in the city with sixteen thousand residents, Batavia, New York, USA, where it is the sole means of public transport.

Among the patterns developed by Christopher Alexander (Christopher A., 2008) there are also guidelines on forming the infrastructure for both bicycle and pedestrian traffic. According to the author, in order for the pedestrians to feel comfortable while travelling along roads with heavy traffic they have to be separated from the lanes for car traffic by means of pavement at least 3.5 metres wide and situated 45 centimetres above the road.

Wide pavements were designed in an exemplary way in the Elysian fields in Paris, at Times Square in New York, and in Piccadilly Circus in London. Yet, if it is possible, the most advisable solution for the routes for the pedestrians is planning the routes in a way that they create their own network independent from the roads, and can be connected with the roads only at the right angle to them. At the points of intersection of both networks, crossings at the same level as the pavement are created for pedestrians. This way of shaping makes the drivers driving through this place slow down and drive with greater caution, which increases the level of pedestrians' security. Alexander also suggests that lanes for cyclists should be situated slightly lower than a pavement, stand out in terms of colour and surface in order for the zones for different uses to be clearly designated. A system of this kind allows increased sense of security and separation between cyclists and pedestrians.

The organization of individual and community transport should not only have a function of transport, but also improve the quality of the existing public space or facilitate the creation of new public space. Since the public space determines the character of urban structure, the aspect of its accessibility to the users is of vital importance. D.Ghirardo (Ghirardo D. 1999) expands the term of accessibility in the book "Architecture after Modernism." The author suggests that the liveliness of public places depends on the degree of accessibility. That is why it is essential that city squares, parks, and promenades be safe, convenient and be accessed easily. The authorities of modern cities realize that open space integrates the urban structure and creates its unique character, and they employ various means of limiting the destructive car traffic.

The development of public and private transport is closely connected to progressing urbanization. Coordinating the expanding of urban buildings and the development of transport system is a complex process. It is advisable to use solutions that have proved successful in modern cities. This requirement is fulfilled by the idea of a compact city, also called the idea of a city of short distances. According to the idea, the city should expand inwards, and not outwards. The rule leads to saving the city's area by limiting the spreading of the buildings. It takes place through supplementing the existing buildings and revitalizing the degraded areas. As a result, instead of covering larger and larger area, the city displays high intensity of buildings. Stopping the expanding of city's boundaries allows creating a more effective transport system within the city. The compact city model assumes that residents have access to basic necessities in their immediate neighbourhood, and access to the remaining services offered by the city is facilitated due to the shorter time of the journey. The realization of such planning premise can be a direct way of relieving the roads.

The city that may serve as an example here is Munich. The plan of its development was contained in the following motto: "Compact – Metropolitan – Green." It presupposed the lack of uncontrolled building development spreading to the outskirts. A part of the description of the strategy reads: "We should limit investing on undeveloped land and bare land of the suburban areas, and concentrate the spatial development of Munich on vacant land within the city instead." Thus, buildings are being created around railway corridors, in

the post-industrial areas and in the area of former barracks. What is equally important is that plans are being made to create parks and gardens of a proper size that will connect the centre to the greenery around the city.

Another city that is expanding in accordance with the compact city model is Stockholm. One of the industrial districts in the very centre of the city on Lake Hammarby is called Sodermalm. It is currently being transformed into a new residential and commercial area. At the same time the authorities plan to build a tram route, ferry connections, bridges and footbridges in order to properly include the new area in the existing structure of the city.

The cities of the United States of America are the examples of a completely opposite trend in developing the city structure. Because of very long distances between pasts of the city the transport in Chicago, Dallas or Las Vegas consists almost exclusively of travelling by car. The main reason for this situation is the car culture, which is predominant in the USA. It results mainly from the tradition of owning a car as property, but the relatively low cost of petrol, and the fact that it is possible to park free of charge in the city centre and to use free motorways also encourage the car culture. For example, only a hundred years ago there were streetcar (tram) routes in Los Angeles, but in the 1940s they were dismantled almost entirely. They were replaced by wide motorways connecting working areas to the city centre. The reason for these decisions was the continuously increasing number of cars. A car ceased to be a luxury and became something that more and more people could afford and keep. The motorways expanded and they cut the urban area until the present state, in which their further development is impossible due to the lack of space. The outskirts of the cities in the USA have a housing function. Every day an average resident spends a few hours in a car in order to do his or her errands. Some of these errands are done without getting out of the car, for example: using automatic teller machines, checking mailboxes, or buying food. This kind of lifestyle and the fact that residential areas have only one function do not encourage the development of public spaces. For example, less than 5 % of people in Los Angels travel on foot. It is necessary to change the organization of transport, but most of all to change the lifestyle. It is important to approach the problem of designing cities comprehensively and to create evenly distributed multifunctional public spaces in the area of a city. It is vital that meeting places connected with one another in individual districts and generating human contact be created.

Community transport can be a competition to private car transport provided travelling by bus is more efficient, faster, and cheaper than travelling by car. This was pointed by mentioned earlier Jan Chmielewski (Chmielewski J.M., 2001) and can be achieved through creating priority lanes for public transport. This improvement proves successful in many cities. A textbook example is the solution used in Almere, Holland, where separate roads were created for buses; the roads have traffic lights giving public transport vehicles the right of way every time their routes cross public roads. An interesting solution used also in this Dutch city is giving the pedestrian and bicycle traffic exclusive access to the entire ground part of the city centre. What is uncommon, car and bus connections run on roads that together with garages are situated underground. It should be pointed out, however, that such advanced infrastructure of traffic segregation is much more difficult to implement in existing cities than solutions found in Copenhagen.

This city successfully limits car traffic in favour of community transport and especially in favour of pedestrian and bicycle transport. In Denmark in the 1950s the importance of a car grew significantly. At the same time, the amount of public space was reduced, and the number of accidents involving pedestrians and cyclists increased. The authorities of Copenhagen affected by this problem noticed that the city centre was becoming devoid of people and started introducing organizational changes. Despite the initial protests of car users, a transformation of the main street of the city of Stroget began in the 1960s and later the whole centre, into a zone closed to car traffic. Parking places were reduced gradually by 2-3% a year, while the number of routes for pedestrians was increased. In 1968 their area covered 20.5 thousand square metres, and by 1995 it increased to 71 thousand square metres. At this point bicycle traffic constitutes 36% of all travel, whereas the number of cars per one thousand residents is one of the lowest in Europe and equals 208.

In his book ”Life between buildings. Using public space”, Professor Jan Gehl (Gehl J. 1987) writes about the street in Stroget: “Today this main pedestrian street is thronged with people walking, sitting, watching events, playing music and talking. Apparently, the initial fears were groundless, and the city life in Copenhagen was greatly limited (…)”

An example of significant and positive changes in transport is the centre of Utrecht, a city in Holland. Currently the city centre is vibrant. Individual car transport is banned here completely. Ever since the pavements were removed from the majority of roads, the whole width of the streets has been allotted to pedestrian and bicycle traffic. Public places in the city are great example of accessible space which was described by D. Ghirardo (Ghirardo D. 1999). Easy to approach and comfortable to stay in.

In the historic city centre there is Potterstraat Street. From the early days of the city (1200) the street has been an important route of transport. The beginning of the twentieth century brought transport problems connected with the growing number of cars. The street dating from the Middle Ages was too narrow to meet the requirements of such considerable traffic. In 1920 the plan of the restructuring of the historic city centre, which

consisted in widening Potterstraat Street by pulling down buildings on one side, was implemented. A fast, wide, four-lane road was created. In the 1950s and 1960s it became the most important east-west route in the city. The flow of the traffic improved but only for a short time and already in the 1970s another rapid increase in the number of cars contributed to a decision about widening other roads in the centre. In 1975 more buildings were pulled down and other buildings – thinner and taller – appeared. The entire structure of the city centre and the scale of the city were changed. The residents' reaction to the new space taken over by cars was very negative. The expensive changes which aimed at improving traffic proved ineffective, and became inconvenient for people. The authorities realized that further widening of the roads in the city centre had no justification and that the residents' conditions of living were deteriorating, therefore, gradually they began to introduce more changes. At first car traffic was banned only in a few streets twice a week, on the days of the greatest trade intensity. Since the effects were positive, by 1990 the fast traffic had been removed from the city centre completely and all the streets which had been widened regained their original width. The demolished buildings were rebuilt, and the space between them was made available to the pedestrians and cyclists. What is more, the main roads were made available to the public transport. The squares no longer served as car parks and became the meeting places and spots for relaxation for the residents. The traffic in the centre was slowed down and became more efficient. Currently an extensive network of bus routes and cycle lanes exists in the city centre and it provides transport to more people, while taking less time than car travel. The streets of the current width are wide enough to accommodate everyone effectively. The leading ways of travelling are inexpensive, safe, and they produce much less noise and pollution. The city centre regained the character of high quality public space.

CONCLUSIONS

The quoted examples describe cities whose structure is revitalized to restore the balance between the elements that shape them. Supported by the theoretical papers mentioned they give guidelines for the cities affected by the problem of excessive car traffic like The city of Rzeszów. The strategies for changes...

The strategy of changes should combine the four main premises. When the structure of transport concentrates on the efficiency of the community transport, it should ensure the coexistence of the community transport, the road system for individual car traffic, and the routes for pedestrians and cyclists at the same time. Public places should receive the status of accessible places by providing the residents with security and convenience as well as easy approach. The expansion of buildings should be directed towards the inside of the city in order to achieve concentrated mixed land uses. In transport infrastructure attention to both macro scale (linking transport networks) and micro scale is necessary. All the details have to be designed and made based on detailed guidelines in order to provide pedestrians, cyclists, and community transport users with convenience.

We should remember that the amount, quality and accessibility of public space are the factors creating the character and atmosphere of the city. Considering the fact that transport in a city is closely connected with the aforementioned factors, its balanced development should be top priority. The access to services provided in a people friendly space as well as the convenience and safety of travelling between places increase the attractiveness of the city. Attracting new residents, and also students or tourists, generates new investments, which leads to considerable general progress.

REFERENCES

Chmielewski J.M., Teoria urbanistyki w projektowaniu i planowaniu miast, [Theory of urban planning in designing of towns], Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2001.

Christopher A., Język wzorców. Miasta, budynki, konstrukcja [A Pattern Language: Towns, Buildings, Construction], Gdańskie Wydawnictwo Psychologiczne, Gdańsk 2008. Vol. 1, 64-98, 110-132, 173-190, 276-297.

Ghirardo D., Architecture after Modernism, Wydawnictwo VIA, Toruń 1999.

Gehl J., Life between buildings. Using public space, Van Nostrand Reinhold Company Inc., New York 1987.

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Buildings of Performing Arts in Latvia's Modern Movement

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EXTENDED ABSTRACT

After WWII, the Soviet Iron Curtain impeded sharing of knowledge between the Baltic socialist republics and other European states. It was necessary to find roundabout ways of introducing the innovative-minded global spirit, combined with the local architectural traditions and the actual possibilities established already in the 1920s and 1930s.

The aim of the study is to make an inventory of buildings of performing arts and their stylistic and functional features, and analyzing an overall development process of various types of buildings in the second half of the 20th century, to determine how the prevailing stylistic trends in the world, having blended with the local building traditions, had influenced and defined the place of Latvian architecture and cultural heritage in the European context. The study is based on the analysis of the architecture of performing arts buildings. A number of unpublished sources and archival materials have been discovered and a method of monographic and historical approach has been used.

In the late 1950s, when construction of large-scale residential districts began in the cities of Latvia using pre-fabricated building constructions, the same degree of industrialisation was also applied to the architecture of public buildings. However, buildings of performing arts were constructed to individual designs. Until the early 1990s, architects' contribution to Modern Movement was considerable, and its influence is still present today both in the capital city and in towns.

After World War II, a strong school of architecture with distinctive national features and accents had formed in Latvia. Architecture became international and it was determined by several factors, namely, the synthesis of values and mass production requirements, standardization of designs and emphasis on functionality at the expense of aesthetic qualities. Therefore, the architecture of Soviet Latvia can be compared to the works of those European architects which reflected a similar understanding of values.

The values of Modern Movement are recognized at a very slow pace in Latvia. In future the architecture of Modern Movement should be divided into several stylistic groups. Such stylistic varieties can be distinguished taking into account the general evolution of the style blending with local traditions, e.g. regional cubism and minimalism. Similarly, characteristic approaches of certain architects can be distinguished. Thus, it would be easier for the local community to identify them as part of their national architectural and cultural heritage.

Keywords: Latvia's architecture, soviet period, performing arts, cultural heritage, history.

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REFERENCES

Krastiņš, J., 2010. Changing Ideals of Modernity: Brīvības iela in Riga. In: Scientific Journal of Riga Technical University Architecture and Urban Planning, Series 10, RTU, Riga, 2010. Vol. 4, 30–36.

Krastiņš, J., Strautmanis, I., Dripe, J., 1998. Latvijas arhitektūra no senatnes līdz mūsdienām. Baltika, Rīga, 1998, 312 lpp. [Krastiņš, J., Strautmanis, I., Dripe, J. Architecture of Latvia from Ancient Times till Nowadays. Baltika, Riga, 1998, 312 p.].

Materials from the archives of Daina Dannenberga.

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Building a Green Roof in Lithuania

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EXTENDED ABSTRACT

Green roofs are relatively new to Lithuania. Traditionally, such earth structures were used for partially submerged food cellars and bomb shelters. However, one sees more and more architects opting for green roofs as an alternative to large flat roofs. The advantages are many fold. A green roof is not only a pleasing aesthetic alternative, but it helps retain thermal energy and provides for better surface drainage for expansive roofed structures.

This paper examines the origins, basic principles and benefits of green roofs, noting examples and a chart indicating various green roof systems. The international standard is largely set by the Forschungsgesellschaft Landschaftsentwicklung Landshaftsbau e. V., or more simply FLL, first developed in Germany in the 1970 s.

I have designed five green roof projects in Lithuania. Two are located in Trakai, two in Vilnius, and one in the Ignalina region. Precedents are cited, along with photos, technical drawings, structural details, materials specifications and the ecological benefits these roofs provide in urban and rural environments.

In conclusion, green roofs are a relative low cost alternative to flat roofs, which provide greatly enhanced benefits. As a result, European cities have set targets for the percentage of green roofs constructed each year, and the European Union has offered financial aid and assistance in meeting these targets. Hopefully, this will encourage more Lithuanian developers, architects, and engineers to consider green roofs as a viable solution.

Keywords: Green roofs, sustainable design, architecture.

REFERENCES

Breuning, Jörg, and Yanders, Andrew, 2008 Edition of the Green Roofing Guideline, Introduction to the FLL Guidelines for the Planning, Construction and Maintenance of Green Roofing.
Costanzo, Michele, MVRDV: Works and Projects 1991-2006, Dutch Pavilion, pp. 70-79, Skira, 2006.
Margolis, Liat, and Robinson, Alexander, Living Systems, Birkhäuser, 2007.
Werthmann, Christian, Green Roof – A Case Study, Princeton Architectural Press, 2007.
Individual projects cited as examples can be viewed at http://www.ferguson-studio.com.

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On the Challenges and Dimensions of Sustainability of Social Housing

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EXTENDED ABSTRACT

The research was aimed to discuss and reconsider the concept and challenges of the social housing in the world and in Lithuania and consists of three major parts: analysis of the evolution of social housing, discussion on the introduction of the dimension of sustainability in the design of affordable housing, and the analysis of the local specifics of the city of Kaunas from the pints of view of localization and design of social housing.

The history and evolution of the social housing projects beginning with the start of the 20th century demonstrates the relevance of this issue both in modernist and postmodernist architectural movements. The experience of the 20th century and the failure of many functionalist affordable housing projects demonstrate that there is no universal model for social housing and even theoretically the most culturally and socially sensitive projects sometimes are doomed to failure. This shows the complexity and contradictions of socially orientated architecture and proves that the individual problem needs individual solution. We had distinguished eight trends of architectural expression and organization of social housing: idealistic or showcase model, functionalist concept, brutalist concept or large housing units, regionalist concept, structuralist concept, postmodernist or individualist concept, ecological concept, and realistic concept. In order to demonstrate the possibilities to integrate the dimension of sustainability in this field we had distinguished several trends of sustainable architecture of social housing: sustainable functionalism, sustainable housing complexes, sustainable regionalism, sustainable structuralism, environmentally friendly postmodernism, trends of ecological sustainability and economic sustainability. The site and context of the social housing project are not less important. The analysis demonstrates that from the one hand the social housing projects should be optimally located and dispersed in the urban fabric in order to avoid social segregation, the formation of ghettoes and the non-sustainable urban expansion. From the other hand, new projects can become catalysts for revitalization of deprived urban areas.

The results of experimental design of sustainable social housing in Kaunas show possible individual solution for the particular place. The abandoned plot surrounded by single-family housing and objects of cultural heritage in the garrison camp in Panemune is transformed into a quarter of social housing. Proposed architectural expression and urban form of the quarter is consistent with the contextual architectural urban and natural environment using the principle of nuance. We propose to use eco-technologies, ecological building materials and vertical planting in the experimental design proposals. The designed quarter will be multi-functional complex, which will additionally create job places and will foster social cohesion. The qualitative changes of adjacent neglected areas are also planned.

Keywords: Sustainable architecture, social housing, Kaunas.

REFERENCES

Benson J. F., Roe M. H. 2000. The scale and scope of landscape and sustainability. In: Benson J. F., Roe M. H. Landscape and sustainability. New York, Spon Press, 2000, 1-11.

Kamičaitytė-Virbašienė, J., Gražulevičiūtė-Vileniškė, I. 2010. Miscellaneous environmental visual impacts of sustainable buildings, In: Proceedings "Advanced construction: the 2nd international conference", Kaunas. 2010, 48-53.

Wines J. 2002. Green architecture. Koln, Taschen.

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Aesthetics and Safety of Road Landscape: Are They Related?

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EXTENDED ABSTRACT

The problem of unsafe roads is very pertinent in Lithuania which is described by of the highest road fatality rates in Europe. This is due to a big amount of traffic on Lithuanian roads caused by the geographical situation of Lithuania as well as poor road cover, hardly visible trades' marks and other. The authors analyze road safety through aesthetic features of landscape. The identification of relations between safety and landscape aesthetic features will enable us to enhance safety by modeling road landscape. This untypical approach would lead to both achievements: decrease of road traffic accidents and increase of visual quality of road landscape.

The research of aesthetic properties of road landscape was conducted in spring 2010 by employing the photo-fixation of road landscape and the qualitative survey (Matijošaitienė, 2011). Aesthetic properties of road landscape were used for the survey and for the analysis of aesthetics and road safety*: interesting, natural, visually safe, skittish, beautiful, outstanding, harmonious, sophisticated, relaxing, majestic, pleasant, elements match for surrounding environment, left an intense positive impression, willing to drive on this road.* These properties were measured by the 5-point semantic differential scale (Matijošaitienė&Stankevičė, 2011). Thus, the aesthetic properties of road landscape are based on respondents' emotions and their opinion about a certain road landscape. The number of respondents was N=486.

Values of the correlation coefficients demonstrate weak or very weak relations between the variable *Quantity of car accidents* and other variables describing aesthetics of road landscape. This could happen due to not very detailed information about aesthetic properties of each road landscape. More detailed data on road landscape aesthetic properties would let us create the guidelines for the design of an aesthetic and safe road landscape, and to forecast potentially dangerous (unsafe) places of road landscape.

The results of the correlation analysis (both Kendall's tau_b and Spearman's correlation coefficients evaluated) revealed that the road safety described through the quantity of car accidents is weakly related with some aesthetic properties of road landscape. Actually, the more landscape is *pleasant*, *beautiful, harmonious, natural* and *elements match for surrounding environment* the more car accidents happen, and the more road landscape is *relaxing, visually safe and sophisticated* the less car accidents happen.

According to the multiple linear regression analysis the more landscape is *beautiful, willing to drive, natural, harmonious* and *majestic* the more car accidents happen on the road, and the more road landscape is *interesting, elements match for surrounding environment, relaxing, sophisticated* and *visually safe* the less car accidents happen on the road. Still, the coefficients of the independent variables and the constant are too high, therefore the equation need to be revised in further research.

Keywords: Road landscape, aesthetics, safety, correlation analysis, linear regression analysis.

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REFERENCES

Matijošaitienė, I. 2011. Automobilių kelių hedonomiško kraštovaizdžio formavimo principai. Daktaro disertacija [The principles of formation of hedonomic road landscape. Doctoral thesis]. Kaunas: Technologija.

Matijošaitienė, I., Stankevičė, I. 2011. Hedonomic Roadscapes in the Context of Urban Sprawl. The Scientific Journal of Riga Technical University, 5, 70-76.

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Attitude Turnover Towards Ecology and its Influence on Housing Development

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Abstract. At the end of the 20th century environmental pollution, human morbidity and worrying predictions of climate change raised importance of ecological architecture and sustainable design. This article reviews the evolution of residential architecture from ancient times to the present days. Also critical points of housing design development are defined based on human social progress and environmental awareness.

Key words: development of residential architecture, sustainability.

INTRODUCTION

In 1923, a pioneer modernist Le Corbusier praised the new century proclaiming the beginning of new era, comparing it with new spirit which overwhelmed all the humanity by showing a new way in life. But today, after almost 100 years after this famous statement, we are witnessing the negative consequences of industrialization. We are running out of natural resources, experience loss of biodiversity, deforestation and climate change (Wines, J., 2008, p. 9).

At the end of the 20th century, architects and the society recognized that, contrary to what was claimed by the Le Corbusier, residential buildings are not machines for living. It was understood that environment and architecture, in particular, has impact on human beings and the relationship between humans and nature was emphasized. New environmental thinking gave birth to a new direction of eco-design. This movement emerged in the early 1990s and is continued up to date (Wines, J., 2008, p. 8).

The aim of this article is to review the evolution of residential architecture and the concept of sustainable development from the first rudiments of human shelters in prehistoric Neolithic period to the present day homes. It is important to highlight specific features of residential buildings at certain periods and their impact on future residential development and on the environment. Also the main trends of modern ecological residential buildings are discussed and main future tendencies indicated.

Figure 1. Skara Brae remains - example of the oldest Neolithic settlements in Europe, around IV century B.C. (Skara Brae)

Neolithic caves – the beginning of ecological housing

Neolithic period was the last part of the Stone Age, associated with pottery, animal husbandry and the start of agricultural. In social terms, this meant the emergence of a sedentary lifestyle: prehistoric people stopped wandering and started establishing first settlements. (Wines, J., 2008, p 37; Neolithic) Based on the first residential constructions English archaeologist Gordon Child called this period a "Neolithic Revolution" (Vere...).

Shelters of Neolithic period were primitive and often unsafe, but they had greater contact with nature than the modern skyscrapers. Simple dwellings in China, Turkey and Egypt did not require heating or air conditioning systems because they were naturally supported by the appropriate inner temperature (see Figure 1).

Moreover, the spiritual relationship of primitive people with nature should be noted. Pantheistic or animalist philosophy of their lifestyle forced to be dependent on environment. The present-day manifestations of such philosophy may be found among the tribes of Polynesia, Africa, and among the American Indians. The best

example could be Australian aborigines, who despite modern technological advantages still keep their spiritual connection with nature (Wines, J., 2008, p 42).

The change of attitude towards environment in Early Ages and its reflection at residential construction

Residential architecture of Early Ages mostly unconsciously paid close attention to sustainability. Those primitive constructions can be called the prototypes of modern green buildings. Even though they were not very good looking, they represented predominant standards of beauty and their design could be called sustainable. (Wines, J., 2008, p 48)

Figure 2. Remains of Ancient Egyptian village Dier-el-Medina about Second millennium B.C. (Ancient Egyptian...)

In ancient times the balance between residential construction and natural environment was closely linked with religious beliefs. In ancient Egypt (about 4000 B.C.) the cult of polytheism led to focus on environmental processes. Egyptians developed environmental management system, based on responsibility to nature and its cycles. While disobedience of the order was punishable. Such approach differs from today's legal environmental programs because they lack spiritual connections with nature (Wines, J., 2008, p. 49).

Egyptian cities can be characterized by an open structure. They were not surrounded by defensive walls, and the city borders were distinguished by relative threshold. Therefore, ancient Egyptian suburbs organically blended with nature. Residential houses were rectangular, built out of sun-burned bricks. They were bleached with lime in order to reflect the sunlight. (see Figure 2) (Springer) Mesopotamian cities, unlike in Egypt, were closed and surrounded by walls (up to 30 meters in height). They had gates that led to the city. However the way of home construction was different – they were built close together in the shape of rectangular (6x6 meters) (Mesopotamia).

Ancient Greek philosophy proclaims change in relationship with nature

Modern perception of anthropocentric world is greatly influenced by ancient Greek scientific and philosophical discoveries. Democritus (about the V century B.C.) formed atomic theory and put the foundation of modern physics. He was among the first stated that nature is not that it was perceived before. Greek discoveries in the field of mechanics allowed relieving amount of work spent on everyday life. However at the same time they exalted the power of human mind and put the foundation of modern western civilization - the idea that man can take control over nature (Wines, J., p. 52).

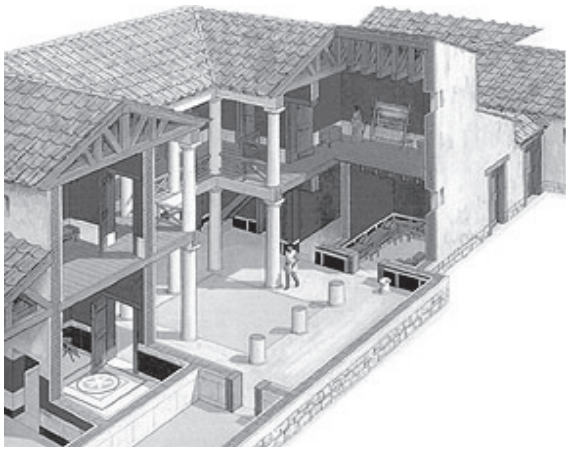

Figure 3. Example of luxurious Greek house in IV century B.C (The Greek...)

Superiority of human mind can be noticed in Greek culture, especially in architecture, which began to emphasize the proportion, scale, correct geometry - as the inevitable aesthetic standards. Ancient Greeks started to change landscape of their surrounding environment sometimes leading to ecological disasters. Namely, the first known environmental disaster appeared in the Ancient Greek city of Athens by cutting down the surrounding forests (Wines, J., p. 53).

Greek houses were built out of sun-burned bricks on a stone foundation, often reinforced with wooden baulks. Roofs were covered with clay tiles. They were significantly more luxurious that Egyptian or Mesopotamian homes. Often the size of the house depended on the wealth of the owner. Also two-storey houses were constructed dividing the space according to the gender on male (andron) and female (ginaeceum) (see Figure 3) (Greek...).

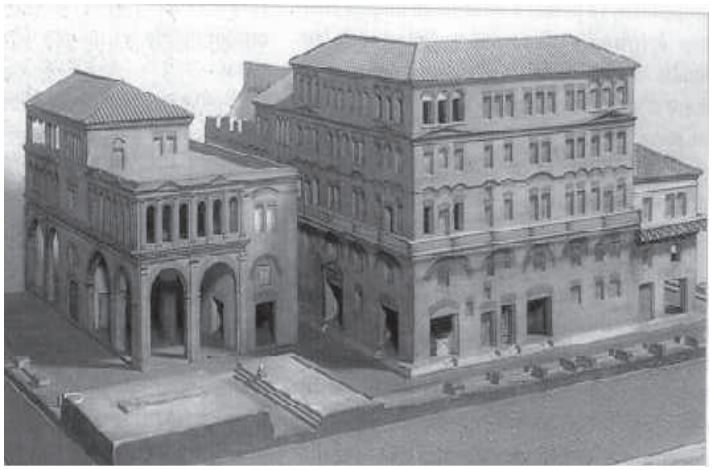

Figure 4. Insula in Ancient Rome about I ct B.C. (Roman…)

Ancient Rome took over the Greek philosophical, religious and scientifical achievements. This determined the continuity of classical style up to the beginning of Christianity. Cement could be named as the most important discovery of Ancient Rome. It allowed increasing the scale of construction: building roads, viaducts, and improving the irrigation systems (Ancient Rome).

During the peak of its power the city of Rome had 1 million inhabitants. Such demographical explosion forced to develop large scale of residential construction. The first Roman houses were one-storey with living and sleeping spaces, often without windows. Atrium had ensured adequate air circulation. Compluvium (uncoated part of the house) allowed eliminating the smoke and provided ventilation. Rain water was collected in the inward basin called impluvium. Some houses had inner gardens – peristyles. They were surrounded by adjacent buildings and colonnades (The Roman ...).

Houses of the later periods of Ancient Rome were two-storied. During the period of Republic also three storey houses were constructed. Cement allowed building the first multistorey dwellings – insulas. They often reached 21 meters in height (see Figure 4). It should be noted that the majority of Roman buildings (except the very poorest ones) had advanced water supply systems and wastewater disposal system. All private houses had separate bathroom facilities, where water was heated to appropriate temperature. Houses in northern Italy as well had heated floors – this is how modified hypocaust system of Roman Baths was adapted for mild northern climate (Ancient Rome, Roaf, S., 2007, p. 35).

Figure 5. Thunder house – example of Gothic style residential building of the 15th century (Perkūnas)

Figure 6. Villa Rotonda – example of renaissance villa in Italy, 1591 A.D. (Renaissance architecture)

Influence of Medieval Ages on sustainable development and housing design

Medieval Ages are characterized by separation from egocentric philosophy of Ancient Greek. Atomic theory and analytical thinking threatened to the law of church, in which center point became God and perception of its fear. Nature didn't seem holy as it was before. Natural and man-made disasters were perceived as manifestations of God's anger, which cannot be avoided. Meanwhile, attempts to resist the Church published "truths" were associated with heresy until the beginning of Renaissance at 14th century (Wines, J., p. 54).

Housing construction in Medieval Ages developed in conjunction with the major architectural styles: Romanesque and Gothic. Early homes were primitive as wood, clay and stone was used as the main building material. Only the wealthy lords could use bricks for residential construction. Meanwhile, during the latter Gothic period bricks were used more often, and variety of forms and masonry techniques were developed (its particularly obvious in the examples of Flamboyant style). Roofs were often covered with tiles (see Figure 5).

Influence of Renaissance, Baroque and Classicism periods on sustainable development and housing design

At the end of the 14th century the power of Church increased and allowed developing large-scale projects, such as construction of cathedrals and monasteries. Considerable financial resources contributed to development of

Figure 7. Chatsworth House Sheffield – luxurious baroque mansion, England the end of the 17th century (Chatsworth house, Derbyshire)

Figure 8. Thomas Jefferson house USA, the end of the 18th century (Llera R. R., 2006, P. 173)

aesthetically pleasing architecture and continuity of ancient building tradition. However achievements of the Renaissance have opposed the ecclesiastical tyranny. "Renaissance Man" became the center of its humanism. He was described with perfection by stressing out the supremacy of human mind (Llera, R., R., 2006, p 87).

Renaissance residential architecture could be characterized by social delamination. Often the social status of the owner could be characterized by the exterior of the building. Peasant houses were simple, built with wood, clay, and stone. Roofs were covered with straws. Meanwhile, houses of merchants and craftsmen were two or three storey and more luxurious - with brick and stucco facades, stained-glass windows, roofs were covered with tiles. Spiral staircases were widely used because they saved space. Luxurious villas became a distinguishing character of rich estates in Italy and Spain. In France, old castles lost their fortification purpose and were adapted for recreation and entertainment. Renaissance proclaimed the revival of ancient forms: pilasters, columns, and arches. Precise geometry and symmetrical composition became widely popular. Dome roof was largely used in villa architecture (see Figure 6). Human scale became a distinguishing feature of Renaissance architecture (Renaissance architecture; Renaissance housing).

Baroque evolved from Renaissance Mannerism at the end of the 16th century and proclaimed the power of Catholicism and the triumph over Reformation. The unity of this style resulted in rich decor. It could be characterized by plastic and curved shapes, decorated details, sculptures and rich colors. Classical orders and decorative elements were combined to obtain a dynamic and dramatic effect. Luxury demanded a significant financial investment that's way the highest level of splendor was reached in ecclesial architecture. Residential homes of this period attempted to convey the exquisite relationship of proportions and elegance. Monumental and luxurious main entrance became the key feature of baroque houses. It demonstrated wealth of the owner (see Figure 7). Baroque spread widely across Europe and other continents. In different countries it was complemented by regional features (Baroque, Llera, R., R., 2006, p 117).

At the end of the 17th century Baroque was replaced by Classicism. This period was largely promoted by new industrialists, seeking to gain power through culture, to retreat from the world in which they were born into higher society and demonstrate their success. Classicism firmly rejected Baroque era imagining the future based on knowledge and scientific progress, assigning individual responsibility for the future and development through formulas that ensured progress. The later wes based on the knowledge of ancient art and its value. By exploring ruins of ancient world (especially ancient Greek heritage) it was expected to find universal beauty patterns that could become the guidelines not only in terms of aesthetics but also in moral sense. In residential architecture main entrance was emphasized with portico and pediment. Proportions and reasonable décor became important and the dome became quite frequently used in villa architecture (see Figure 8) (Llera, R., R., 2006, p 117).

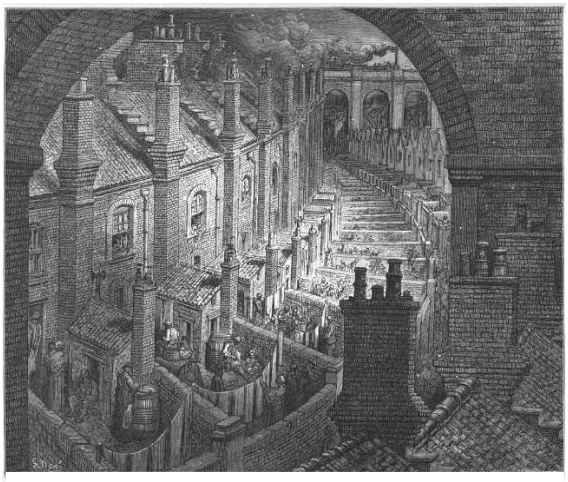

Figure 9. Industrial district in London at the beginning of the 19th century. (Industrial...)

Figure 10. Bedford park the example of Romantic English residential neighborhood, designed in 1879 by R. N. Shaw (Bedford...)

The Industrial Revolution

Rapid industrialization at the end of the 17th century resulted in separation from the nature. This period gave rise to a gradual increase in urban population growth – its quantity since 1800 over two centuries has increased six times. Mechanization and trade affected natural environment – roads, canals, tunnels were built. Increased demand for wood resulted in rapid deforestation. Pollution became the common phenomenon of the 19th century (see Figure 9) (Industrial...).

Despite the poor living conditions, villagers flocked the cities in search for work. It marks the start of construction cheap semidetached houses, the first prototypes of social homes. Many cities began to improve sanitation conditions by designing sewage and water systems. Moreover, relevant legislations were passed. Opposite to industrialization new Romantic movement appeared. Its members urged to turn back to nature. During this period classical buildings were enriched with regional features, they sought the co-existence with other styles of the past, such as Gothic, Romanesque and Renaissance (Lleras, R., R., 2006, p 179).

The largest contribution to Romantic period was made by England, with its Revival architecture. It can be distinguished by free planning, combination of various styles, high chimneys and asymmetrical composition. Such expression is also known as "picturesque" style, which evolved from free shaped English gardens where the main construction principal was to be in harmony with nature. Residential homes often were enriched with regional features - local materials, colors and textures. The first middle class residential neighborhood Bedford Park was built in the outskirts of London (architect R. N. Shaw, 1879). (see Figure 10) Unsophisticated red brick houses with small gardens approached the human scale and respected its aesthetical needs (Llera, R., R., 2006, p 191).

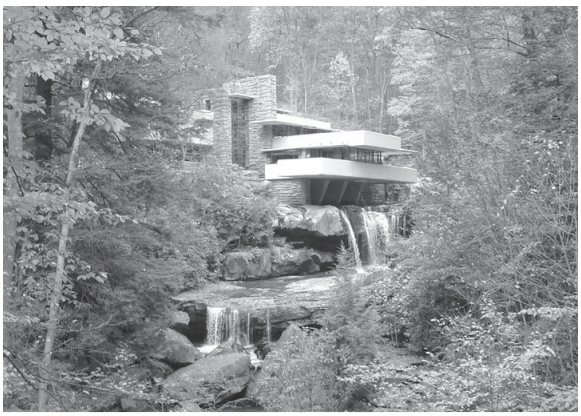

Figure 11. Wrights Falling Water –example of organic architecture, built in 1934. (Frank...)

Changes in the 20th century

The most distinguishing feature of the 20th century could be certainly named the use of new building materials, like: steel and concrete. During the first decades these materials allowed to express new vivid look in residential buildings. It was entitled as Art Nouveau. Iron allowed creating lineal and geometric forms. Floral elements and decorative details became popular in both interior and exterior of the house. Also it raised the importance of decorative industrial items widely used in Residential buildings (Llera, R., R., 2006, p 215).

However, subsequently architectural styles opposed the opulent Art Nouveau and showed the willingness to distance from any previous traditions. For example, Rationalism stated the importance of reasonable decoration, efficient design and construction. It stood for implementation of simple forms and increased the use of reinforced concrete, steel and glass. Particularly should be mentioned C. E. Jeanerette (or Le Corbusier), who developed a system of residential construction, as he called it “Domino”. It consisted of a simple reinforced concrete frame supported by columns. Concrete slabs divided floors and connected it with staircase. Such approach allowed developing cheap housing units and opened the way for mass residential construction (see Figure 11). “Domino” theory became especially relevant after the 2nd World War, when Europe faced demographical explosion and shortage of housing. (Llera, R., R., 2006, p 239)

Another important direction of the 20th century became Organic architecture. It was popularized by such notable architects as F. L Wright and A. Aalto and could be called as pioneering stream of green architecture. The term "organic” expressed housing design with close connection to nature. It stood for the use of local materials (especially wood), free planning and harmonious contact with nature. Design of organic houses sought to erase the boundary between interior and exterior. Nature often became a part of the whole architectural composition (see Figure 12). Such versatile understanding allowed to implement more regional features and could be described as counterweight to modern Rationalism (Llera, R., R., 2006, p 253).

Figure 12. Unite d'Habitation - the first modern multistorey residential building designed by Le Corbusier in 1947 Marseille. (Unité...)

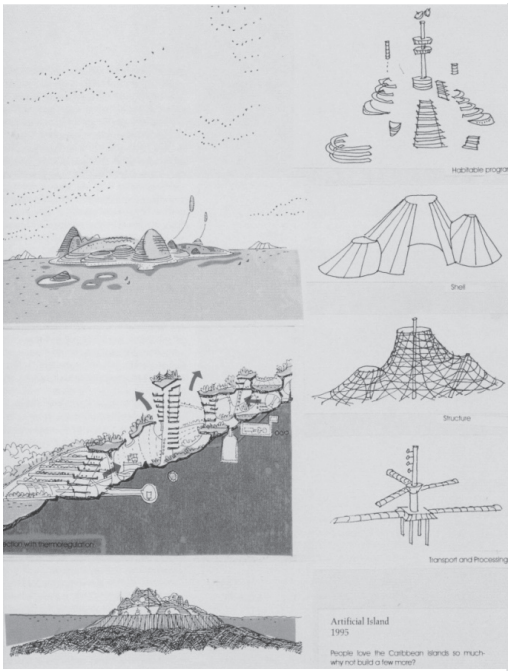

Figure 13. Jeffrey Miles Artificial Islands – Vision of future underground living (WINES J., 2008, P. 197)

However, eventually F. L. Wright ideas were forgotten. It seemed that Le Corbusier, Mies van der Rohe or Melnikov produced more attractive solutions. Their thoughts seemed to be simple and could be easier implemented into everyday life. Progressive design was understood as cheap and functional. All this determined that at the end of the 20th century our society lost complete contact with natural. Residential architecture became repetitive, pale and faceless. It lost its regional features and symbolism (Wines, J., 2008, p 11).

Challenges and trends of the 21th century

Modern era of information and technology is forcing to change views towards residential construction. At the beginning of the 20th century Le Corbusier praised geometrical forms such as: cube, cylinder and sphere. However, now modernist philosophy became too precise to define the new ephemeral and changing world of communications. It's emphasizing the importance of dialog and conceptuality. Exterior without its surroundings lost its meaning. Only responsible architecture that states future questions such as: ecology, aesthetics and social integration became meaningful (Wines, J., 2008, p 20).

However, it should be noted that the future vision of sustainable residential buildings is vague because the search for new technologies has just begun. Currently a lot of modern examples of sustainable buildings are more experimental than real solutions against wasteful way of life. Depending on a few successful examples the following main streams of sustainable homes could be pointed out: passive, active and modern organic homes (Passive House, Active House, Private ...).

Talking about trends of future sustainable houses J. Wines points out two possible solutions: underground habitat and living on the water. The first solution is taken from the nature and people will have to adopt it when the exponential population growth will result in the shortage of land. People will be able to move to underground when future technologies will ensure reliable infrastructure and inflow of natural light. Whereas living on the water is not a new solution. It has already been used in land-deprived countries like Holland or Japan. However, due to technological limitations, such idea can be seen as too sweeping and ambitious when we talk about cities with million inhabitants. Especially when it is not clear how living on the water will affect human mind but so far it is certain, that apocalyptic scenario on the land must not be repeated on the seas (Wines, J., 2008, p 194).

CONCLUSION

To conclude, it's only remains to add that approach towards ecology evolved gradually with the progress of science and human desire to exploit nature. During Neolithic period, nature was regarded as sacred and any contradiction to that was punishable. In Ancient times, science praised human mind and mechanical advances that allowed starting transforming natural environment. A breaking point occurred in the Middle Ages, when Christianity finally unholyfied the cult of nature. Since then, the opposition between human activity and nature occurred. The whole world was understood as the will of God. Meanwhile, the only duty of humankind was to obey the will of church, which often had nothing to do with ecology.

Since Middle Ages the wasteful use of natural resources has been rapidly increasing. Renaissance could be seen as an era that praised the power of human mind and its inventions. However, environmental situation began to deteriorate gradually. It was not only until the 20th century than pollution, global warming and diseases forced

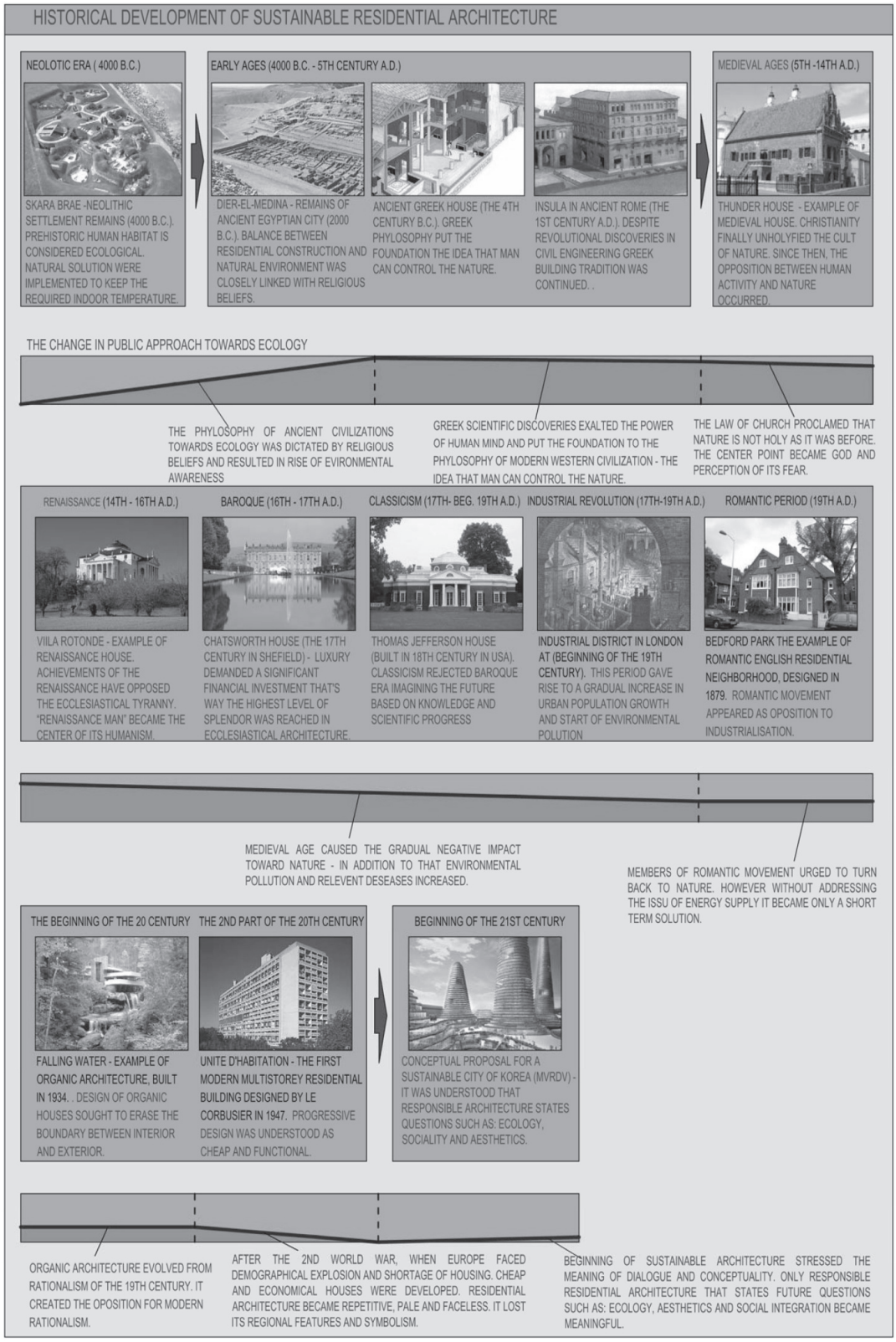

Figure 14. Historical development of sustainable residential architecture and the change in public approach towards ecology

to rethink the values of modern societies. New residential construction models were developed. Environmental wareness increased the idea that mental illnesses could be regarded as consequence of isolation from the natural environment. In other words, "egocentric" thinking started transforming into “ecocentric” (see Figure 14).

REFERENCES

Active House. Available from internet: http://www.activehouse.info/ (cited 16-12- 2010).

Antient Egyptian lives 2. Available from internet: http://homepage.powerup.com.au/~ancient/life2.htm (cited 24-12-2010).

Antient Rome. Available from internet: http://en.wikipedia.org/wiki/Ancient_Rome#Technology (cited 08-12-2011).

Baroque. Available from internet: http://en.wikipedia.org/wiki/Baroque (cited 28-11- 2010).

Bedford Park, London. Available from internet: http://en.wikipedia.org/wiki/Bedford_Park,_London (cited 25-12- 2010).

Chatswoth house, Derbyshire. Available from internet: http://www.tourist-information-uk.com/chatsworth.htm (cited 25-12-2010).

Frank Lloyd Wright—Falling Water. Available from internet: http://harryblaine.com/images/Frank_Lloyd_Wright/Falling_Water/fallingwater.jpg (cited 25-12- 2010).

Greek clothing and housing. Available from internet: https://questgreekmythology.wikispaces.com/Housing+and+Clothing (cited 25-10-2010).

Industrial revolution. Available from internet: http://en.wikipedia.org/wiki/Industrial_Revolution (cited 25-11-2010).

Llera R. R., 2006, Trumpa architektūros istorija. Naujoji Rosma, 2006. 252 psl.

Medieval houses. Available from internet: http://www.spartacus.schoolnet.co.uk/YALDhouses.htm (cited 29-11-2010).

Mesopotamia. Available from internet: http://en.wikipedia.org/wiki/Mesopotamia (cited 04-12-2010).

Neolithic. Available from internet: http://lt.wikipedia.org/wiki/Neolitas (cited 02-12-2010).

Passive House. Available from internet:http://en.wikipedia.org/wiki/Passive_house (cited 12-12-2010).

Perkūnas, Available from internet: http://lt.wikipedia.org/wiki/Perk%C5%ABnas (cited 25-12-2010).

Private residence. Available from internet: http://www.makearchitects.com/#/projects/9067/ (cited 16-12-2010).

Renessaince architecture. Available from internet: http://en.wikipedia.org/wiki/Renaissance_architecture (cited 12-11-2010).

Renesaince housing. Available from internet: http://www.suite101.com/content/renaissance-housing-a78729 (cited 09-12-2010).

Roaf S., 2007, Ecohouse: A design guide. Great Britain, 346 p.

Roman Art. Available from internet: http://www.proprofs.com/flashcards/cardshowall.php?title=roman-art_1 (cited 24-12-2010).

Skara Brae. Available from internet: http://www.theslideprojector.com/art3/art3lecturepresentationssummer/art3lecture3.html (cited 12-12-2010).

Springer I. Welcome to the ancient Egyptian home. Available from internet: http://www.touregypt.net/egypt-info/magazine-mag10012000-magf1.htm (cited 04-12-2010).

The Greek House, Prieiga internete: http://depthome.brooklyn.cuny.edu/classics/dunkle/athnlife/domestic.htm (cited 24-12-2010).

The Roman house. Available from internet: http://www.roman-empire.net/society/soc-house.html (cited 08-12-2010)

Unité d'habitation, Marseille, France, 1945. Available from internet: http://www.fondationlecorbusier.fr/corbuweb/morpheus.aspx?sysId=13&IrisObjectId=5234&sysLanguage=en-en&itemPos=58&itemSort=en en_sort_string1%20&itemCount=78&sysParentName=&sysParentId=64 (cited 25-12-2010).

Vere Gordon Childe. Available from internet: http://en.wikipedia.org/wiki/Vere_Gordon_Childe (cited 02-12-2010).

Wiliams D., 2007, Sustainable Design. Ecology: Architecture and Planning. Canada, 2007. 263 p.

Wines J., 2008, Green architecture. Los Angeles, 240 p.

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Eco Education. Eco Recreation

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Abstract. The environmental education of the public is fundamental for the future of humanity. Today's natural resources management and recycling are crucial for the environment and the quality of progeny life. The paper focuses on projects that, despite low budget, broaden mental horizons in terms of ecology and stimulate community initiatives organized around this theme. Provided examples, inter alia 'Between the Waters: The Emscher Community Garden' (an autonomous water treatment system in Essen), 'Island. Synchronization.' (active treatment of water from the Vistula River), 'Theatre evolutif in Bordeaux', show that often a simple activity is able to initiate great changes. By means of various elements of space such as plants, different types of surface, landscaping, small architecture, sports facilities, and other ecological engineering solutions, the designed space is a great place for free time activities, and at the same time it builds public awareness of the methods of protecting the environment.

Keywords: eco-education, eco-recreation, water treatment, public spaces

INTRODUCTION

At present, architecture is undergoing dynamic, global changes. In order to keep up with the rapidly transforming reality, it should seek for a new, complete assortment through interactions with other fields of life Current issues of ecology and environmental protection are increasingly becoming a major motivator for actions of designers, architects and artists. This article presents three case studies of urban space and combining recreation and environmental education: 'Between the Waters - Community Garden, and autonomous water treatment system in Essen', 'Island. Synchronization' and 'Theatre evolutif in Bordeaux'. Selected examples are focused on issues of water resource management. They are placed in different locations. Each project shows the process of water purification in the urban landscape in a different way, using different means of expression. They show that an architecture that can be both short-term intervention in urban space, and a kind of artistic performance activity.

There is lot of information in literature about public space: the value of public spaces, the nature of public life, human dimensions of public space, needs of its users. The issue of ecology in architecture and sustainable design reviewing techniques available for reducing the energy impact on the environment is also widely documented. Examples quoted in this article are difficult to be qualified for any of these groups. The combination of architecture, ecology and education seems to be fresh and innovative idea. Presented examples prove that care for the environment can be creatively included while designing a particular part of urban space.

Between the waters: the emscher community garden

'Between the Waters: The Emscher Community Garden' was a garden designed for the local community and a water treatment station. The authors of this project were Marjetica Potrc, an architect and artist, and Ooze Architects, a architects' team. The project came into existence within the international exhibition Emscherkunst.2010, where twenty artistic installations were presented. It all took place on the Emscher Island, which lies between the Emscher River and the Rhine-Herne Canal. The Emscher River, flowing through the Ruhr region, used to be a mine sewer, but now it is being subjected to various processes of restoration. Along the river, there is a landscape park with a system of cycle paths, where concerts, picnics and an outdoor cinema are held. Unfortunately, due to severe water pollution, the area in close vicinity of the river is fenced and impassable for visitors.

The 'Between the Waters' project pointed at the problem of water treatment. The installation was placed in the narrowest part of the island, linking the banks of The Emscher River and Rhine-Herne Canal. Water from local, renewable sources was treated: from the Emscher River, two toilets and rainwater. By means of low-tech technology, a high-tech effect was achieved. The proper location of elements of the sustainable water supply and treatment system, such as two toilets located by the Emscher River (the most polluted river in Germany), a water

pump, a helophyte filter, a rainwater-harvesting roof, and water storage bags, was enforced by the characteristic topography of the site. The Emscher River is situated higher than the Rhine-Herne Canal, and the area slopes gently towards a footway and cycle path stretched along the canal (Fig. 1).

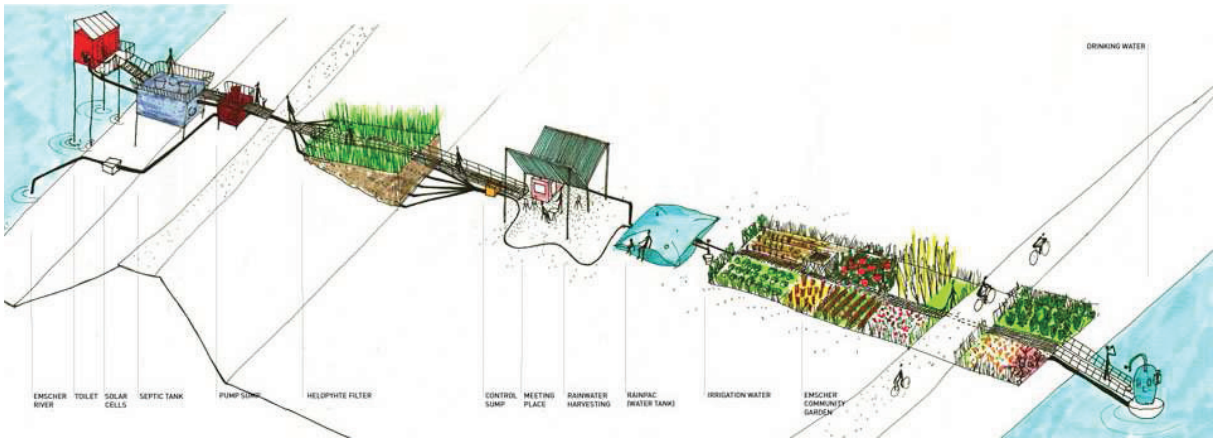

Figure 1. Concept / "Between the Waters: The Emscher Community Garden" / Marjetica Potrč & Ooze (Eva Pfannes and Sylvain Hartenberg) / Emscherkunst 2012 / Courtesy of the artists / http://www.ooze.eu.com/?pro=194

The treatment process begun upon the Emscher River, opposite to the entrance. The two toilets installed by the river were both a humorous landscape feature and a scenic overlook, providing a view over the Emscher River, so that visitors could see for themselves how badly polluted it was. The water from the toilets together with the water from the river was pumped into a septic tank, what made the whole process visible and served the project's educational purpose. All possible elements of the water system were installed outdoors, so that all the stages of water filtration process were easy to examine. A system of stairs and landings led the visitors downstairs among the verdured containers which were parts of the helophyte filter. The purified water was then mixed with rainwater harvested by a specially constructed roof of 40 m2 area. The initially filtrated water was stored in clean water tanks – two, big, blue "pillows", each of them of 5000 l capacity, which were also used as trampolines and settees. Water at this stage was destined to water the Community Garden. The garden, of 170 m2 area, was situated upon the Rhine-Herne Canal and intended for leisure, a "green gate" as it was the entrance to the installation. The culmination of the whole venture was a fountain installed by the Rhine-Herne Canal, which provided visitors with drinking water (Fig. 2).

The installation was designed in a bold, industrial style. The project's coloured elements were immersed in greenery: yellow toilets and rainwater-harvesting roof, red sedimentation tanks and blue "pillows" accumulating clean water. They drew the attention of passer-bys and emitted positive energy (Fig. 3).

Despite the fact that the presented solution was temporary installation, it might be easily adapted to other, riverside areas. The project focused on the protection of natural environment and it combined recreation with education in a very creative way. By architectural and engineering means the process of water treatment can be learned in a simple and pleasant manner – through the interaction of a user with the elements of installation. This project also touches upon the issue of creating a user-friendly public space for local community.

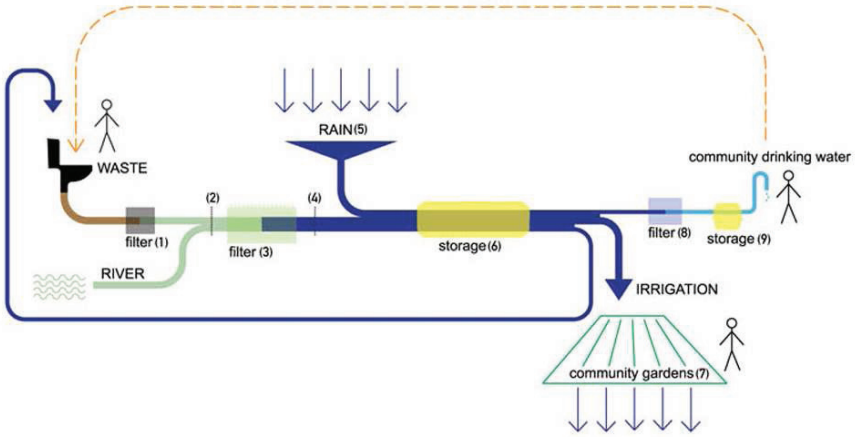

Figure 2. Water treatment process "Between the Waters: The Emscher Community Garden" / Marjetica Potrč & Ooze (Eva Pfannes and Sylvain Hartenberg) / Emscherkunst 2012 / Courtesy of the artists / http://www.ooze.eu.com/?pro=194

Figure 3. View from the garden to the path / "Between the Waters: The Emscher Community Garden" / Marjetica Potrč & Ooze (Eva Pfannes and Sylvain Hartenberg) / Emscherkunst 2012 / Courtesy of the artists / http://www.ooze.eu.com/?pro=194

Island. Synchronization

The problem of water treatment was also brought up by a project 'Island. Synchronization'. It presented a very useful idea of a mobile water treatment station, placed on the surface of the Vistula River. The project by Jakub Szczęsny, a member of the Designers' Team "Centrala", combined two, very important aspects – care for the environment, in that case the treatment of river water, and care for human health (Fig. 4).

Figure 4. 'Island. Synchronization'– visualization, http://www.centrala.net.pl/our-work/wyspa

This floating island was a platform on a dodecagon plan with a centrally situated fountain, around which fitness facilities were disposed: three treadmills, three exercise bicycles and three rowing machines. With the help of muscle strength – while running, cycling or rowing – polluted river water was pumped and filtrated. Kinetic pumps carried water to tanks which surmounted the fountain and were equipped with special filters: sand, carbon and reverse osmosis filter. Water, purified by means of muscle strength, flowed through the fountain ready to drink (Szczęsny, 2010) (Fig. 5).

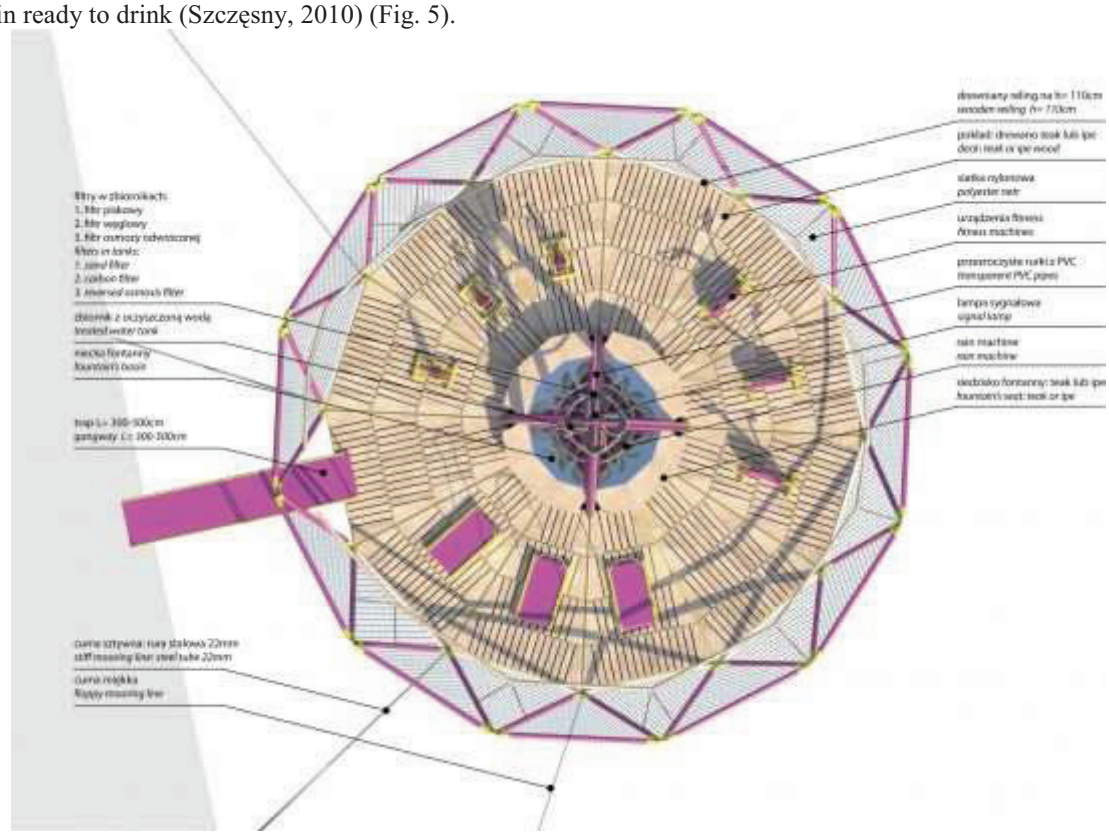

Figure 5. 'Island. Synchronization'– plan, http://www.centrala.net.pl/our-work/wyspa

The construction of the platform drifted thanks to the system of space frame trusses rested on twenty four steel barrels. The platform was connected with mainland by a ladder, which was closed for the night and wide enough to board the platform on a wheelchair. In winter, off-season, the platform could be moored at one of the local wharves (Fig. 6).

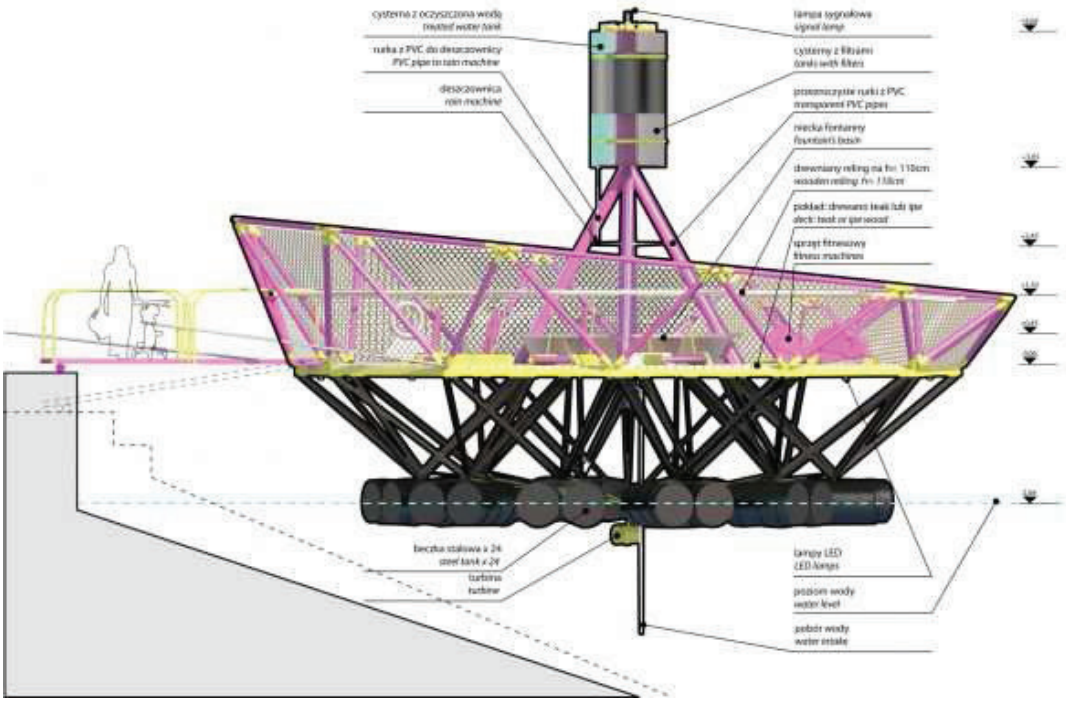

Figure 6. 'Island. Synchronization'– section, http://www.centrala.net.pl/our-work/wyspa

'Synchronization' was an idea of a joint effort – both muscle and community work. Drinking water, being the result of teamwork, proved that everybody could do something to increase the quality of natural environment in their city. This project pointed out the fact that modern architecture might and should meet current needs related to ecology and restoration of urban public space. The problem of river pollution is commonplace in Poland. 'Island. Synchronization.' project had the chance of succeeding. Consulted with experts on alternative energy, hydrodynamics, water treatment systems, ecology and ornithology, it could become a prototype of local water treatment stations on a national scale. Alas, the implementation of the project did not come into effect.

Theatre evolutif

A positive, because an accomplished example of urban space restoration is the design of 'Theatre evolutif' on a square in Bordeaux. The authors are: Ooze Architects (Eva Pfannes & Sylvain Hartenberg), Marjetica Potrc, Bureau d'etudes (Xavier Fourt & Leonore Bonaccini). The project was implemented as part of international artistic festival Evento 2011 with a motto "Art of re-evolution". The name 'Theatre evolutif' relates to a theatre as a place of interaction between an audience and an actor as well as to the process of evolution – here, a process of adaptation to the ever changing surroundings and their users needs. The subject of the project was a square in the centre of Bordeaux, near a railway station. Three months before the beginning of the festival, a team of architects, artists, city dwellers and representatives drew up a charter outlining the common goals of a future project. The crucial idea was filling the void of this centrally situated square, which up to that moment did not exist in the dwellers' consciousness. All actions taken were aimed at using the potential of the area and restoring it to the city. The square now presents a new form of human and nature coexistence in urban structure. The space was arranged by means of simple and cheap elements. The Basic building material is timber regained from neighbouring building sites. Soil from a nearby underground car park building site was used to diversify the relief. An element predominating over the square's space is a wooden, open-work roof construction (Fig. 7).

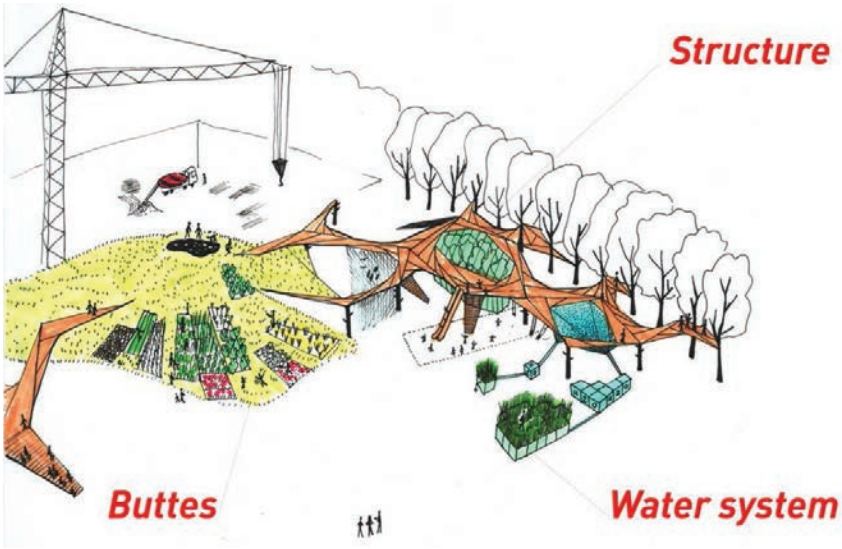

Figure 7. Concept / Théâtre évolutif / Marjetica Potrč, Ooze (Eva Pfannes and Sylvain Hartenberg) and Bureau d'études (Léonore Bonaccini and Xavier Fourt) / Evento 2011 / Courtesy of the artists / http://www.ooze.eu.com

Wooden posts box off various zones – clusters which serve as: a library, a scene – a place for expression, kids zone, a bricolage room and a tool closet, a music stand, bee and insects keeping, a field kitchen, a cafe and a gridiron. The important feature of the project is water circulation. Rainwater is harvested from the roof and supplies a public, open air toilet, surrounded by bushy greenery. It is also used to water the garden. Additionally, after flowing through a helophyte filter, purified, it runs to a drinking water station and is ready to drink (Fig. 8).

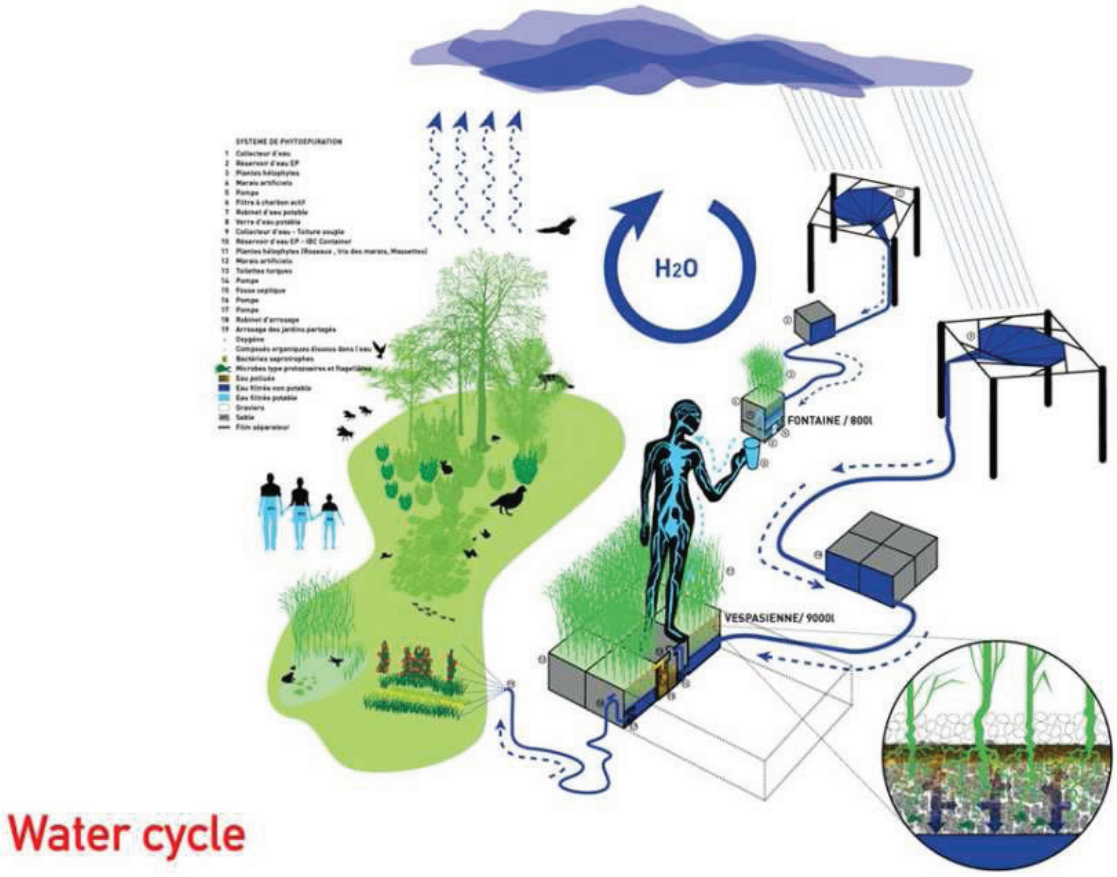

Figure 8. ' Water cycle / Théâtre évolutif / Marjetica Potrč, Ooze (Eva Pfannes and Sylvain Hartenberg) and Bureau d'études (Léonore Bonaccini and Xavier Fourt) / Evento 2011 / Courtesy of the artists / http://www.ooze.eu.com

This is a modern agora. A place where people can meet, share their views and interests. The project can be viewed as a prototype of an urban ecosystem – an elastic public space, filled with people and their activities. An extraordinary and innovative thing about this project is the real commitment of dwellers in creating and building. This architecture is not a monument, an unwitting element of space, but a living organism manipulated, transformed and adapted to the needs of its users (Fig. 9).

Figure 9. "L'Assemblée" – "Atelier construction d'habitats pour les insects" / Théâtre évolutif / Marjetica Potrč, Ooze (Eva Pfannes and Sylvain Hartenberg) and Bureau d'études (Léonore Bonaccini and Xavier Fourt) / Evento 2011 / Courtesy of the artists / http://www.ooze.eu.com

CONCLUSIONS

The presented examples come from different countries: France, Germany, Poland. But the idea is common. They show how modern architecture can react to the current issues of ecology and sustainable development. They prove that every one of us has a true effect on the condition of the environment we live in. Every one of these projects concerns the problem of water treatment:

- project 'Between the Waters - Community Garden, and autonomous water treatment system in Essen' presents the process of purifying contaminated water from the river as part of a friendly and interesting public space installations,
- project 'Island. Synchronization' promotes an active way for spending free time, as well as benefits of collective effort, and the idea of easily adaptable riverside recreation facility
- project 'Theatre evolutif in Bordeaux' uses simple forms of expression and recycled materials and shows the way of building community at the same time promotes environmental responsibility.

They are designed to combine recreation with information on water use cycle and its renewable sources. They are temporary and easily adapt to new, different venues. They also have a very important, social dimension. They refer to the idea of social responsibility by creating a place in public space where people can co-operate for common cause. Presented in the article examples challenges to rethink architecture and see it in the context of social intervention tactics.

REFERENCES

Between the Waters: The Emscher community Garden - Art installation for Emscherkunst 2010, OOZE [Online]. Available from: http://www.ooze.eu.com/[Accessed 6th June 2012].

Künstler & Projekte, Emscherkunst.de [Online]. Available from: http://www.emscherkunst.de/ausstellungsraum-6/kunstwerke/marjetica-potrc-und-ooze-architects-between-the-waters-the-emscher-community-garden.html [Accessed 3rd June 2012].

Placemaking ."Théâtre évolutif" in Bordeaux, Ecosistemaurbano.org [Online]. Available from: http://ecosistemaurbano.org/english/placemaking-theatre-evolutif-in-bordeaux/ [Accessed 6th June 2012].

Projekty przyszłości, Architektura.muratorplus.pl/ [Online]. Available from: http://architektura.muratorplus.pl/aktualnosci/archiwum/projekty-przyszlosci_74795.html [Accessed 5th June 2012].

Szczęsny J., 2010, Island. Synchronicity.

Theatre Evolutif - Art installation for Evento 2011 – Bordeaux, OOZE [Online]. Available from: http://www.ooze.eu.com/[Accessed 6th June 2012].

Wy-spa / Synchronicity 2, CENTRALA [Online]. Available from: http://www.centrala.net.pl/our-work/wyspa [Accessed 5th June 2012].

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Urban and Architectural Aspects of the Prevention of Noise Emissions and Reduction of Their Negative Effects

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Abstract. Considerations concerning the environmental quality of human life, conducted by experts in the field of architecture usually lead to study of the spatial and functional elements of selected settlements and the relationships that occur in their structure. One of the elements supporting the ongoing processes of urbanization and reurbanization is a sound generated by the space components, which in the case where its intensity becomes too much onerous - is called 'the noise'.
It seems that the way to improve the quality of the built environment is a comprehensive and multidisciplinary analysis of the research area, to define the problems and conflicts caused by excessive emission of sound, resulting in an indication of proposed architectural and urban solutions to reduce impact of noise harmful to the human. Initially, one can hypothesize the idea that first and foremost the noise reduction should take place through the implementation of appropriate spatial policies and proper planning strategy for the investment. The local scale actions undertaken in order to prevent the spread of noxious sound waves may include different of settlement infrastructure facilities systems such as natural and artificial anti-noise curtains or barriers, assuming that they do not destroy the landscape values.

Keywords: architecture, urban planning, housing environment, noise, aerospace industry.

INTRODUCTION

Analysing the demographic changes of the modern world, it is difficult not to discover the fact that the number of people living in cities is much higher than the rural population. According to forecasts by the UN experts in 2030, 60.2% of people will live in cities; while in developed countries will be 82.6%[1].This situation changes the nature of existing relationships in the spatial structure of cities, including significant changes in the sound layer of landscape[2]. Considerations concerning the environmental quality of human life, conducted by experts in the field of architecture usually come down to study the spatial and functional elements of selected settlements. Increasing urbanization in addition to positive effects on quality of human life causes many negative effects, especially in relation to environmental quality, such as excessive air pollution or generated by the components of the space sound, which with its excessive intensity becomes inconvenient and bothersome.

With regard to the social processes taking place in the workplace and residence, it should be noted that the noise significantly affects the people, determining their negative behaviour. The level of audible sound affects the quality of life, and - if exceeded - often results in the loss of health, brings the feelings of discomfort and annoyance. Particularly important for health is the protection against the harmful effects of sound emissions. Such an obligation is imposed with a number of legal acts, both Polish and European Union law[3]. The issue of environmental protection in the EU is treated as a priority and is subject to regulation under several legal acts, of which one of the most important is the European Parliament and Council's Directive relating to the assessment and management of environmental noise[4]. The regulations resulting from this directive are included in the Polish legislation - the Act on Environmental Protection[5]. The mentioned Directive 2002/49/EC introduces the requirement related to the preparation of noise maps[6] and then the requirement related to development of programs to protect against noise[7].

[1] The data are cited by D. Szymanska in the monograph titled Urbanization in the world, PWN, Warsaw 2007. p.32-36 [orig. ref.: Urbanizacja na świecie, Wydawnictwo Naukowe PWN, Warszawa 2007. s.32-36]

[2] The issues of sound landscape analysis, noise policy and acoustic renewal are presented by S. Bernat in his works.

[3] In relation to EU member states

[4] The talk is about the Directive 2002/49/EC of June 25, 2002 (Journal of Laws of the EU, L.02.189.12)

[5] Environmental Protection Act of April 27, 2001.(Journal of Laws No. 2008.25.150 as amended)

[6] Based on noise maps are defined areas where noise levels exceed acceptable levels, and among other are designated areas of most unfavourable acoustic conditions.

[7] For urban agglomerations of more than 100,000 inhabitants

The noise level in the urban space is constantly growing. As the principal factor affecting the intensification of this phenomenon are considered the progressive civilizational changes such as for example various forms of human activity, development of industry, or transport and traffic density. The number and variety of potential sources of noise indicates the importance of the problem and also the need to develop effective ways to resolve it. From the perspective of an architect or urban planner, an important question shall be classification of potential sources of noise made not due to the functional aspects[8] but the spatial ones, location, extent and form, and to indicate the directions and options for countering the effects of its emissions.

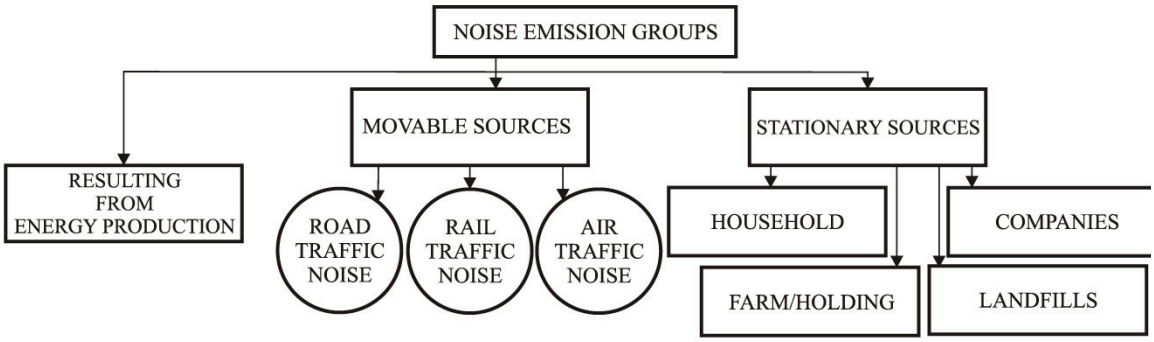

Figure 1. The classification of the noise groups. Identification of noise sources allows you to isolate the groups of problems related to counteraction with architectural and spatial (urban) instruments (the content compiled by authors based on the EU Community Programme *Environment 2010: Our Future, Our Choice)*

It seems that according to the spatial approach, the ways of preventing harmful effects of excessive sound may be divided into two main groups: the spatial (planning) ways - linear and area, and local (architectural and urban) - associated with the use of appropriate solutions and forms of spatial objects. Space solutions concern inter alia the design or location of residential settlement (housing estate) or individual residential buildings in the context of sound reflectivity of the surface of elements of city planning, noise attenuation (suppression) by the planting of greenery, or noise shielding with natural and artificial objects and provisions of planning that make the spatial policy related to prevention against noise pollution.

Planning solutions

Due to changes in urbanization, and thus increased demand for land situated in the city, one can observe a progressive transformation of the landscape, its industrialization and sometimes degradation as well. Appropriate management and development is not just a question regarding preserving the *spatial order* within the meaning of space harmony in terms of viewing, but the maintenance of *the order* through the appropriate combination of functions (and also the forms), as well as conflict prevention and resolution of problems. These activities, coordinated by the urban planner, shall require knowledge coming from and related to different fields, including knowledge of methods of preventing the spread and impact of noise.

Spatial solutions (i.e. space management) regarding the negative effects of noise emissions mainly come down to the corresponding entries made in the strategic and planning documents. At the municipal level these documents include the Study of Conditions and Directions of Regional Planning and Local Development Plan[9] (prepared for land areas identified in the Study). The findings of above mentioned documents concern the spatial development directions, including the location of the elements of communication in accordance with the principles of prevention of the spread of the annoying sound[10], the design of protection zones around the areas that generate noise, or exclusion of land areas from residential development in their vicinity. At the same time,

[8] The study of noise sources indicate three main groups of emission: from mobile sources (transport industry), emissions from stationary sources (companies, households, farms and landfills), and emissions from the energy production process: the systematic given by the EU Community programme *Environment 2010: Our Future, Our Choice*

[9] The names and extent of development of further specified documents (the Study of Land Use Conditions and Directions - *PL acr.: SUiKZP*, and the Local Land Use Plan - *PL acr.:* MPZP) are based on the being in force in May 2012 the Law on Spatial Planning and Development (Act of March 27, 2003 on Spatial Planning and Development - Journal of Laws No. 2003.80.717 with subsequent amendments)

[10] According to previously mentioned programme of implementation of the Directive 2002/49/EC on the assessment and management of environmental noise, "the main source of noise nuisance to humans and the environment, especially in urban areas, is traffic."

despite the implementation of the Directive 2002/49/EC, it was requested to make arrangements for the determination in the local zoning plan of environmental noise standards, as the Act on spatial planning and development does not impose this obligation.

A relatively new issue related to the *anti-noise prevention* in the context of spatial planning is the need to generate energy from renewable sources[11]. Location of wind farms raises a lot of controversy. On the one hand, there is generally understood the need to develop national energy security, on the other there is a need of identifying the location of areas suitable for these functions, and they must be specific areas free from development, precisely because of the noise produced by the wind turbines. Because of the noise protection, it is mandatory to determine the extent of equal-loudness contour at the value equal to 40dB[12] and determining the absolute prohibition of building area development[13]. For locations close to existing buildings or areas subject to investment pressure, it is associated with numerous protestation actions undertaken by residents, who are convinced that as a result of planned investments in the area, land values will fall.

The main source of noise and its nuisance, particularly in urban areas is the traffic[14]. In the case of identifying the location of new roads with high class, the methods to counteract the harmful effects of noise involve the entries that limit building development near the lines of demarcation of roads, or the design of the road in undeveloped areas of agricultural or forestry[15]. If it is possible to develop (build up) the areas along the proposed road, so it is compulsory to determine in a zoning plan a building (development) line, located in a distance that gives a chance to reduce the harmful effects of noise on health and human's well being[16]. As in the case of location of wind turbines, an indication of land for the road course raises a number of protests, which can effectively block the course of construction work; and indication of building line shall limit the investment opportunities, because it prevents the development and building on all the plot or a part thereof.

Local solutions (urban and architectural)

Following the discussion, the next element in limiting the harmful effect of traffic on the status of noise pollution of residential environment are acoustic barriers - natural and artificial urban elements. They can be divided into three groups; sound-absorbing-and-scattering barriers (green and/or building components with small spatial dimensions), shielding barriers (screens, buildings, excavations, embankments, overpasses, natural terrain features such as ravines) and sound-absorbing & reflecting-shielding barriers (such as embankments covered with vegetation)[17]. One of the most common artificial items used in developed (built-up) space are very controversial acoustic screens[18], considered as ambivalent, especially from the visual point of view, due to their interference in the "image of the city"[19] as well as social and environmental aspects.

Analyzing the impact of sound-protective barriers on the appearance of space considered in the overall scale, it is clear that almost always they adversely affect the composition and aesthetics of environment. This is particularly evident in areas of high landscape values, areas located over water or in areas with large height differences - in the mountain areas[20]. It can be prevented by proper location of the traffic elements, so that there

[11] The increase in the share of renewable energy sources in final consumption is one of the main objectives of the Polish energy policy taken under the environmental commitments towards the European Union. It is planned that by 2020 this proportion will rise to 15%, and in the following years this ratio will further increase (based on document titled "Polish energy policy until 2030" being the Annex to resolution No. 202/2009 of the Council of Ministers of November 10, 2009.

[12] The size of allowed noise limit according to the Decree Law of the Minister of Environment of June 14, 2007 on the allowable levels of noise in the environment (Journal of Laws No. 120, item. 826).

[13] Based on the authors' design practice it can be said that in the case of location of the five wind turbines with a capacity of 2MW, the area may include the prohibition of construction of about 130 hectares. There is an estimative assumption that the minimum distance from the built-up areas to the wind turbine mast is 500m.

[14] Implementation of the Directive, *op cit* ...

[15] Restrictions on the possible location of buildings concern also the areas of routes (in case the standard procedure; placement of the course of road in the Local Development Plan) - a consent is required for a redeployment of agricultural and forest land for non-agriculture and non-forestry purposes (as in the case of wind energy locations in agricultural areas with high grades).This often involves the refusal to issue such an authorization, which can effectively block the investment.

[16] In the case of expressway road it may be, for example 25 or 30m. (based on the authors' design experience)

[17] The systematic is given according to J. Sadowski: *Basics urban acoustics,* Arkady Publishing, Warsaw 1982, pp.127-129.

[18] The name of the noise barrier shall be used for artificial or natural barrier, located between the source of sound (noise) and the reception area (protected). Bringing the technical issues, noise barriers can be divided into types because of the way in which they protect against harmful noise. These screens include: scattering screens, absorbing screens, tones reflective screens and screens that combine these characteristics. These properties depend on the materials used in the design of these elements, the shape and coverage, such as specially selected species of vegetation.

[19] he term used by K. Lynch, *The image of the city,* Harvard College, 1960.

[20] This question was mentioned by H. Hrehorowicz-Gaber and T. Gaber in *The importance of analysis of viewpoints in the preparation of planning studies for small towns located in mountainous areas* [in:] *Technical Journal, Issue 10/2009* (Year 6), Series Architecture, Z. 2-A/2009, Publishing House of Cracow University of Technology, Kraków 2009

was no need for noise barriers in the areas of exposure, such as viaducts or overpasses located nearby settlements[21]. On a local scale are used the activities consisting in minimization of a negative impact on the site through the use of transparent screens, wood screens or screens overgrown with vegetation.

In situations where the introduction of noise barriers or other elements of the noise containment is impossible, it is necessary to apply appropriate architectural solutions in the form of modern spatial forms of designed objects and applied materials. It is important to use the elements with improved sound insulation, window frames, and external building partitions. One way to reduce the negative impact of noise on people is such a configuration of rooms inside the designed building that involves location of the utility rooms, kitchens, bathrooms and corridors at the traffic route side.

The specific source of sound nuisance is air traffic noise. It is characterized by a high level and range[22]. It is generated by a number of acoustic elements, such as take-off, landing, flying time and cruising. If the noise sources are located in air, acoustic screens are useless. As the main way to prevent conflicts is considered the use of green roofs on buildings[23]. This helps to reduce noise while increasing biologically active surface and aesthetic object. This solution is also energy efficient and has high visual value which is particularly important in areas of open landscape in scattered buildings areas, villages and cities that are increasingly subjected to the phenomenon of urban sprawl. This involves the areas being most vulnerable to the adverse effects of noise emission from a height, it may be the noise of air traffic, or ground traffic (road and rail), the source of which is located higher than the inhabited areas, e.g. in the field of different heights.

SUMMARY AND CONCLUSIONS

As is apparent from the foregoing considerations, the noise is now one of the major environmental pollutants. Its negative impact is particularly evident in urban areas (both intensively and extensively) adversely affecting the quality of human life.

There are a number of measures to prevent and mitigate the negative effects of noise, both spatial-planning and urban-planning and architectural, but they have an ambivalent structure. On one hand, they limit the expansion of noise, on the other hand - they often have a negative impact on the quality of the landscape. As per result of analysis of existing and planning procedures and architectural elements used to reduce the noise, you can attempt a preliminary indication of optimal solutions.

At the level of planning is necessary to introduce respective provisions to existing laws, which require analysis of the sources and effects of noise, and records indicating the possibility of counteracting the harmful effects of excessive emission of sound in the living environment. In the case of architectural operations, it is needed to be aware of the impact of the designed elements on the environmental quality of both open and built environment, and consequently the use of solutions minimally intrusive toward the space. A good practice would also be a comprehensive and multidisciplinary analysis of the research area, to define the problems and conflicts caused by excessive emission of sound (the question to be solved in collaboration with the scientific community, representing different areas of research), and ultimately identification of new and innovative proposals for architectural and urban solutions to reduce impact of noise, that is harmful to the human.

REFERENCES

Bernat, S. Environmental protection against noise - a qualitative approach [in:] Technical Journal, Issue 14/2007 (year 104), Series architecture, z.7-A/2007, Publishing House of Cracow University, Kraków 2007 [orig. ref.: Bernat S., Ochrona środowiska przed hałasem – podejście jakościowe [w:] Czasopismo Techniczne, Zeszyt 14/2007 (Rok 104), Seria Architektura, z.7-A/2007, Wydawnictwo Politechniki Krakowskiej, Kraków 2007].

Bernat, S. Sound quality management in public spaces. [In:] E. Klima (ed.), Social factors in land management and spatial planning. Space - Society - Economy, Vol. 9, University of Lodz, Lodz 2009 [orig. ref.: Bernat S., Zarządzanie jakością dźwiękową w przestrzeni publicznej. [w:] Klima E. (red.), Czynniki społeczne w gospodarce przestrzennej i planowaniu przestrzennym. Space - Society - Economy, t.9, Uniwersytet Łódzki, Łódź 2009].

[21] This situation occurs for example in the area of Głogów Małopolski (a city located in Podkarpacie - Sub-Carpathian province in Poland) where the acoustic panels located at the ring road flyover can unfavourably affect the reception of silhouette and panoramas of historically developed city (Renaissance urban layout).

[22] In the design of airports the equal-loudness contour 60d as the limit value for residential development. However, in contrast to the locations of wind turbines (which constitute a relatively new phenomenon in Poland) this action does not eliminate the adverse effect on housing development, as it is applicable only to new airports. In the case of existing airports, in the land use plans there is implemented a ban on new housing projects and the requirement for a functional transformation of the existing building development, but it does not involve a specification of a time in which these transformations were to take place (based on the authors' experience of project)

[23] Such a roof has been applied to facilities in the area of Frankfurt airport. According to data posted on the website of the airport, depending on the layer thickness and type of vegetation, the sound intensity level can be reduced by up to 50dB.

Bukowski, Z. Environmental Protection Law of the European Union, published by CH Beck, Warszawa 2007 [orig. ref.: Bukowski Z., Prawo ochrony środowiska Unii Europejskiej, Wydawnictwo C.H.Beck, Warszawa 2007].

Hrehorowicz-Gaber, H., Gaber, T. The importance of analysis of viewpoints in the preparation of planning studies for small towns located in the mountain areas, [in:] Technical Journal, Issue 10/2009 (Year 6th), Series Architecture, Z.2-A / 2009, Publishing House of Cracow University, Kraków 2009 [orig. ref.: Hrehorowicz-Gaber H. Gaber T., Znaczenie analiz widokowych przy sporządzaniu opracowań planistycznych dla małych miejscowości położonych w obszarach górskich, [w:] Czasopismo Techniczne, Zeszyt 10/2009 (Rok 6), Seria Architektura, z.2-A/2009, Wydawnictwo Politechniki Krakowskiej, Kraków 2009].

Lynch, K. The image of the city, Harvard College, 1960.

Sadowski, J. Basics urban acoustics, Publisher Arkady, Warsaw 1982 [orig. ref.: Sadowski J., Podstawy akustyki urbanistycznej, Wydawnictwo Arkady, Warszawa 1982].

Szymanska, D. Urbanization in the world, PWN, Warsaw 2007 [orig. ref.: Szymańska D., Urbanizacja na świecie, Wydawnictwo Naukowe PWN, Warszawa 2007].

The Act of March 27, 2003 on Spatial Planning and Development (Journal of Laws No. 2003.80.717 as amended).

The Act of April 27, 2001. Environmental Protection Act, Journal of Laws No. 2008.25.150 as amended).

The Polish Energy Policy until 2030 - the Annex to resolution No. 202/2009 of the Council of Ministers of November 10, 2009.

The Directive 2002/49/EC of June 25, 2002. (Journal of Laws of the European Union, L.02.189.12) relating to the assessment and management of environmental noise.

The programme of implementation of Directive 2002/49/EC of June 25, 2002 (Journal of Laws of the EU, L.02.189.12).

Environment 2010: Our Future, Our Choice - European Union action program, available on the website of the European Parliament.

The Decree Law of the Minister of Environment of June 14, 2007 on the allowable levels of noise in the environment (Journal of Laws No. 120, item. 826).

A Study of Conditions and Directions of Pawłów Community Municipal Planning (Świętokrzyskie Province, Poland), Chief designer: Mr. Rafał Kozieł, MSc, designer: Ms. Anna Sikora, Dr. Ing. Arch.

Local Development Plan of Szerzawy village administration in the municipality of Pawłów (Świętokrzyskie Province, Poland), Chief designer: Mr. Rafał Kozieł, MSc., designer: Ms. Anna Sikora, Dr. Ing. Arch.

Local Development Plan of Masłów Pierwszy village administration in the municipality of Masłów, Chief designer: Mr. Rafał Kozieł, MSc., designer: Ms. Anna Sikora, Dr. Ing. Arch.

Noise map of the city of Poznań and the programme of environmental protection against noise, Research materials prepared by the Acoustics Research Centre, The Foundation of the University of Adam Mickiewicz, at the request of the City of Poznań Office, Poznań 2008, (materials provided in the digital version).

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Ecology of City" Levels and Components

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EXTENDED ABSTRACT

Urban ecology is a phenomenon that gets lots of attention nowadays. There are many drivers of the topic, but the key drivers promoting discussions are likely to be only two: 1) the rapid growth of the world population and 2) environmental changes it causes. The article aims to describe "ecology of a city" from an urban planner's perspective. However, the article aims to consider solely about "ecology of a city" and thus firstly it seeks to analyse what is a difference between sustainability in general and its ecological "ingredient". Secondly, it tries to sort city's ecology in accordance with impact it has on the environment.

Speaking about sustainability in general and its constantly failing implementation in practice, one can hypothesize that it occurs due to the nature of a process, i.e. its flexibility. That means that sustainability is not a fixed and final result, which once reached will last forever. In practice a delay is an integral part of sustainable development; it is a constant process occurring continuously over a period of time and thus perpetual alterations have to be done. And exactly at this point, i.e. the action of correcting something, sustainability in general is different from its separate elements. It is extremely well noticeable if environmental issue is considered. Hence, the major aim considering ecological compound of sustainability is not to "lose", i.e. do not over abuse the planet and do not exceed the critical level.

The world's greatest ecological problem is global climate change, frequently described as a threat to humanity's future (IPCC, 2007b; McMichael *et al.*, 2003). In general, climate change itself is not dangerous: it is resonant turn of events that is so much important and in recent decades majority of problems are caused by global warming. Global warming or to be more precise increasing concentration of greenhouse gases is caused by many anthropogenic activities, e.g. industrial processes or farming. However, the most responsible sector contributing to global greenhouse gas emission is energy sector. Therefore, "outer" ecology of a city is nothing more but greenhouse gas emission, which is generated in order to fulfil city's energy demand and thus the objective of "outer" ecology is city's energy management.

There is a huge difference between "inner" and "outer" city life: things important in a city can be completely non-essential at a global scale and vice versa. Slightly more than a decade ago in 1999 the EU started an international project – the European Common Indicators initiative – which focused on helping local authorities monitor environmental sustainability of its urban environment (Tarzia, 2003). Such practical aim required moderate number of indicators and thus only the key ones were selected. The Initiative has two indicators that could have relations with "inner" ecology, these indicators are the fifth and eighth: quality of local ambient air and noise pollution.

Summarizing ecology of city is: 1) "outer" – greenhouse gases from energy sector and 2) "inner" – 2.1) quality of local ambient air and 2.2) noise pollution.

Keywords: urban ecology, level, component, assessment, impact.

REFERENCES

IPCC, 2007b. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [online]. Geneva. Available from: http://www.ipcc.ch/publications_and_data/ar4/syr/en/contents.html [Accessed 9 February 2012].

McMichael, A. J., Campbell-Lendrum, D. H., Corvalán C. F., Ebi, K. L., Githeko, A. K., Scheraga, J. D. and Woodward, A., eds., 2003. Climate change and human health – risks and reponses [online]. Geneva: World Health Organization. Available from: http://www.who.int/globalchange/publications/climchange.pdf [Accessed 9 February 2012].

Tarzia, V., ed., 2003. European Common Indicator: Towards a Local Sustainability Profile [online]. Milano: Ancora Arti Grafiche. Available from: http://euronet.uwe.ac.uk/www.sustainable-cities.org/indicators/ECI%20Final%20Report.pdf [Accessed 5 January 2011].

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Alytus Fortress and its Impact to Urban System of the Town

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Abstract. During XIX c. end – XX c. beginning, there were built III class Alytus fortresses or Alytus fortified positions. It was stipulated by that time geopolitical situation, strategic meaning of the place, geographic location, nature conditions.

Alytus fortification was built for defense of important bridges through Nemunas. It maximally used relief distinctiveness in the town surroundings. Important strategic roads were built, as well as internal roads of the fortress and military railway, that connected Alytus with Varėna, Gardinas, Suvalkai, Augustavas.

Forts built in Alytus, belong to the type of forts that are shaped from the soil and has only wooden buildings.

In 7-8 decade of XX c., when town was growing quite fast, forts 2 and 3 were destroyed, part of military complexes too. Parts of the roads and internal roads of fortress that have got into expansion of the town, became base of urban frame in the western part of the town, railway line – main urban axis of the town.

In such way, objects of Alytus fortress still have a very strong impact to the urban structure of the town. Abundance of military heritage, distinguish Alytus from other towns of Lithuania and is one of the most important town identity factor.

Keywords. Fortress of Alytus, fortified position, strategic roads, railway, urban structure.

INTRODUCTION

As well as Kaunas, Alytus town and its districts historical and urban development is related to Czarist Russia fortress, build in XIX c. end – XX c. beginning. At that time, Alytus was one of the most military town in Lithuania, which life and development in big part was predetermined by interests of military departments, important aspect of town growth was its military function. Differently from Kaunas fortress, in Alytus there were found III class (last but one) fortress, later named fortified position, which of course was much weaker. Kaunas fortress now has quite a lot attention, scientific and popular articles as well as publications appeared. Alytus fortress is almost not research. It is shortly described with Alytus town urban development (Miškinis, 1999), mentioned by authors that were writing about Alytus history (Žepkaitė, 2004), some small articles appeared in periodical press, internet. Till now there were no scientific publications about Alytus fortress.

In 2011, in Territory planning center of KTU Institute of Architecture and construction, there were made preliminary Alytus fortress investigation preparing the work "Analysis of Lithuanian military heritage". Researched fortresses importance to the town and its urban structure formation their objects urban potential.

Aim and tasks of the article: to elucidate all objects, built for military needs in Alytus and its surroundings in XIX c. end – XX c. beginning. Also to analyze their meaning to the urban structure and identity of the town.

Methods of research: iconographic, analysis, analytical – discriptional, comparative, reconstructional. Additional specific methods of research: inventorisation of objects, digitalization, fotoficsation. Field research of remaining objects was also made.

This research is continued on 2012-2013, National science program „Country and nation: heritage and identity" project „XVI c. end – 1940 military heritage objects (buildings, their complexes, areas) of Lithuania" project manager – prof. K. Zaleckis.

This article will try to show fortress of Alytus foundation, development, specific features of defensive buildings, their influence to urban structure and identity of the town. This will be done on the base of scanty archive, literature sources and research, made in the place. Article represents results of mentioned above research.

Review of alytus fortress foundation and historical development

Same as much towns of Lithuania Alytus town history from old days was related with wars. In written history sources Alytus started to be mentioned from 1377, when army of Crusaders devastated districts of Alytus and Merkinė. Rudiment of the town was near the castle on the right side of Nemunas river. It formed near castle, which was built in northern side of Alytupis outfall. Alytus castle belonged to Lithuanian defensive system, that

was created near Nemunas river in purpose to defense from Crusaders. Castle preserved ford through Nemunas in one of the most important Crusaders war ways from Karaliaučius to Trakai and Vilnius. The ford near mound was marked in 1797, in the plan of Alytus town and district. It was called “threshold of ram” (Miškinis...1999).

Lower ward formed in northern part of mound. Even then net of Alytus town streets were basically war ways – the way from the ford to Vilnius and other ways to Kaunas and Merkinė, going by Nemunas.

After Žalgiris battle and Melnas peace, wars with order of the Crusaders were over. The castle lost strategic meaning, Alytus turned into small town which developed trade and handicrafts. In XVII c. Alytus was devastated during the war between Russia and Sweden. This happened because it was near war way from East to West.

After third Lithuania-Poland state division in 1795, Nemunas divided Lithuania into two parts. Alytus town was divided as well. Western side of the river was received by Prussia, eastern – by Russia. After 1812 war, when army of Napoleon lost, western bank of Nemunas became a part of Czars Russia Suvalkai province. At that time, government of Russia started to strength western borders of empire. Large meaning for this had revolts in 1831 and 1863. After them, there were planed to fortify area of former Lithuania-Poland state. It was believed, that fortresses and military garrisons in towns may have a large meaning not only in case of war with other enemies, but in case of national unrest in the borders of Russian empire as well. Building borderland fortresses was stimulated by political situation that formed after France-Prussia war in 1870-1871. Then turned out, that main coming war opponents would be Germany and Austria-Hungary. In 1873, Czar Aleksandras II convoked special meeting, in which strategic place of Russia was analyzed and program of western borders of Russia strengthening was created. It was foreseen to create system of fortresses near Nemunas, Bug, Bebrsza and Narew rivers: to build or to modernize the fortresses. Four of them – Warszawa, Modlin, Brest and Kaunas had to become especially strong – I class fortresses. In 1873 geodesic research of these places started, project documentation was prepared. Relationship between Germany and Russia became especially critical after Russia and Turkey war end, that had grown influence of Russia in Balkans. (Bochenek...1996).

Main changes of geopolitics and real possibility of new war, made government of Russia not to isolate oneself only in main towns defensive development, it was decided to organize fortification for defense of large river floating of borderlands.

Figure 1. 1887 general plan of Alytus fortified position. Made works are shown (Российский центральнный госсудаственный военно исторический архив, Ф. 349, оп. 27, д. 776)

These fortifications had to block opponents army access to strategic bridges and roads. In 1883, leaded by war minister of Russia Vanovskij, committee decided to organize fortified positions near Nemunas and Narew rivers, near Alytus, Pultusk, Roszany, Ostrolenko and Lomsza towns. (Jakovlev...1995). Fortified positions were formed from few forts or redoubts, few stationary batteries, ramparts of fortification. In these towns, beside defensive buildings, had to settle smaller or bigger military garrisons.

Same as for large fortifications, places for fortified positions were chosen on the banks of big rivers, on the hills, in areas with natural obstacles – with small rivers, ravines, etc., where through, were going strategic roads and important bridges were built.

For fortifications of Alytus, III class fortification status was given. At that time, large Kaunas fortification was built, a lot of means for that was given. This is why building of less important Aytus fortification was delayed. Only in 1887, when first stage of Kaunas fortification construction was over, construction started in Alytus. (Miškinis...1999).

Alytus fortification was intended for defense of bridges and floating through Nemunas. Defensive line from forts in west part from Alytus, was built on the hills and made a half arc that closed curve of Nemunas. Behind defensive line was town, military complexes and two bridges. (Generalnyj...).

In the beginning of XIX c., war roads were started to built: from Alytus through Simnas, Krosna and Kalvarija bas built road to Marijampolė, later were built roads from Alytus to Seinai, Varėna. On the right bank of Nemunas was built road to Kaunas, going through Jieznas and Rumšiškės. This road branched of to Vilnius. In the south part of the town, metal Kaniūkai bridge was built.

Together with forts, barracks were built too. Their territories occupied a lot of space. On the right bank of Nemunas were built two complexes of barracks – Pontonas and Saratovas. Accordingly they were constructed for battalions of pioneers and infantrymen. On the left bank of Nemunas, was built the biggest complex – complex of artillery barracks. Near these barracks, by the road to Kaniūkai bridge, in 1891 Alytus garrison church was built. Small churches were built in Saratovas and Pontonas barracks complexes too. Construction of forts and barracks was finished till 1900. (Miškinis...1999).

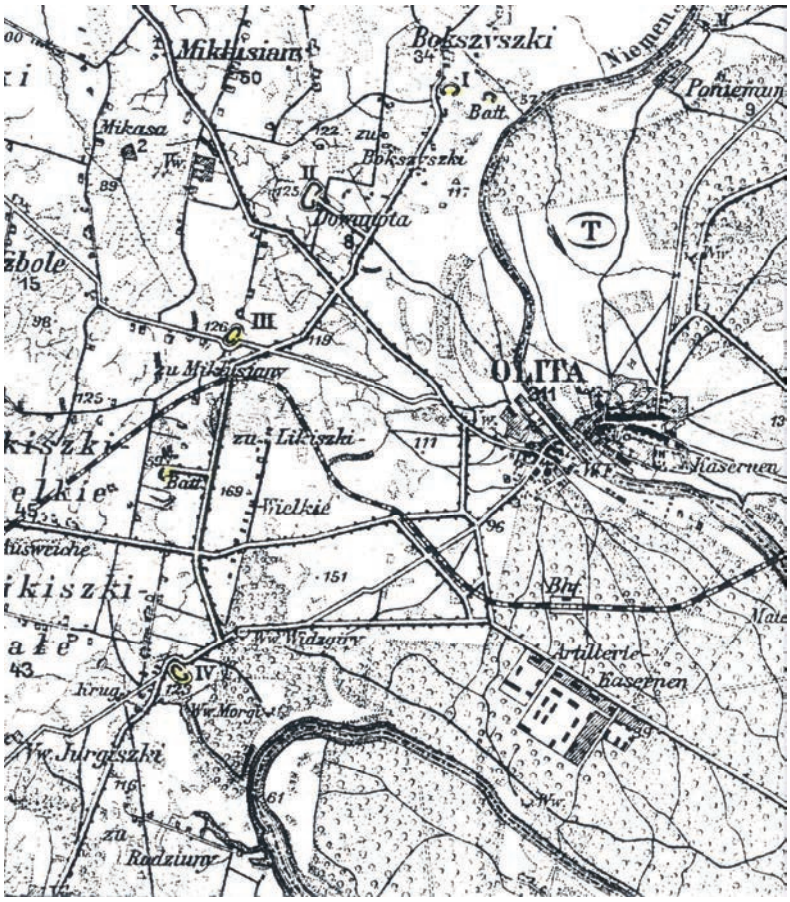

Figure 2. 1917 plan of fortified position (Karte des westlichen Russlads (1:100000), 1917-1921)

Alytus fortress in the beginning of XX c. officially was called Alytus fortified position. (Obozrenije...1906). It stimulated growth of the town. As long as main parts of fortress – forts, artilery barracks, railway station were on the left bank of Nemunas river, this part of the town was growing fast.

At the end of XIX c., around 1898, reconstruction of most fortresses of Russia was started, Kaunas fortress as well. Modernization of Alytus fortifications was discussed too: reconstruction of Alytus fortified position was foreseen (Obozrenije...1906), but there are no any documents if something was done.

In 1906, fortified position of Alytus was critically evaluated. (Obozrenije...1906). It was defined, that inner area of fortress did not correspond to that time demands of defense. Artillery of the opponent could easily fire the roads, bridges and town. It was planned to strengthen second and third lines of fortification, additionally.

During World War I, in August of 1915, army of Germans assaulted Alytus. Forts were not participating in defense. Retreating Russian army detonated bridges, the town was occupied.

Between World War I and II, forts of Alytus were not used, in artillery barracks settled Lithuanian army. In some buildings of Saratovas barracks, industry enterprises were established. Near them, in 1939 Alytus war aerodrome was founded. In Pontonas barracks there were established hospital, school, some became a dwelling houses. (Žepkaitė...2004).

During World War II, the town was suffered a lot, but forts and most of the barracks remained. After World War II, former artillery barracks were used by Soviet army, a lot of buildings of Saratovas barracks were destroyed.

In the second part of XX c., around 1965, Alytus started to develop as centre of industry. The town started to spread on the left bank of Nemunas, to the west. Mass construction of many-flat houses started, in northern-west part huge industrial district raised. Industrial enterprises were built by demolishing forts No. 2 and 3. (Alytaus...1964).

Now remain few forts, fragments of battery, complex of former artillery barracks, fragments of railway station. Roads of fortress overturned to the streets of the town. Instead of abolished railway, pedestrian – bicycle way was created.

Defensive fortifications

In 1887 Alytus fortress plan, there are shown five fortifications, spread out in a half arc. No. 4 is battery. Double first fort parts are marked as 1a and 1b. Half arc of forts surrounded the town and forest in the south. All forts were connected by road that crossed all ways from the town and made united radial circular communicative system. (Generalnyj...1887).

Fortified positions of Alytus general plan (date is not given), with shown works that were made, signed engineer General Konstantin Zverev and engineer General Major Ivan Valberg. They were signing Kaunas fortress general plans as well. Third signed was engineer Captain Karazin. (Generalnyj...).

Military district of Vilnius, in 1906 review (Obozrenije...1906) fortifications of Alytus are called fortified positions of Alytus. It is characterized so: front of fortifications is lasting on the hills of left bank of Nemunas, in front of Alytus settlement, in arc that is faced to the west. Length of the front is 8 versts (8,536 km). Flanks of the position lean to Nemunas river – right one is 3 versts lower than Alytus settlement, left one – near Kiršai ravine. Hills, where fortifications are located, dominate in the valley of the river. Fortified position is formed from five temporary profile forts (each for 2-3 companies and 2-3 guns) and 2 batteries that were built in the center of fortification line, each of them had 8 guns (historic plans, that was found, shows only one battery). The strongest fortification center was in the so-called "signal hill". Left flank was valued as the weakest; it is written that in steep, woody Kiršai ravine slopes, soldiers and military equipment hardly can move. It was certified, that in the left flank opponent might easy come to defense line through woody area and not set under the fire, by bank of Nemunas can get into the back.

Same as in Kaunas fortress, forts were built by using relief maximally. Selected territories were the highest, the best places in defensive respect. Forts of Alytus are ascribed to the half stable fortification type. They are forts – redoubts, formed from soil: they don't have brick buildings. Ditches around the forts were profiled in triangle or trapezium, height of ramparts was until 6 m.

1 fort. In the plan of Alytus fortress (the date is not defined) (Generalnyj...) it is shown, that both parts of the fort are not finished to build. The fort is in north part from the town, near the way to Punia, now at about 46 m to the east from it. The fort consists from two parts: second one is away from the first one at about 200 m to the east, near steep slope of Nemunas valley, in the piece of land that is made of Nemunas and deep (30-35 m) ravine of small river Sidabrius.

In historic plans, first part of the fort is called 1a, second – 1b.

1a fort plan configuration is closed to triangle, corners are rounded. Front – fosa line formed over 200 m, back one – 70 m. Inside the fort there were formed bankets for the riffles to stand, barbets (grounds) for guns. Inside – three travers – embankments, under them shelters were formed. The fort was surrounded by two ditches and flat outward slope – glasis (Generalnyj...).

In 1920 plans of Alytus fortress measurement (Alytaus...1936) it is shown, that 1a fort occupied the territory of 5,5116 ha. Now its territory is 3,4 ha (Lietuvos...2005), glasis that surrounded the fort is destroyed. Even if embankments are disintegrated, this Alytus fort is in the best condition. It is not covered with woods and dominates in surroundings as green hill.

Figure 3. Aerial view of 1a fort in 2008. Photo E. Raubickas

1b fort has irregular plan configuration, in eastern part it merges with natural relief that became part of this defensive object. 1b fort area in 1920 plan, where it is called 1 battery, is 6,1483 ha (Alytaus...1936), now – only 1,7 ha (Lietuvos..2005). it is possible, that not all territory is included to the register, because 1b fort is covered with woods and it is hard to understand where borders of the object are. Structure of the fort differs from the first part. In eastern part, there are two brustvers (embankments-covers), glasis function of the fort is changed by terraces, that are formed from ravine and slopes of Nemunas valley. Both parts of the fort were connected by embankment, which did not remain. Near double fort complex, huge territory now is occupied by garages.

2 fort was built near road to Balbieriškis, in high place (125 m) and was the biggest and the only one that around 1900, in the plan was called as finished. Its front – fosa line formed over 300 m, back one – about 150 m. This fort, by its configuration was close to bigger forts of Kaunas. Fort was formed from trapezium profile outward and inner ditches and two travers. (Generalnyj...). In front sides of the fort, there were formed wide, regular configuration outward slope – glasis. It may be seen in 1944 Germans made aero photograph very well. (http://www.maps4u.lt). Plan of the fort is regular pentagonal with rounded corners. In 1920 inventory (Alytaus...1936) mentioned its area is 9,0017 ha.

3 fort was near the road to Ūdrija, beside the railway, in the height of 126 m. Fort was also formed as regular pentagonal, it was surrounded by two ditches. This fort was smaller. Front fire line formed about 160 m, back one – about 130 m. (Generalnyj...). In 1920 mentioned fort was shown as covering area of 5,2126 ha. (Alytaus...1938). The fort was destroyed during construction of industry enterprises.

4 fort is formed in the height of 123 m, near the road to Miroslavas (near is passing by the road to Simnas, too). The fort was unusual, in front part concaved regular pentagonal plan. It was surrounded by oval glasis, where road was going. Its front line formed about 260 m, back one – 160 m. The fort is particular, it completes

united complex with Kiršai ravine which goes down to Nemunas and the mound of Radžiūnai. (Generalnyj...). In 1920 plan, area of the fort is shown as 20,0801 ha. (Alytaus...1936). Fragments of fort construction now remain, but they are covered with woods, part of the fort is demolished. It is hard to say what size the fort is now. In 2004 ethnographers of Alytus measured remnants of the fort (III and IV...). In the plan they made can be seen, that fort was surrounded by two – lower and higher embankments and two ditches profiled like trapezium.

The battery. As long as distance between 3 and 4 forts was big – more than 3 km, in the highest place between them, in the height of 159 m, the battery was built. In 1900 plan it was marked as pentagonal plan liunet – type of fortification, which back is open (Generalnyj…). In 1920 plan shown area of the battery is 4,4219 ha. (Alytaus...1936).

Figure 4. View of 1a fort in 2007. Photo M. Černiauskas

Figure 5. View of 1b fort in 2009

Military district of Vilnius review in 1906 (Obozrenije...1906), are mentioned second and third lines of defense, that were going first (forts) line: second one started in 1,5 verst lower Alytus settlement – between the roads of Simnas and Seirijai, it based to Nemunas 1 verst lower the Kiršai ravine. Third line of defense ranged over Jefimovičius manor on the bank of Nemunas, by western border of Alytus, glade of forest, perpendicularly to the railway and further on the same way towards Nemunas.

The bridge of the road in the back was absolutely unseen in the thicket of forest and protected from fire from the territories in front, so suitable for safe movement of army to the right bank of Nemunas.

However, railway bridge that rises 18 sagene up Nemunas level, when left bank was quite lower than right one, was seen from western hills and open. It would be safe from fire only if those hills would be in our army hands.

This is why floating near Alytus were unsafe. Because of fortified position segments weakness, there were prepared development plan of fortified position of Alytus. In this project, construction of fortifications was planned. That would strengthen main, second and third lines of defense. Additional fortifications near the bridges and two pontoon bridges with fortification were planned. One of the bridges – lower Alytus, between Jefimovičius manor and forest, second – between both railway bridges. (Obozrenije...1906).

No information founded if these plans were realized. In the town and its districts there are no marks of mentioned fortification lines.

Fortress objects influence to urban structure of the town and their present condition

At about 1965, Alytus started to develop as industry center, north-west industry district was started to build. During this process, 2 and 3 forts were destroyed. 2 fort was destroyed absolutely in 1965, when Alytus cotton fabric was built. (Poškus...).

New many-flat houses districts were started to be planed, later they were built. Territory of the town spread to west in the left bank of Nemunas very fast. Planning new constructions, main urban frame were former roads of the fortress and roads to other towns. Now a lot of streets of the town are former roads of the fortress – Putinų, Kalniškės, Punsko, Ulonų, Santaikos, Radžiūnų, Gamyklos, Alovės, Daugų, Kepyklos, Kauno, Jonyno, Suvalkų, Tvirtovės, Parko, Ūdrijos, Miškininkų, Lakūnų streets, parts of Statybininkų, Pulko streets. Sveikatos way was created on former line of military railway. Part of the streets formed by perimeter of barracks complexes.

Both parts of 1 fort were written to LR Register of unmovable heritage in 2005-04-18, as complex of fort remnant. Zone of protection with physical and visual parts was established. In spite of that, 1b part was damaged during construction of skiing rout in the slope of Nemunas. Near the forts there is huge territory of garages, objects are not regulated.

Nobody cares about fragments of 4 fort, most part of residents don't know about such object.

In so called Hill of the terns there are fragments of the battery.

In Alytus remained huge territory of former artillery barracks with XIX c. end "brick style" buildings. Military complex was planned in geometric principle, reminds Žemieji Šančiai barracks in Kaunas. Near stands former Alytus garrison church (now the church of St. Kazimieras). Fragments of former Saratovas and Pontonas barracks complexes remained. Even war railway through Alytus to artillery polygon of Varėna didn't remain, it is seen on pedestrians – bicycles way, that goes on the same route. By this way remained unique in height embankments of railway. They lifted railway up to the highest at that time railway bridge in Russian empire (remained fragments of the bridge piers are written to LR Register of unmovable heritage).

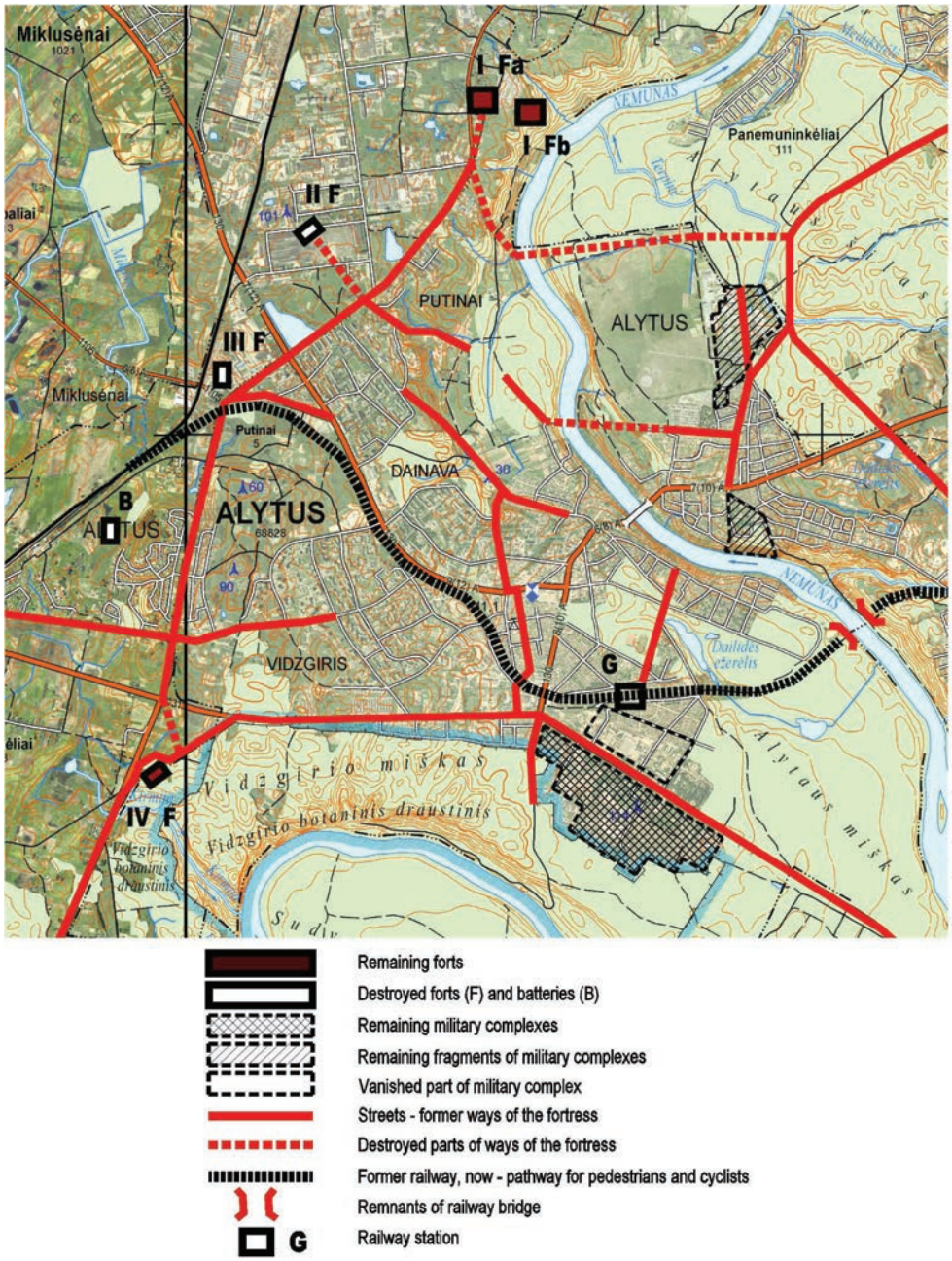

Figure 6. Status of objects of Alytus fortress now

It is important to mention, that in Alytus it is possible to find tracks of former fortress in many places. Military heritage objects exclude Alytus from other towns of Lithuania. The town is not distinguishable by original architecture houses in its historic district, but remained forts, complexes of barracks, fragments of military railway marks that this is town of the fortress. In one article is hard to analyze all objects, related to

Alytus fortress – railway, roads, bridges, engineering equipment. So carrying out mentioned National science program „Country and nation: heritage and identity“ project, new article is planned.

CONCLUSIONS

1. Foundation and growth of Alytus town, from old times was relates with wars. Rudiment of town street net were military ways. Foundation of Alytus fortress, the same as other XIX c. end fortresses in western Russia border, was decided by political situation, geographic location and nature conditions.

2. Designing and building the fortress of Alytus, specific features of the place were maximally used.

Line of fortification was designed on the hills and surrounded the town by half arc with complexes of barracks and bridges. Two flanks leaned to the deep ravines near Nemunas. Forms of relief supplemented fortification.

3. Together with forts, in Alytus there were built big military complexes, military roads and railway. Alytus became one of the most militarized town of Lithuania. Military function – defensive strengthenings and military complexes, as well as dislocation of big military garrisons, stimulated speedy growth of the town in XIX c. end – XX c. beginning.

4. Alytus fortress belonged to fortifications, intended to defense floating through strategic rivers. It was called fortified position of Alytus. Such fortified positions were also built near the rivers of Narew and Bebrsza.

5. Forts of Alytus belong to the type of forts, that are shaped from the soil and had only wooden buildings.

6. During seventh decade of XX c., Alytus sprawled and two forts on the left side of Nemunas were destroyed. Net of the streets in the town urban structure is made of the roads of fortress. Main urban axis became former line of railway, that crosses whole town and now is used as pedestrians – bicycles way.

7. Remained forts are not used now. Woods cover them more and more, embankments are vanishing. These important to whole Eastern Europe fortress heritage defensive objects may vanish very fast.

8. It is not enough to write one fort to LR Register of unmovable heritage and stop care about it. Preservation status must be given to 4 fort, former complex of artillery barracks, embankments of railway, unique engineering equipment. It is important to attract investments and start to use concrete means to preserve and regulate objects of military heritage. Preservation of fortress heritage that shows identity of the town, must be priority aim of Alytus municipality.

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REFERENCES

Alytaus apskr. ir valsč. Alytaus tvirtovės KAM žemės nuo gretimųjų žemių atsienojimo planas, padarytas 1936 m. Karo butų Valdybos matininko Antano Babiliaus naudojantis Karo butų skyriaus matininko kapitono Vėgelio plano, sustatyto 1920 m. matavimo duomenimis. Lietuvos Centrinis valstybės archyvas, F.1250, ap. 4, b. 1/6, lap. 514.

Alytaus medvilnės kombinato projektas. Dalis: architektūrinė. Genplanas. 1964. Pramoninės statybos projektavimo institutas. Kaunas.

Bochenek, R., Fuglewicz, St. 1996. Twierdza fortowa w Modlinie. Fortyfikacja. T. IV. Warszawa – Krakow.

Karte des westlichen Russlads (1:100000), 1917-1921.

Malaškevičiūtė, B., Bernatavičius, G. III ir IV Alytaus fortai, Alytaus naujienos, 2004-10-22.

Miškinis, A. 1999. Užnemunės miestai ir miesteliai. Alytus. Vilnius: Savastis.

Navickas, T. 1988. Alytus ir jo apylinkės. Chicago. Lietuvių istorijos draugija.

Poškus, V. Alytaus fortai, Šiaurės Atėnai, 2005-11-12.

Генеральный рлан Олитской укрепленной розиции с показанием работ, произведенных в 1887 году. Российский центральнный госсудаственный военно исторический архив, Ф. 349, оп. 27, д. 776.

Генеральный рлан Олитской укрепленной розиции с показанием построенных и проектируемых военых шоссе 1887 г. Российский центральнный госсудаственный архив военно морского флота, Ф. 3, оп. 25, д. 1559.

Обозрение Виленского военного округа. Часть вторая. Средне-Неманский район. 1906. Составил Генерального штаба подполковник Иванов. Вилна. Типография штаба Виленского военного округа.

Яковлев, В. 1995. История крепостей. Санкт Петербург.

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Social Housing for Rent in Poland in the Beginning of 21st Century. Analysis of Chosen Concepts

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EXTENDED ABSTRACT

The period of economic transformation in Poland started from 1989 and resulted in significant changes on the housing market. Flats became goods and process of privatizing of the housing market took place in last decade of the 20th century. It became clear, that it was necessary to create the system of housing for the people who cannot afford to buy the flat on free market. Such solutions were implemented in 1996 and since then affordable housing associations started coming into existence – organizations building flats for rent, supported by city and government budget. Large complex of such housing for rent was build in Bialystok, the major city of north-eastern Poland, and it is regarded as one of the biggest in the country. The purpose of author's study is characteristics of the contemporary social housing for rent in Bialystok, as good example of that kind of housing realized in Poland.

The method using in that study is called parametrical and includes several factors describing quality of housing environment. That means analyses of urban composition of complexes, solutions of wheeled and walking transport, spatial concepts of surroundings, semi-public space, recreational space, the access to the social services, architectural concepts and standards of apartments.

Complexes of affordable dwellings for rent carried out in Bialystok in years 1996 – 2011 are good, valuable solutions of that type of social housing. Every next quarter which was built carried higher architectural and urban standards. Particularly Bacieczki I-V estates are interesting examples, located next to each other, they form large housing complex (2169 flats). Although mentioned estates were not designed as the whole one area from the beginning, according to one master plan – they create district of good neighbourhoods (with right spatial and functional relations). Main conclusions from the research are: affordable social housing for rent constructed in Bialystok create the **city of good neighbourhoods with clearly urban quarters** realize **proper standard of housing buildings** by using good quality materials and details, achieve very **fine spatial design of semi-public and recreactional spaces** (even small park). All flats located in groundfloors are available for disabled inhabitants. As a positive feature we can count location of parking places, providing some basic services, shops, kindergarten and school (the last one was planned in master plan and realized not by the Society but by the city). We can evaluate that standards of usable surface of flats is rather low, we would expect larger flats planned for families with children, providing flats for young people, smaller quarters with more individual architectural character and identification. It seems that what we really need more is seeking forms suitable for peripheral locations and apply environment-friendly solutions (technical and structural-material). This Polish model of affordable housing for rent is worth promoting in other developing countries with huge housing needs.

Keywords: social housing, urban concepts, architecture, housing standard, Poland

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REFERENCES

Barek R. 2009. Architektura środowiska mieszkaniowego tworzonego z udziałem środków publicznych. Wydawnictwo Politechniki Poznanskiej, Poznan, 2009.

Gehl J. 2009. Zycie między budynkami. Uzytkowanie przestrzeni publicznych. Wyd. RAM, Krakow, 2009.

Municipal Public Building Society Report. 2011. Bialystok, Poland, 2011.

Statistical Yearbook of the Republic of Poland. 2010. Central Statistic Office. Warsaw, p.350 -363.

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Space Syntax Analysis of Kaunas: Some Methodological Aspects

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EXTENDED ABSTRACT

City is a complex organism and as such it requires complex methods of investigation. Complex investigation should consider all levels of urban reality and its social, economic, cultural dimensions. Space syntax represents one of the complex methods for urban investigation because it focusses not on the spatial characteristics itself but on the social uses of the space. In this way the method integrates spatial, social, economic, cultural dimensions. During the preparatory stage of investigation of Kaunas spatial structure and its influence on security of inhabitants some discrepancies between t traditional space syntax method and real situation in Kaunas were noted and some modifications of the method were proposed.

Space syntax method is used as the basic method in presented research. Two different axial maps of Kaunas are created. Various characteristics of the maps are compared between themselves and validated for the correspondence to the observed facts of urban life of Kaunas.

The following proposals for modification of Space Syntax analysis were made:

- The two different axial maps should be created for the analysis of global and local integration of the city. Map of the local integration should include spaces of the public and semi-public transit pedestrian spaces. At the same time axes that are not accessible for pedestrians and public transport should be excluded from this map.
- Axial map should not be limited to the formal administrative borders of the city; closely integrated suburban parts and roads should be included in the map;
- The aggregation of the segments of curved streets of the city should be respected in the axial maps. In fact it could be done by introduction of continuity lines. According to Figueiredo *"…the notion of continuity is already embedded in the axial system*" and the continuity lines represent the chosen movement roads with the higher percent of probability.

Suggested improvements in Kaunas case helped to do the following: to identify the main axes of global and local integration more precisely; to evaluate the depth of the map more correctly; to reflect the real street network in more accurate ways, etc. Could be that the above mentioned proposals are suitable for application in other cases too.

Keywords: space syntax, axial maps, pedestrian routes, continuity lines, Kaunas, Lithuania.

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REFERENCES

American Planning Association. 2006. Planning and Urban Design Standards. John Wiley & Sons, Inc.

Figueiredo, L., Amorim L. 2004. Continuity lines: aggregating axial lines to predict vehicular movement patterns. Proceedings of the Third Great Asian Streets Symposium, Singapore, National University of Singapore.

Hillier B. 2007. Space is the machine: a Configurational Theory of Architecture. London: Space Syntax.

Zaleckis, K., Matijošaitienė I. 2012. Hidden urban revolution in Kaunas downtown area: 1935-1988-2011. Eight International Space Syntax Symposium, January 3-6, 2012, Santiago de Chile, Chile : proceedings, Santiago de Chile, Pontificia Universidad Católica de Chile, 1-16.

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Urban Potential of the Fortified Objects of Kaunas and Alytus Fortresses According to the Space Syntax Analysis

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EXTENDED ABSTRACT

Military architecture is a technological, historical and cultural phenomenon. In various forms it is present in all stages of urban development since the appearance of the first cities until today. The essential architectural-urban features of the code of military architecture are unique in the contemporary civil context. Because of the unique architectural-urban code the objects of military architecture have a huge meta-functional potential. There the urban potential of the fortified objects of Kaunas and Alytus fortresses is analyzed in the article.

Space syntax methods (Hillier, 2007) were used to evaluate the functional potential of some objects of military architecture in Kaunas and Alytus.

Location of the forts of Kaunas and Alytus fortresses within the maps was analyzed from the point of view of global integration, local integration and global depth. According to the results of analysis conclusions regarding the city and local level functions, multi-functionality and mono-functionality, everyday or more episodically uses were made. Structure of convex spaces of the following single typical objects of the both fortresses were analyzed: Fort No 1 in Kaunas, Battery No 1 in Kaunas, Redoubt on the right bank of Nemunas in Kaunas, Artillery ammunition depot in Panemune in Kaunas, Forts No 1a and 1b in Alytus, Fort No 4 in Alytus. Analysis was performed in the terms of depth, control, integration of the inner structure of the objects. Attempt to identify archetypical urban-architectural model or a type of the object was taken.

The following conclusions were made:

- Forts of Alytus Fortress are located on the edge between city center and periphery. They have potential to become objects of multi-functional specialized local centers of the neighborhoods.
- Forts of Kaunas fortress are located in various places of the city. Part of the forts has a potential to become multi-functional central places of the city. The forts from urban periphery are not integrated into city life but can become .attraction points for the tourists and objects of recreation.
- Convex analysis revealed the following patterns of the fortified objects of the fortresses: gallery, flat, family house, town, town square, congress complex, etc.

Keywords: military architecture, forts, urban potential, space syntax, Kaunas Fortress, Alytus Fortress, Lithuania.

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REFERENCES

De Jung R. 1999. Environmental psychology. Encyclopedia of environmental science. Hingman, MA: Kluver Academic Publishers. 741 p.

Hillier B., 2007. Space is the machine: a Configurational Theory of Architecture. Space Syntax. 368 p.

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Heat-Protective Properties of Outer Walls with Ventilated Façade Heat Insulation Systems

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Abstract: The results of full-scale and benchmark studies are given for aerodynamic and heat-to-humidity behavior of outer walls of buildings with ventilated façade heat insulation systems. The procedures are described for the design calculation of the ventilated gaps and for the outer wall assessment in terms of heat and humidity. The heat protection characteristics are calculated for outer walls of the building with the ventilated façade heat insulation system.

Keywords: Façade system, ventilated air gap, air speed, heat transmission resistance, façade system classification.

INTRODUCTION

Effective heat insulating materials are used, by way of additional heat insulation, to improve the outer walls heat protective properties, both for existing buildings (during their repair, reconstruction or modernization) and for new buildings. When the heat insulation is made on the outer side, the insulating material is covered by the layers of plaster or by the separate protective shields. The shields may be solid (with inlet and outlet holes for air), or may be made of pieces with open vertical and (or) horizontal joints. The heat insulation systems with separate protective shields and ventilated air gaps (VAGs) are referred to as ventilated façade systems (VFSs).

Many publications exist that describe researches of heat-to-humidity behavior of outer walls with VFSs (Bogoslovski, 1982; Fokin, 1973; Hens, 2008 etc.). The researches described in these publications cover the VAGs aerodynamic behavior as a function of their geometric dimensions, determination of heat protection levels for walls with façade systems, heat insulation layer protection against air filtration etc. However, contradictory data exist with regard to some matters, e.g. how the structures under facings and the heat insulation layer fasteners affect the heat transmission resistance of the walls with VFS; how the roughness of the heat insulation and the shield affects the pressure losses when air moves inside gaps; how the interrelated processes of heat, moisture and air transfer affect the heat-to-humidity behavior of walls with façade heat insulation systems.

The results given in this publication describe the heat and mass transfer processes in outer walls with VFSs and shields comprising the solid protective facing that covers one or several stories or the building throughout its full height. The studies were carried out in 1999-2012, as full-scale researches on seven buildings with various numbers of stories, and on laboratory benches. Also, mathematical models of heat and moisture transfer processes were used.

FULL-SCALE STUDY RESULTS

Within the scope of these studies, test positions were arranged on the facilities; sensors were mounted on VAGs height, on the surfaces of heat insulation materials and protective shields, within the layer of the heat insulation material and within the dense layers of outer walls. Air speeds in gaps, wind directions and speeds, and fencings' heat transmission resistance were recorded. The IR survey was used to analyze the temperature fields on shield surfaces and on the inner wall surfaces. As a part of this study, bulk humidity values versus the wall material layer thickness were determined for walls with VFS. See Figure 1 for the structure of the test position on the wall of the multistory office building.

Figure 1. Test position on the building wall with VFS (Minsk, Nezavisimosti Ave.):
a) – building façade overview (with test positions); b) – the position where the temperature sensors and pressure pipes were mounted; c) – the same position with sensors.

The results of the full-scale study were as follows (Protasevich and Krutilin, 2008). Air speed in VAG significantly depends on the wind and on the protective shield type. For systems with protective shields made of pieces with open vertical and (or) horizontal joints, local zones with higher pressure (as compared with the adjacent areas) can appear, resulting in possible longitudinal filtration in the heat insulation material layer.

VFS with solid shields are much less affected by longitudinal filtration. Air speed in VAGs for the façade systems with solid shields (when the ambient temperature is below $t_н = -15°C$, and the building is not exposed to wind) does not exceed 0.3 m/s, i.e. it is much less than the calculated values for such a structure resulting from standard design procedures. For the purposes of VAG dimensions determination, the conditions with no wind affecting a building, and the air moving in the gap only because of the gravitational pressure, shall be considered as the worst-case conditions for calculations.

Temperature and heat flow measurements on the walls near the heat-conducting elements (shield and heat insulation fasteners etc.) have demonstrated the reduced levels as compared with the positions on the wall far from the heat-conducting elements. This was the case for all facilities with VFSs.

Samples of the wall materials were taken in winter and in spring; the analysis of these samples has demonstrated that the characteristics of the outer walls with VFS, in terms of humidity, shall be considered favorable. Bulk humidity values of samples are within their sorption moisture content, and they are much less then the calculated values listed in standards and norms.

On the basis of the full-scale study results, the procedure for VAG dimensions calculation was developed, and the proposals were prepared for the purposes of protection against air filtration in the heat insulation layer and for determination of heat protection level for outer walls with VFS.

METHODS

The method is proposed for calculation of VAG dimensions. This method is based on heat and moisture balance equations for winter (Protasevich and Krutilin, 2007; Protasevich and Krutilin, 2011). For the purposes of this method, steady-state mode of processes is considered.

The air speed in ventilated gaps of the heat insulation VFS, with solid protective shields, is calculated for the conditions when the air is moved by gravitational pressure. For this calculation, the successive iteration procedure is applied. The temperature on the inner surface of the protective shield is assumed to be the

convergence criterion, because this temperature depends on all parameters recalculated in the iterations (gravitational pressure, air speed in VAG, gap surface heat exchange coefficients etc.).

The calculation is carried out for the preset conditions in accordance with two algorithms (see Figures 2 and 3). The first algorithm is applied for calculation of the air speed in the gap; the second algorithm determines whether the moisture condensation exists on the inner surface of the protective shield.

The procedure for calculation of the air speed in VAG shall be as follows:

1. For the first approximation, the convective and radiant heat exchange coefficients for "warm" and "cold" surfaces of the gap ($\overline{\alpha^{\hat{E}}_{\hat{O}.\ddot{I}}}$, $\overline{\alpha^{\hat{E}}_{\hat{O}.\ddot{I}}}$, $\overline{\alpha^{\hat{E}}_{\hat{O}.\ddot{I}}}$, $\overline{\alpha^{\hat{E}}_{\hat{O}.\ddot{I}}}$, W/(m^2·°C)), average air temperature and density ($t^{\tilde{n}\eth}_{\hat{a}.\ddot{i}}$, °C, and $\overline{\rho_{\hat{a}.\ddot{i}}}$, kg/m^3), and air speed in the gap ($\upsilon_{\ddot{i}\eth}$, m/s) are specified. The temperature distribution within the wall and the average temperature on the inner surface of the protective shield ($\overline{\tau_{\tilde{O}.\ddot{I}}}$, °C) are calculated.

2. The values are calculated as follows: air flow in VAG (L, m^3/h), effective heat transmission resistances for inner and outer parts of the structure ($R_{вн}$ and $R_{нар}$, m^2·°C/W), air temperatures on the VAG outlet ($t^{вых}_{в.п.}$, °C), gap height average temperature, air density at the gap inlet, gap height average air density, gravitational pressure ($\Delta P_{ГР}$, Pa) and total pressure losses for the air movement ($\Sigma\Delta P$, Pa).

3. If the gravitational pressure is less than the total pressure losses, then the air speed is reduced, with 0.001 m/s decrement, until the gravitational pressure becomes higher than the total pressure losses. If the gravitational pressure is higher than the total pressure losses, then the air speed is increased, with 0.001 m/s increment, until the gravitational pressure becomes equal to or less than the total pressure losses. As a part of these cyclic recalculations of the air speed in VAG, in each loop, the values are recalculated as follows: air temperature at the VAG outlet and average air temperature in the gap; average air density in the gap; gravitational pressure; total pressure losses for the air speed in the gap for the particular loop.

4. The values are recalculated as follows: convective and radiant heat exchange coefficients for "warm" and "cold" VAG surfaces; temperature distribution within the wall; average temperature on the inner surface of the protective shield.

5. The newly calculated average temperature on the inner surface of the protective shield is compared with that calculated in Step 2. If the difference exceeds s = 1%, the new iteration shall be carried out, starting from Step 2.

For the key equations used in these iterative calculations, see below.

Equation (1) shall be used to calculate the average temperature on the inner surface of the protective shield. This equation is derived from the balance of the heat inflow to the inner surface of the shield and the heat outflow through the shield:

$$\overline{\tau_{\tilde{O}.\ddot{I}}} = t^{\tilde{n}\eth}_{\hat{a}.\ddot{i}} - \frac{t^{\tilde{n}\eth}_{\hat{a}.\ddot{i}} - t_{\acute{i}}}{\left(\frac{1}{\alpha_{\acute{i}}} + \frac{\delta_{\acute{Y}\hat{E}\grave{D}}}{\lambda_{\acute{Y}\hat{E}\grave{D}}} + \frac{1}{\overline{\alpha_{\tilde{O}.\ddot{I}}}}\right)\cdot\overline{\alpha_{\tilde{O}.\ddot{I}}}}. \tag{1}$$

Equation (2) shall be used to calculate the height-average air temperature. This equation is derived by solving the VAG heat balance equation [8]:

$$t^{\tilde{n}\eth}_{\hat{a}.\ddot{i}} = t_h - \frac{(t_h - t_{\acute{i}})\cdot\left[1-\exp\left(-\frac{h\cdot b\cdot(\overline{\alpha^{\hat{E}}_{\hat{O}.\ddot{I}}} + \overline{\alpha^{\hat{E}}_{\hat{O}.\ddot{I}}})}{0{,}28\cdot\tilde{n}_{\hat{A}}\cdot\overline{\rho_{\hat{a}.\ddot{i}}}\cdot L}\right)\right]}{h\cdot\frac{b\cdot(\overline{\alpha^{\hat{E}}_{\hat{O}.\ddot{I}}} + \overline{\alpha^{\hat{E}}_{\hat{O}.\ddot{I}}})}{0{,}28\cdot\tilde{n}_{\hat{A}}\cdot\overline{\rho_{\hat{a}.\ddot{i}}}\cdot L}}, \tag{2}$$

where $t_h = \frac{t_{\hat{a}}\cdot R_{\acute{i}\grave{a}\eth} + t_{\acute{i}}\cdot R_{\hat{a}\acute{i}}}{R_{\acute{i}\grave{a}\eth} + R_{\hat{a}\acute{i}}}$; $R_{\hat{a}\acute{i}} = \left(\frac{1}{\alpha_{\hat{a}}} + \sum_{i=1}^{n}\frac{\delta_i}{\lambda_i} + \frac{1}{\overline{\alpha^{\hat{E}}_{\hat{O}.\ddot{I}}}}\right)\cdot r_{\tilde{N}}$; $R_{\acute{i}\grave{a}\eth} = \frac{1}{\overline{\alpha^{\hat{E}}_{\tilde{O}.\ddot{I}}}} + \frac{\delta_{\acute{y}\hat{e}\eth}}{\lambda_{\acute{y}\hat{e}\eth}} + \frac{1}{\alpha_{\acute{i}}}$,

$t_н$, $t_в$ are the inner and outer air temperatures, °C;

$R_{нар}$, $R_{вн}$ are the effective heat transmission resistances of the "ventilated façade's" inner and outer parts, m^2 °C/W;

r_c is the coefficient describing the additional heat inflow to the air in the VAG through the fasteners of the heat insulation layer and of the protective shield;

h, b, δ are VAG dimensions (height, width and thickness, respectively), m;

$c_в$ is the air heat capacity, kJ/(kg·°C).

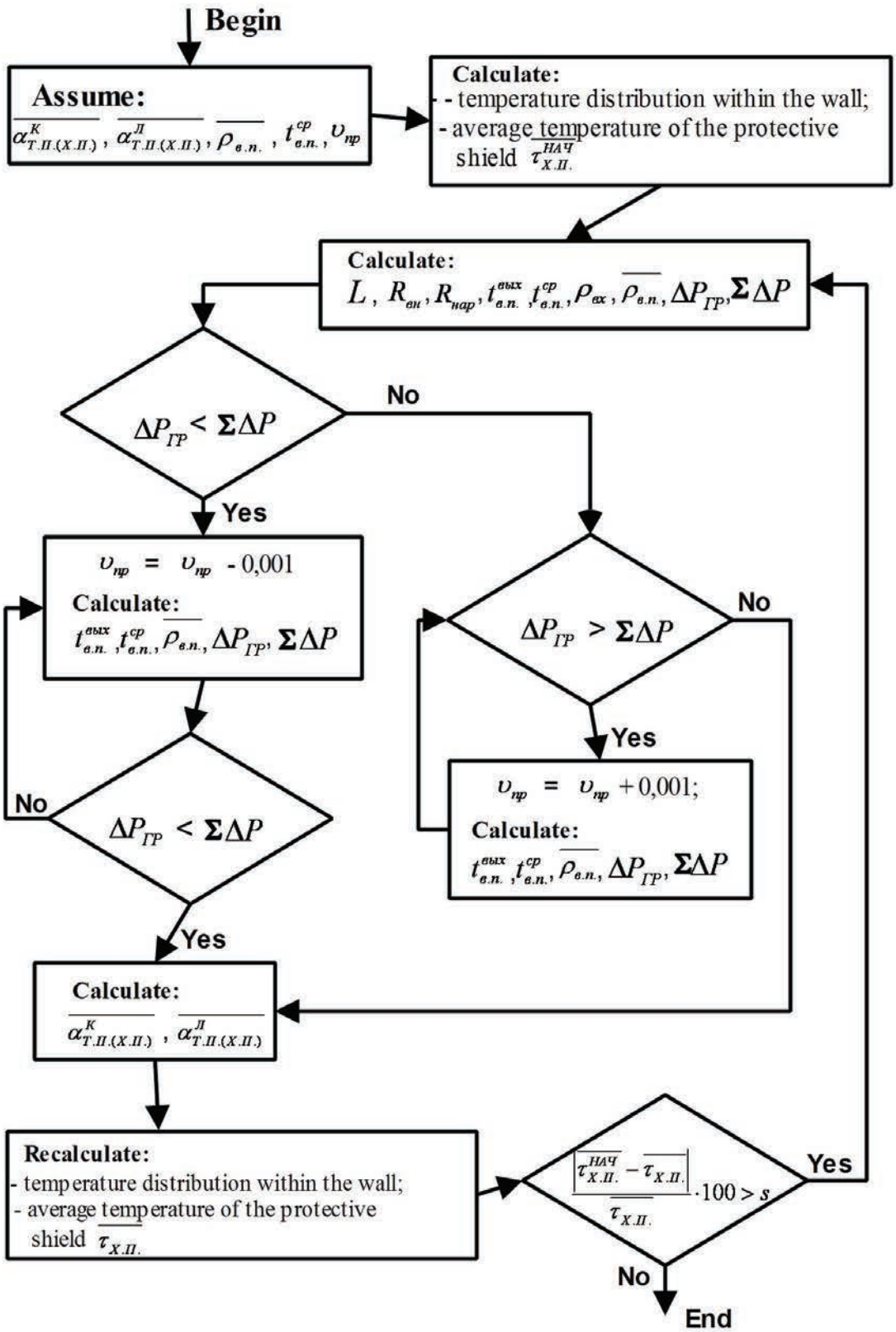

Figure 2. Air speed in the VAG of the heat insulation VFS: calculation algorithm

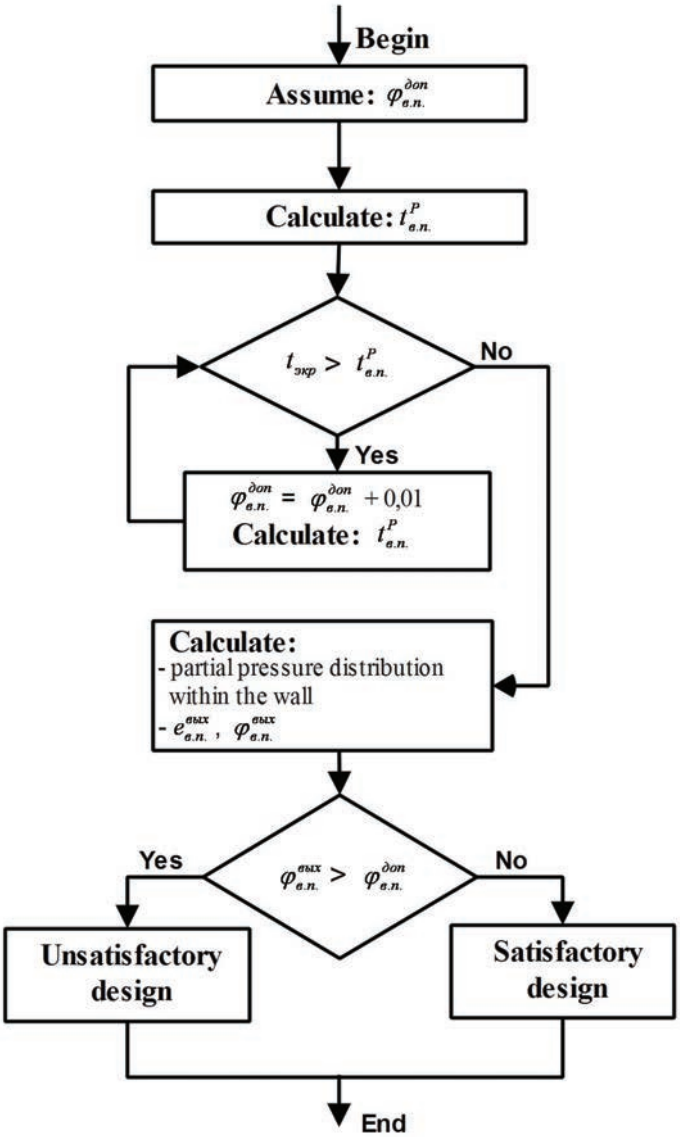

Figure 3. Checking for condensation on the inner surface of the shield in the heat insulation VFS: algorithm

Pressure losses for the air movement in the gap shall be calculated as follows:

$$\sum \Delta P = R_h + \sum_{i=1}^{n} \xi_i \cdot \frac{\overline{\rho_{â.ï.}} \cdot \upsilon_{ïð}^2}{2}, \tag{3}$$

where R_h are the pressure friction losses throughout the VAG height, $R_h = R_l \cdot h$, Pa;
R_l are the specific friction losses for the appropriate air speed in VAG, Pa;
$\sum \xi_i$ is the total of local resistance coefficients.

The specific friction losses, as a function of the air speed in gaps, δ = 20 ... 100 mm thickness, for VFS with metal smooth shields, are calculated on the basis of the laboratory test results as follows:

$$R_l = \upsilon_{ïð} \cdot (1{,}27 - 0{,}012 \cdot \delta). \tag{4}$$

To check the VAG dimensions, the calculation shall be carried out to determine whether the moisture condensation is possible or not on the inner surface of the protective shield. For this purpose, the maximum permissible relative air humidity in VAG is calculated, for which there would be no moisture condensation on the “cold” surface of the shield. This calculation shall be carried out as follows (see Figure 3).

1. The permissible relative air humidity in VAG ($\varphi_{\text{â.ï.}}^{\text{äîï}}$, %) is selected which is known to be below the range of its practically possible values.

2. The calculated air temperature on the VAG outlet and the assumed relative air humidity in the gap are used to calculate the dew point ($t_{\text{â.ï.}}^{\text{Ð}}$, °C).

3. If the temperature on the "cold" surface of the shield is higher than the dew point temperature, then the assumed permissible relative air humidity in VAG is reduced with 1% decrement, until the dew point temperature becomes higher than the temperature on the "cold" surface of the shield.

4. The values are calculated as follows: water vapor partial pressure distribution within the outer wall; partial pressure of the air water vapor at the gap outlet ($e_{\text{â.ï.}}^{\text{âûõ}}$, Pa); relative air humidity at the VAG outlet ($\varphi_{\text{â.ï.}}^{\text{âûõ}}$, %).

If the relative air humidity at the VAG outlet is higher than the maximum permissible relative air humidity, calculated in accordance with the condition that there must be no condensation on the inner surface of the shield, then the VAG dimensions must be corrected, or other structural solutions must be chosen to reduce the water vapor inflow into the gap.

To calculate the partial pressure of the air water vapor at the VAG outlet, the equation of the moisture balance in the gap shall be solved:

$$e_{\text{â.ï.}}^{\text{âûõ}} = \overline{e_{\text{Ò}}} - (\overline{e_{\text{Ò}}} - e_i) \cdot \exp\left(-\frac{h \cdot \overline{\beta_{\text{Â.Ï.}}}}{\overline{\rho_{\text{â.ï.}}} \cdot L \cdot 1{,}5526} \right), \tag{5}$$

where $\overline{e_{\text{Ò}}}$ is the gap height average partial pressure on the "warm" VAG surface, °C;

$\overline{\beta_{\text{Â.Ï.}}}$ is the gap height average mass exchange coefficient for the wall surface facing the VAG air, mg/(m^2·hour·Pa).

In (Protasevich and Krutilin, 2011), the VAG dimensions influence on the air flow behavior in it was studied. It was found that, when the air is moved by gravitational forces, the friction pressure losses may be as high as 90% in the total pressure losses. Relative humidity of the air flow at the VAG outlet, for which there would be no moisture condensation on the inner surface of the protective shield, is below 100%, and, in general, it must be calculated. The criterion, $e_{\text{â.ï.}}^{\text{âûõ}} < E_{\text{â.ï.}}^{\text{âûõ}}$, recommended in several widely applied procedures, is inapplicable as an assessment criterion to check the VAG dimensions in VFS for heat insulation with solid shields.

Under-facing structure influence on the heat transmission resistance of the walls with vfs

The metal fasteners are heat-conducting elements that significantly reduce the heat transmission resistance of the wall. Each fastening point (both the heat insulation layer and for the shield), fasteners material, protective shield structure and other factors have an influence on the heat transfer.

The heat transfer performance uniformity factors are used to take into consideration the wall heat transmission resistance reduction resulting from heat-conducting elements:

$$r = \frac{R_T^{\text{Вк}}}{R_T}, \tag{6}$$

where R_T is the heat transmission resistance along the "smooth surface" of the outer wall, m^2·°C/W;

$R_T^{\text{Вк}}$ is the heat transmission resistance for the outer wall segment to be studied, with the heat-conducting elements influence taken into consideration, m^2·°C/W.

The calculation of heat transmission resistance of an outer wall with VFSs, along the "smooth surface", is figured out according to a known dependence:

$$R_T = \frac{1}{\alpha_{\text{Â}}} + \sum_{i=1}^{n} \frac{\delta_i}{\lambda_i} + \frac{1}{\alpha_{\text{ÂÏ}}}, \tag{7}$$

where δ_i is the thickness of every i layer of an outer wall, m;

λ_i is the coefficient of het-conductivity of every i layer of an outer wall, W/(m^2·°C);

n is the quantity of layers within the outer wall in the limit of its inner surface to VAG;

α_B is the heat exchange coefficient of the inner surface of an outer wall, W/(m^2·°C);

$\alpha_{\text{ВП}}$ is the heat exchange coefficient of an outer wall surface, reversed intoVAG, W/(m^2·°C).

The heat transmission resistance for the outer wall segment to be studied, with the heat-conducting elements influence taken into consideration $R_T^{\text{Вк}}$ is defined in the following succession:

— for each of the heat-conducting elements geometrical model of a wall segment is constructed;

— temperature distribution of 3D segment of a wall model with each heat-conducting element is calculated on the bases of approximation of a heat conductivity differential equation in the finite-element form;

— on the bases of calculated average temperatures on the inner surfaces of models and conditions of heat exchange, heat transmission resistance is defined taking into consideration the influences of heat-conducting elements;

— considering the area of inner surface for each segment of an outer wall with heat-conducting elements, average heat transmission resistance is calculated — $R_T^{Вк}$.

While defining heat transmission resistance of an outer wall wind influence is taken into consideration. This unfluence defines the motion mode and intensity of heat exchange into VAG.

Here, let's consider the example of heat transmission resistance calculation for the segments of the outer wall with the VFS (for the dwelling house) (Protasevich and Krutilin, 2011), with the influence of the heat-conducting elements taken into consideration.

The outer wall, for which the calculation is carried out, is made of expanded clay concrete slabs, with the outer reinforced-concrete layer, δ = 30 mm thickness, middle expanded clay concrete layer (ρ = 1000 kg/m^3), δ = 250 mm thickness, and inner patterned concrete layer, δ = 20 mm thickness. The ventilated façade system includes a heat insulation layer made of mineral wool slabs with basalt fiber used as a basic material (ρ = 90 kg/m^3, λ_A = 0.0406 W/(m·°C)), δ = 100 mm thickness. The protecting shield is made of metal shaped siding; brackets and anchors are used to fasten the shield on the wall base. Dowels with metal cores, ∅5 mm, are used to fasten the mineral wool slabs on the base. VAG thickness is δ = 60 mm; the heat transmission resistance along the "smooth surface" is $R_T \approx 3.5$ m^2·°C/W.

In calculations, the variable factors were as follows: number of bracket mounting points per 1 m^2 of the wall area (1 or 2 pcs/m^2); bracket material (steel or aluminium); number of dowels with metal cores used to fasten the heat insulation layer (2, 4, 6 or 8 pcs/m^2).

For the temperature fields characterizing the outer wall segments containing the heat-conducting elements, see Figure 4. For the results of calculation of the heat transfer performance uniformity factors, see Tables 1 and 2.

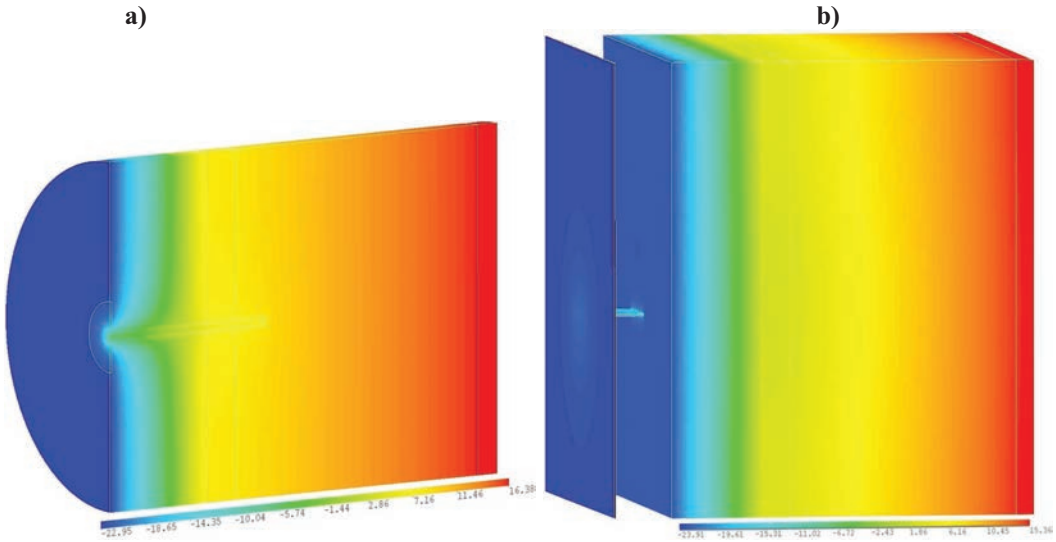

Figure 4. 3D temperature fields (t, °C) for segments of the outer wall with the heat insulation VFS: a) dowel; b) bracket.

Table 1. The results of calculations of heat transfer performance uniformity factors

Heat transmission resistance along the "smooth surface" of the wall, R_T, $m^2 \cdot °C/W$	Heat transfer performance uniformity factors, for various heat-conducting elements							
	Brackets with anchors, pcs/m^2				Dowels with metal cores, pcs/m^2			
	aluminium		steel		2	4	6	8
	1	2	1	2				
3.446	0.768	0.536	0.858	0.717	0.986	0.972	0.957	0.944

Table 2. The results of calculations of heat transfer performance uniformity factor and heat transmission resistance

Type and number of heat-conducting elements, per 1 m^2 of the wall surface	Heat transfer performance uniformity factor for the outer wall with the heat insulation VFS	Heat transmission resistance for the analyzed segment of the outer wall (taking into consideration the heat-conducting elements), $R_T^{Вк}$, $m^2 \cdot °C/W$
Steel bracket with an anchor (1) and dowels with metal cores (6)	0.816	2.81
Aluminium bracket with an anchor (1) and dowels with metal cores (6)	0.726	2.50

The brackets, their material and number (per unit façade area) have decisive influence on the heat protection of the outer wall with the VFS. Steel brackets are more preferable than aluminium ones, because the former result in higher heat transfer performance uniformity factors for the heat-insulated wall.

For one bracket and six dowels (with metal cores) mounted per 1 m^2 of the outer wall area (see Table 2), the total heat transfer performance uniformity factor for the heat insulation VFS is r = 0.726 ... 0.816; the heat transmission resistance (taking into consideration the heat-conducting elements) is $R_T^{Вк}$ = 2.50 ... 2.81 $м^2 \cdot °C/W$. This value is below the standard heat transmission resistance, $R_{T.H.}$ = 3.2 $m^2 \cdot °C/W$, applied in Belarus (TKP 45-2.04-43-2006).

For heat insulation VFSs with "heavy" shields (made of ceramic, ceramic granite or concrete slabs), larger number of points used to fasten the protective shield reduces the effectiveness of the heat insulation (for the outer wall as a whole) even more. In several cases, it's quite difficult to achieve the required standard heat transmission resistances only by increase of the heat insulation thickness.

Ventilated façade systems: classification

Now, several VFS classifications have been proposed in a number of countries. In Lithuania (Recommendations: Design and Construction of Walls with Air Gaps), VFSs are classified in accordance with the gap ventilation type. This classification is used as a basis for measures intended to prevent air filtration in the heat insulation layer. In Canada and the USA (Salonvarra, 2005), the classification is used, covering the structures of the outer walls built with protective shields and ventilated by way of air gaps.

However, these classifications don't cover several structural solutions for VFSs being in use in Belarus and in CIS countries, hindering their effective use. The results of studies, carried out both in CIS and in other countries, and the results obtained by the authors of this publication (Protasevich and Krutilin, 2011) demonstrate that, taking into consideration the climatic conditions in Belarus and other CIS countries, the factors that must be considered for the purposes of the VFS classification shall be as follows: VAG ventilation type; VAG location in the wall structure; VAG ventilation rate; protective shield type; number of stories.

For the proposed classification of VFSs and outer walls with VAGs, see Figure 5.

This classification provides more strict requirements in terms of the heat insulation protection against longitudinal filtration for buildings with higher number of stories, and in terms of the number of inlets and outlets per 1 m^2 of the façade and in terms of the mineral wool heat insulation density. In accordance with this classification, for buildings with the number of stories not more than five, VFS with solid shields may be designed without any special solutions for protection against longitudinal air filtration.

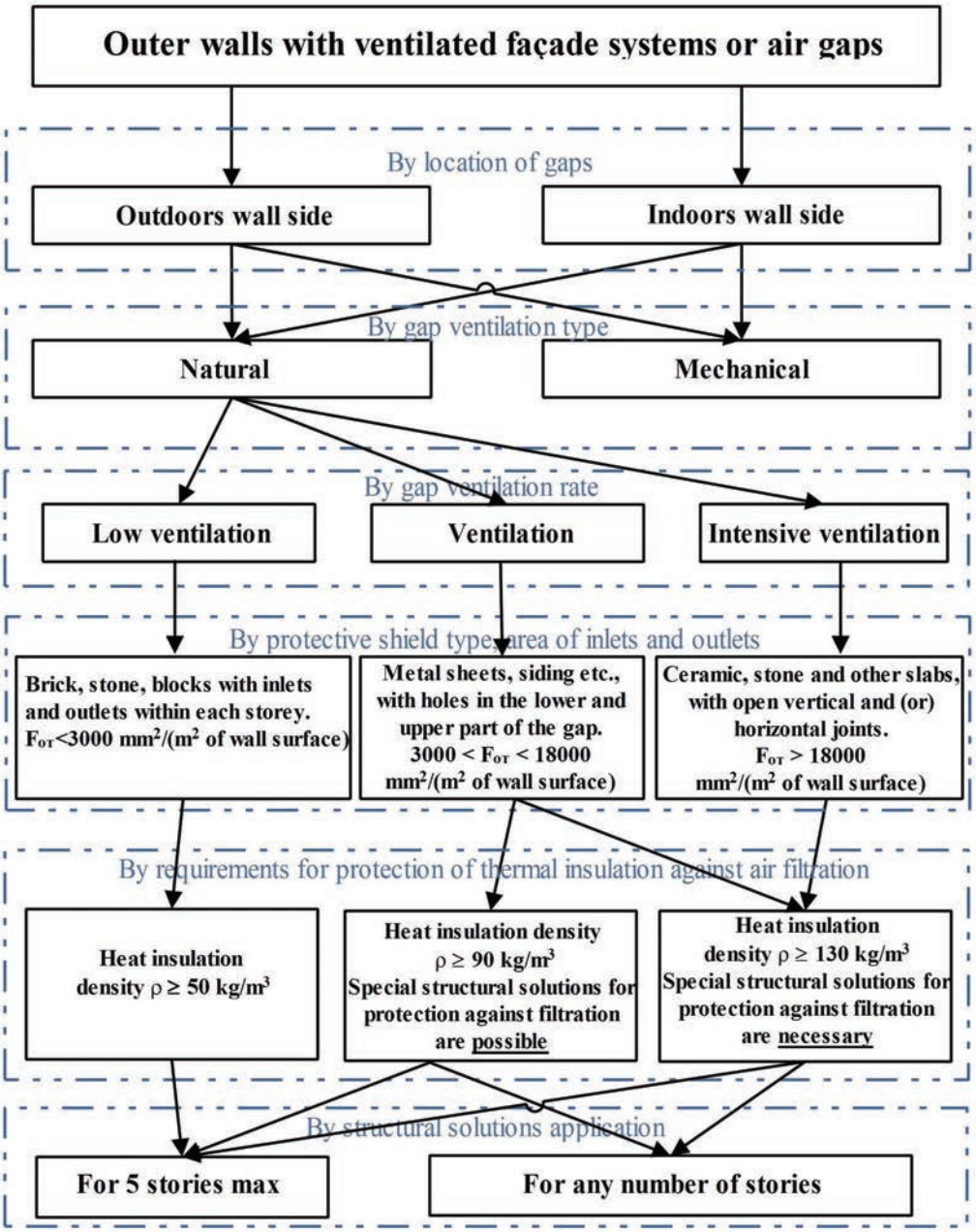

Figure 5. Outer walls with ventilated air gaps and VFS: classification

CONCLUSIONS

The results of the full-scale, laboratory and analytical studies of processes of heat and moisture transfer in outer walls with VFSs are used to develop the procedure for the design calculation of the ventilated gap based on the icing prevention criterion for protective shields.

The influence of heat insulation fasteners and protective shield on heat transfer through the wall is defined by the input of heat transfer performance uniformity factors. It is demonstrated that depending on the type and and quantity of heat-conducting elements per 1 m^2 of a surface for a specific wall structure heat transfer performance uniformity factors may vary within the scope of r = 0,726 ... 0,816.

The classification of outer walls with ventilated façade systems and air gaps is proposed. The classification takes into consideration the demands for the heat insulation layer protection against longitudinal air filtration in terms of buildings with higher number of stories, heat insulation density and other factors.

REFERENCES

Hens, Hugo S. L. C. U. Building Physics Heat, Air and Moisture: Fundamentals and Engineering Methods with Examples and Exercises / Hugo S. L. C. Hens. – Weinheim: Wiley-VCH, 2008. – 284 s.

Salonvarra, M. Air Cavities Behind Claddings — What Have We Learned? / M. Salonvarra, Achilles N. Karagiozis, M. Pazera, W. Miller // 10th Canadian Conference on Building Science and Technology. – Ottawa, Canada, May 12-13, 2005.

Богословский, В.Н. Строительная теплотехника / В.Н. Богословский. – М.: Высшая школа, 1982. – 415 с. [Bogoslovski, V.N. Heat Engineering for Construction / V.N. Bogoslovski – Moscow: Vysshaya Shkola Publ., 1982. – 415 p.].

Протасевич, А.М. Натурные исследования наружных стен зданий, теплоизолированных по системе “вентилируемый фасад / А.М. Протасевич, А.Б. Крутилин // Современные фасадные системы: эффективность и долговечность: Материалы научно-технической конференции. Москва, 21 ноября 2008 г. / МГСУ – Москва, 2008. – с. 212 – 217. [Protasevich, A.M. Outer Building Walls with “Ventilated Facade” Heat Insulation Systems: Full-scale Studies / A.M. Protasevich, A.B. Krutilin // Modern façade Systems: Effectiveness and Durability: Proceedings of the Scientific Technical Conference. Moscow, 21 November 2008 / Moscow State Construction University – Moscow, 2008. – p. 212 - 217].

Протасевич, А.М. Тепловой режим вентилируемых воздушных прослоек фасадных систем / А.М. Протасевич, А.Б. Крутилин // Строительные материалы. – 2007. – №6. – с. 13 – 15. [Protasevich, A.M. Ventilated Air Gaps in Façade Systems: Heat Behavior / A.M. Protasevich, A.B. Krutilin // Building Materials Journal. – 2007. – No.6. – p. 13 – 15].

Протасевич, А.М. Аэродинамический расчет вентилируемых фасадных систем зданий со сплошными экранами / А.М. Протасевич, А.Б. Крутилин // Жилищное строительство. – 2011. – №7. – с. 37 – 40. [Protasevich, A.M. Ventilated Façade Systems for Buildings with Solid Shields: Aerodynamic Calculation / A.M. Protasevich, A.B. Krutilin // Dwelling Construction Journal. – 2011. – No.7. – p. 37 – 40].

Протасевич, А.М. Классификация вентилируемых фасадных систем. Влияние теплопроводных включений на их теплозащитные характеристики / А.М. Протасевич, А.Б. Крутилин // Инженерно-строительный журнал. – 2011. – №8. – с. 57 – 62. [Protasevich, A.M. Ventilated Façade Systems: Classification. Influence of Heat-conducting Elements on Heat Protection Characteristics / A.M. Protasevich, A.B. Krutilin // Journal of Construction Engineering. – 2011. – No.8. – p. 57 – 62].

Рекомендации по расчету и конструированию вентилируемых стен промышленных зданий с влажным и мокрым режимами / НИИСФ. – М.: Стройиздат, 1988. – 43 с. [Recommendations for Calculation and Design of Ventilated Walls for Industrial Facilities with Humid and Wet Modes of Operation / Scientific Research Institute of Construction Physics. – Moscow: Stroyizdat Publ., 1988. – 43 p.].

Рекомендации “Проектирование и строительство стен с воздушными промежутками” / Институт архитектуры и строительства. – Вильнюс.: Министерство окружающей среды Литовской Республики, 2002. – 24 с. [Recommendations: Design and Construction of Walls with Air Gaps / Architecture and Construction Institute – Vilnius: Ministry of Environment of the Lithuanian Republic, 2002. – 24 p.].

Строительная теплотехника. Строительные нормы проектирования. ТКП 45-2.04-43-2006. – Минск: Министерство архитектуры и строительства Республики Беларусь, 2007. – 32 с. [Heat Engineering for Construction. Construction Design Norms. TKP 45-2.04-43-2006. – Minsk: Ministry of Architecture and Construction of the Republic of Belarus, 2007. – 32 p.].

Фокин, К.Ф. Строительная теплотехника ограждающих частей зданий / К.Ф. Фокин – М.: АВОК-ПРЕСС, 2006. – 256 с. [Fokin, K.F. Heat Engineering for Construction: Fencing Parts of Buildings / K.F. Fokin – Moscow: AVOK-PRESS Publ., 2006. – 256 p.].

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Specific Details of Behavior of Composite Steel and Reinforced-Concrete Ceilings in Spatial Frames of Multistory Buildings Based on Light Metal Structures and Hollow Concrete Slabs

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Abstract. The new design solution is described for a frame based on light composite steel and reinforced-concrete structures of ceiling disks made of precast autoclaved hollow-concrete slabs. The specific details are described that are necessary for calculation and design of prefabricated cast-in-situ ceilings for spatial frames of multistory buildings.

Keywords: Building frame, light steel, concrete structures, slabs, ceiling disks.

INTRODUCTION

Metal is one of the oldest materials used for many centuries in construction of buildings and structures of different purposes, included those that entered the treasure house of world architecture. Unique properties of metal structures, steel in particular, that combine high strength and stiffness with lightness and efficiency, promote their increasingly wide application in domestic construction practice. By order of the Ministry of Architecture and Construction of the Republic of Belarus specialists of Institute BelNIIS RUE have carried out a set of experimental-theoretical and development and construction works that resulted in universal design system of new generation – light steel and concrete frame on the basis of bent and welded profiles, hollow concrete ceiling slabs and cast-in-situ concrete (Patent of the Republic of Belarus No. 5673). All frame components are produced by enterprises of Belarusian building industry. In particular, steel structures are manufactured by Molodechno Light Metal Structures Plant, and hollow concrete slabs are manufactured by Zabudova OJSC Plant of Construction Structures. This is an essential factor in minimizing cost of final building product.

METHODS

Description of design system of buildings based on composite steel and concrete frame

The specific feature of the frame design (Figure 1) consists in providing combined work of all elements. At the stage of statistical calculation such known factors as volumetric stress of concrete, longitudinal and transverse thrust in ceilings, real deformation and strength properties of materials are taken into consideration. Among advantages of such system is also the possibility of arbitrary arrangement of slabs within the floor and in adjacent cells of columns' grid, no matter how they are placed on the other floors. Overwhelming majority of frame joints are bolted with minimum number of welded joints made under construction conditions. Required stiffness of connection joints is provided by cast-in-situ concrete and steel in the form of rolled sections and bar reinforcement (where necessary). New frame belongs to the type of braced frames and its resistance to action of horizontal loads is obtained by means of brace rods and stiffening diaphragms.

Frame columns that have mounting flanges at their end faces, are made of joist-welded webs of square or rectangular cross-section. Under high-level loads to enhance bearing capacity and stiffness of columns without expanding their cross-section and increasing steel consumption, the inner space of webs is filled with cast-in-situ concrete that efficiently works under volumetric stress. In this case bearing capacity of columns increases up to 75%. Their joint in height is made by means of special butting element (Figure 2) of smaller cross-section to provide direct support of girders on the flanges of the columns. Strength balance of the columns abutment at the ceiling level with columns proper is achieved by selecting cross-section of butting element and including embedding concrete into compression strain.

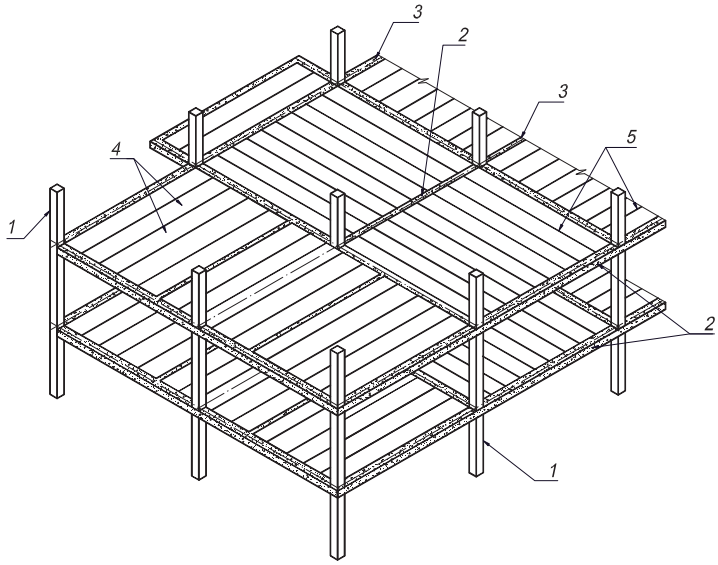


Figure 1. Diagram of steel and concrete frame based on light metal structures and hollow concrete ceiling slabs: 1- column; 2 – bearing steel and concrete girder; 3 – braced girder: 4 – hollow concrete ceiling slab; 5 – between-slab seam

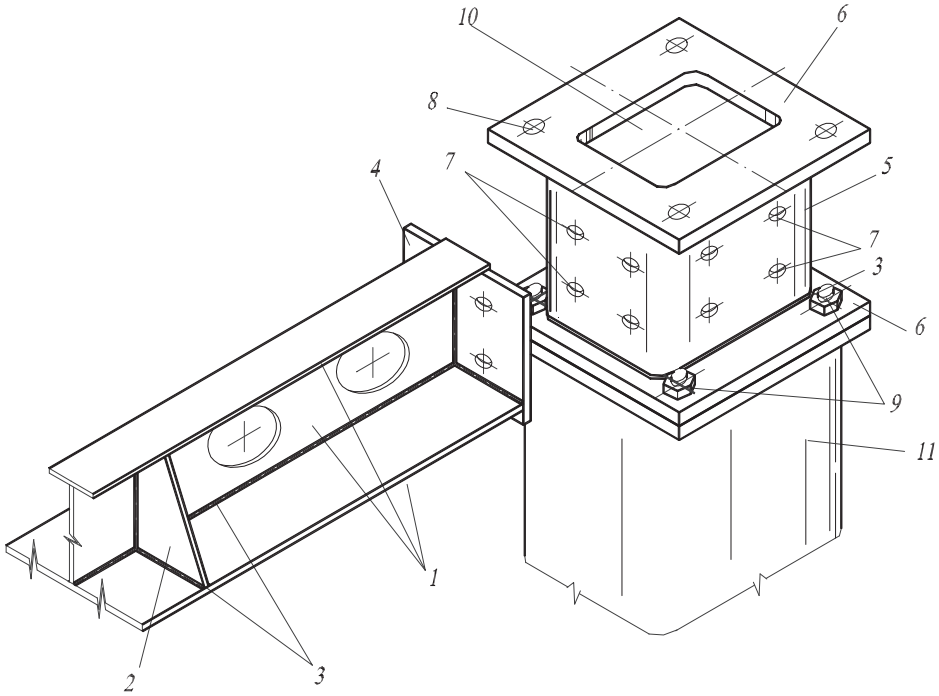


Figure 2. Connection joint between steel welded beam of the bearing girder and column: 1 – steel beam, 2 – stiffening rib, 3 – welded seams, 4 – end face flange of the beam, 5 – joint element, 6 – joint element flange, 7 – bolt openings for fixing steel beams, 8 – bolt openings for fixing columns, 9 - bolts, 10 – through opening for supply of cast-in-situ concrete in the body of column and joint element, 11- column.

Ceiling structure

The structure of prefabricated cast-in-situ ceilings includes a floor made of hollow-concrete slabs that are supported by the outline consisting of load-bearing and bracing girders made of composite steel and concrete. This structure is made to take maximum and most effective advantage of physical and mechanical properties of materials (such as strength, deformability, thermal conductivity etc.), resulting in optimal structural system in terms of the most of parameters.

The frame girders are made of composite steel and concrete by filling the composite steel section, consisting of sheet elements, with a heavy concrete (class C12/15 … C30/37 in terms of compression strength).

The cast-in-situ concrete in girders implements two functions: it makes up the composite steel and concrete section of girders that bear the load from ceilings and, at the same time, makes up the prefabricated cast-in-situ ceiling disk to provide the interface between the slabs and also between the girder and slabs.

Steel and concrete girders rested on columns end face flanges consist of composite steel section having double tee asymmetrical cross-section and cast-in-situ concrete. The web cross-section is arranged in a way to take the load of ceiling slabs rested on bottom flange with minimal metal intensity (Figure 3). The top flange of girders cross-section serves for taking part of force acting in compressed area of cross-section. The optimum cross-section of steel section of girder is selected in accordance with design loads.

Cast-in-situ concrete of girders placed inside space between slabs forms closed loop along ceiling cell perimeter, and in combination with embedded between-slabs seams provides work of ceiling disk under conditions of two-axis thrust and redistribution of forces. Resultants of thrust forces applied to the bottom section of slabs thickness (approximately at the level of extended reinforcement) enhance bearing capacity, cracking resistance and stiffness of the ceiling up to 70%.

Frame girders are subdivided into bearing and bracing ones. Bottom flanges of bearing girders take ceiling slabs load at the stage of erection, and after concreting and when concrete gains design strength forces between bearing and bracing girders are redistributed. The share of load taken by girders in different directions depends on the ratio of sides of the ceiling disk cell. Account of longitudinal and transverse thrust that arises in ceiling disk cells is one of major reserves for reduction of frame material consumption and opens possibilities for the use of slabs made of such relatively low-strength material, as gas concrete. Gas concrete slabs are produced by cutting technology that allows to have products of practically any length (up to 6 meters including) in accordance with columns grid, as well as beveled in plan end faces. It provides possibility to design buildings of practically any outlines with minimum amount of cast-in-situ concrete.

This design of girders, made of composite steel and concrete, is appropriate to reduce significantly the element section dimensions and, in particular, their height. As a result, coarser grid of columns becomes applicable in multistory buildings, with the constructional depth of ceilings between the stories not enlarged, i.e. with the story height remaining unified. For this purpose, the economically reasonable column pitch for hollow-concrete ceiling slabs is found to be within 4.5 … 9.0 m.

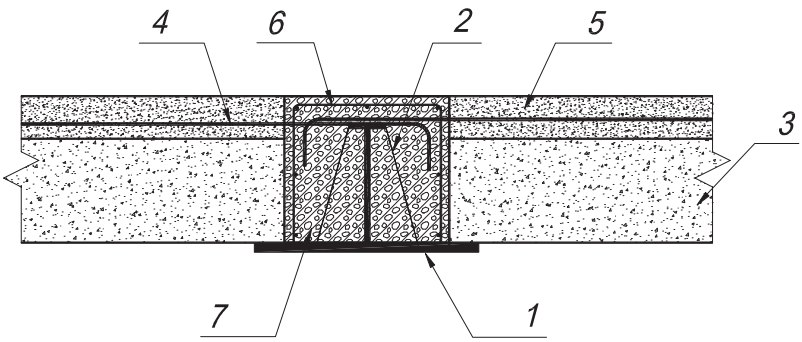


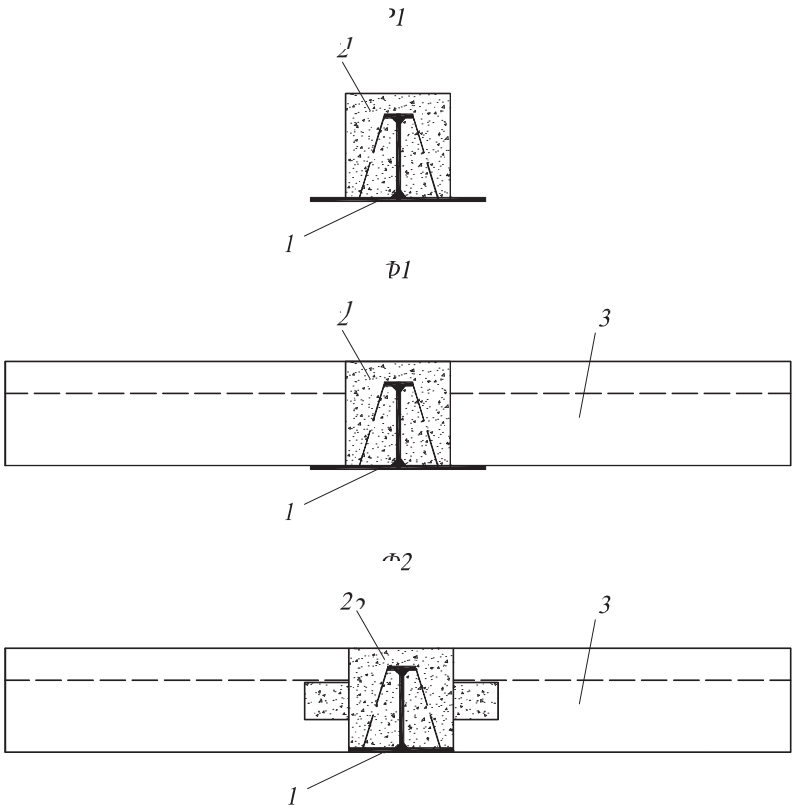
Figure 3. Connection joint of gas concrete ceiling slabs rest on bearing girder: 1 – composite steel section; 2 – stiffening ribs; 3 – gas concrete slabs; 4 – reinforcement bars in between-slab seams; 5 – concrete (mortar) for concreting between-slab seams; 6 – reinforcement mesh; 7 – concrete for embedding bearing girder

Composite steel and concrete ceiling member tests

The experimental researches were carried out in Institute BelNIIS RUE, covering the behavior of composite steel and concrete girders in combination with prefabricated hollow-concrete slabs. These researches were intended to improve the construction solutions for these ceilings and the procedures for their design and calculation: in these procedures, real behavior of structural elements and materials (heavy concrete, hollow concrete and steel) shall be taken into consideration more reasonably.

To study the distribution of material deformations, internal stresses and forces in the normal section of a composite steel and concrete girder, when it is used in combination with hollow-concrete slabs, stressed states of the series of composite steel and concrete girders were observed in experiments. The experimental series included the reference composite steel and concrete girder, G1 (see Figure 4a), and the parts of prefabricated cast-in-situ ceiling consisting of the composite steel and concrete girder and hollow-concrete slabs (up to 1 m length) abutting against it at both sides: in one part (P1), slabs were resting directly on the bottom flange of the girder (G2) (see Figure 4b), and in other part (P2), slabs were resting on the girder (G3) indirectly, with the intermediate cast-in-situ concrete keys (see Figure 4c).

Load tests were carried out for specimen structures at the power floor of the BelNIIS experimental facility; standard equipment, instruments and accessories were used. Static loads were applied to test the structures. Hydraulic piston jacks were used to generate forces applied to the structures for loading.



1 – welded profile, 2- cast-in-situ concrete, 3 – hollow-concrete slab

Figure 4. Test specimen sections: a) reference girder; b) P1 part; c) P2 part

Concentrated forces were applied uniformly along the girders' length to simulate the load distributed uniformly. For ceiling parts P1 and P2, load was transmitted to the girder through the hollow-concrete ceiling slabs abutting against the girder (loads were applied at 100 mm from the girder's side surface). See Figure 5 for the overview of the prefabricated cast-in-situ ceiling part under test.

RESULTS

The tests have demonstrated that the composite steel and concrete girders fail in their normal section, within the middle part of the span, simultaneously, the compressed part of the composite steel and concrete section also fails. For the girder specimen destruction overview, see Figure 6.

Visual inspection of specimens after the test has demonstrated that, in the course of loading, the bond between the heavy concrete of girders and hollow concrete of slabs was not damaged in their interface areas. This fact confirms the hypothesis that the girder and the ceiling slabs abutting against it jointly take up the shearing forces during the structure operation.

To assess the material deformation distributions resulting from the experiments (see Figure 7) and, also, to assess internal stresses and forces in the normal section of the composite steel and concrete girder, the calculation method based on the deformation model was applied, taking into consideration real deformation diagrams for concrete and steel. The similar function σ-ε for concrete was assumed in accordance with SNB 5.03.01-98 project guidelines; for steel, the Prandtl diagram for ideal elastoplastic material was accepted for this function.

Concrete deformations, corresponding to the concrete compression resistance (prism strength), were assumed to be ε_{cI}=220·10^{-5}; deformations, corresponding to the ultimate strength at the descending branch of the

Figure 5. The part of the prefabricated cast-in-situ ceiling under the test

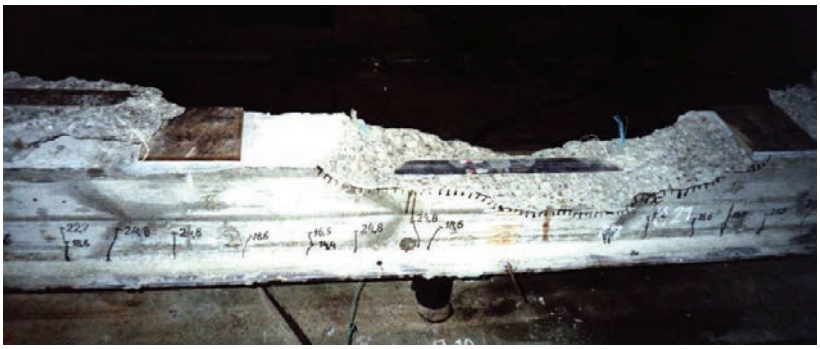


Figure 6. Girder specimens destruction in tests

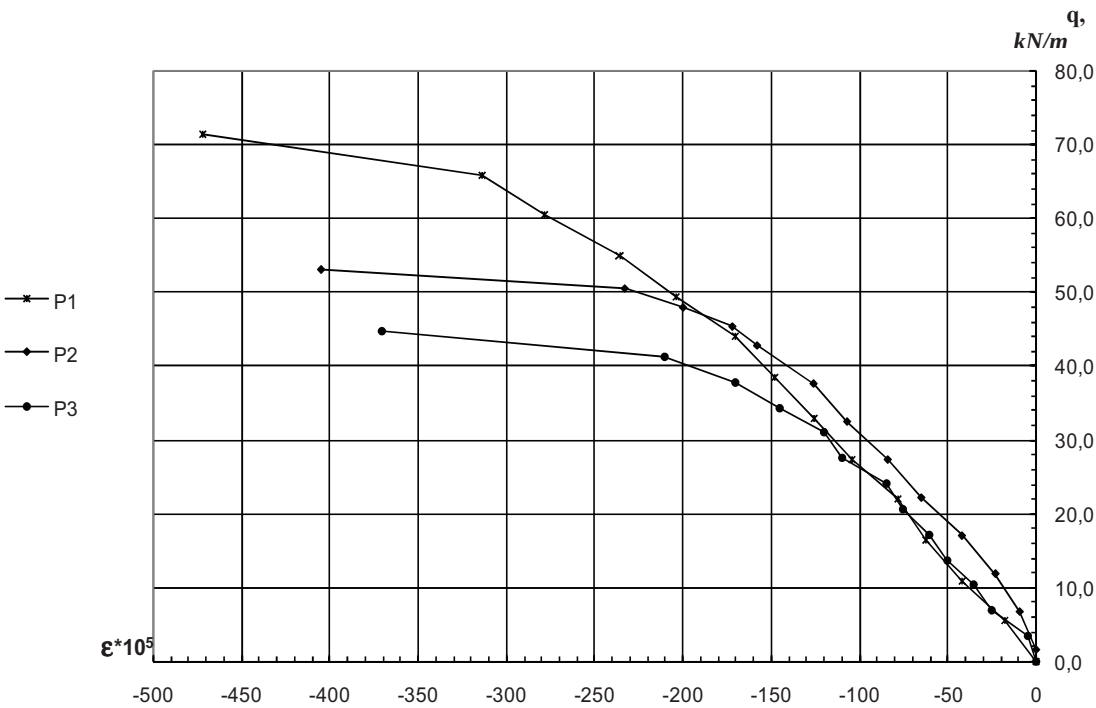


Figure 7. Deformation of the girder edge compressed most strongly (in the middle of a span)

diagram, were assumed to be ε_{cc}=340·10^{-5} for C$^{20}/_{25}$ concrete. For the diagram range describing tension, the characteristic points were chosen in accordance with SNB 5.03.01-98 as follows: $\varepsilon_{ctl}=1.5f_{ctm}/E_{cm}$, $\varepsilon_{ctu}=2.0f_{ctm}/E_{cm}$, where f_{ctm} is the mean tensile stress of the concrete, E_{cm} is the mean secant module of elasticity of the concrete found in accordance with the functions specified in SNB 5.03.01-98.

Steel deformations, corresponding to the proportionality limit, were calculated in accordance with the Hooke law: $\varepsilon_{sR}=R_s/E_s$. Engineering deformations, corresponding to the ultimate breaking strength, were assumed to be ε_{su}=500·10^{-5} because there is no standard value at the current stage.

The plane-section hypothesis (Bernoulli hypothesis) was used as the basis for the deformation model that was applied for calculation of a normal section in the composite steel and concrete girder.

The results of a normal section calculation, based on the deformation model, were as follows. The height of the compressed zone in the concrete section is greater than the height of the compressed zone in the nominally solid section (see Figure 8). The factor resulting in growth of the compressed zone height for the concrete is the strong reinforcement in the tensile zone; this results in shift of the section resistance center to its bottom boundary (when there are no external longitudinal forces, it coincides with the neutral axis).

It should be noted that this fact favorably influences the concrete behavior in the compressed zone, because the growth of its height results in reduction of edge deformations and stresses caused by these deformations; as a result, the calculated compressed reinforcement becomes unnecessary (for details, see below). Edge deformations of concrete in the compressed zone along the top edge under the design load exceed ε_{cl}

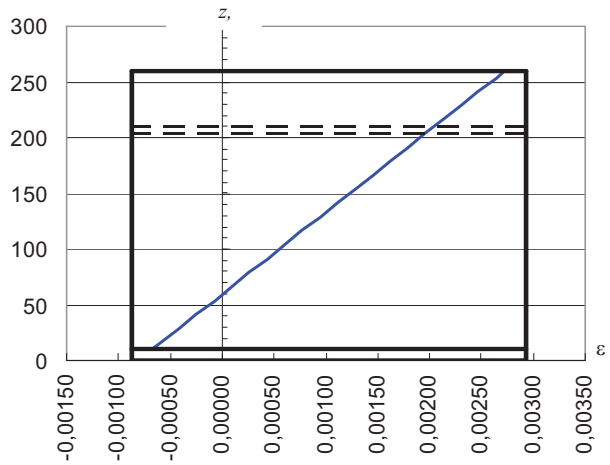


Figure 8. Deformation distribution by section height in the girder concrete under the design load

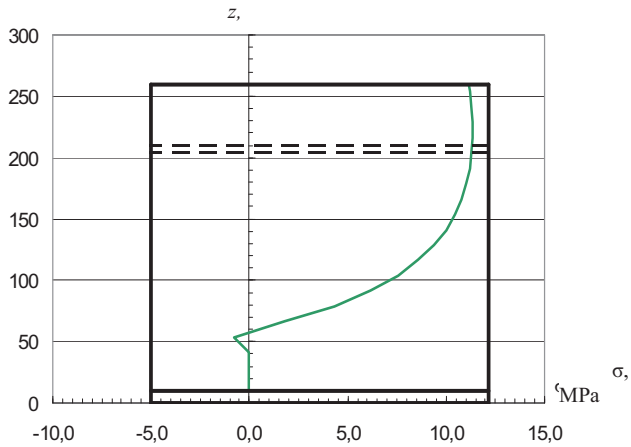


Figure 9. Stress distribution in the girder concrete (compressed zone) under the design load

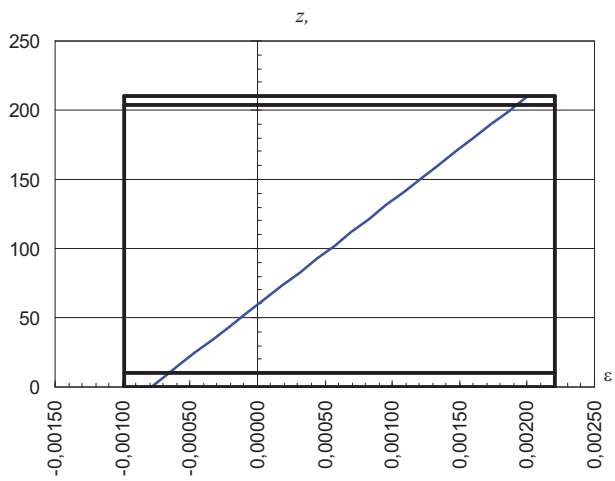


Figure 10. Deformation distribution in the normal section of the girder's steel part under the design load

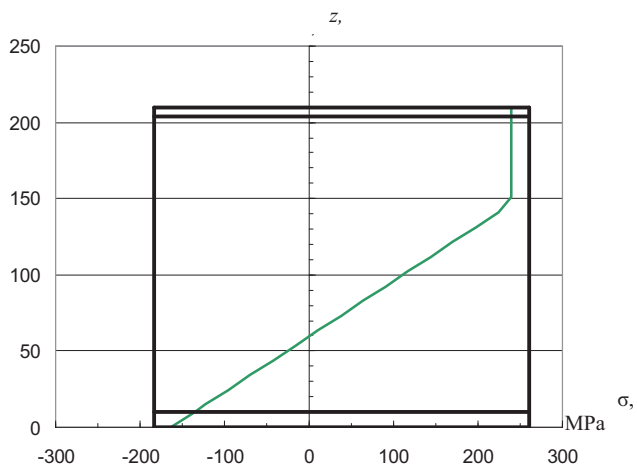


Figure 11. Stress distribution in the girder's steel part under the design load

deformation values corresponding to the ultimate strength. The stress distribution diagram for the compressed zone is obviously non-linear (see Figure 9). The stress distribution diagram filling factor is ω=0.69.

In practical terms, stress distribution in the steel part of the girder is even more interesting (for the corresponding deformations, see Figure 10).

Edge deformations of the compressed flange are higher than the deformations of the tension flange and, also, they exceed ε_{sR} deformation values corresponding to the proportionality limit for steel C245. The tension flange behavior corresponds to the elastic stage.

For the specified deformations, stresses in a part (29%) of the compressed zone in steel have reached the yield point; the remaining part of the compressed zone and the tensile zone of the girder's steel part section demonstrate the behavior corresponding to the elastic stage (see Figure 11). Edge stresses in the tension flange are about 68% of the design strength (yield point).

DISCUSSION

It should be noted that, in accordance with the modern theory of steel structure design, operation of sections beyond the yield point shall be considered acceptable, and sometimes even reasonable, subject to the conditions making the yield hinge impossible. For the case described here, there is one more factor making the plastic deformations in the compressed zone of the girder's steel part nonhazardous: yielding of steel exists within the yoke provided by the surrounding concrete in the compressed zone, and this concrete, in turn, expands during the compression stage. It's obvious that real edge deformations of the compressed flange can be slightly less than those resulting from the calculation based on the idealized model ignoring the complex processes in the interface between two quite different media that demonstrate the volumetric stress-strain behavior.

The convergence of theoretical calculation results to the experimental data can be various but, in terms of the safety factor, it is at least 1.23.

CONCLUSION

The results of this research can be used to improve the design and calculation procedure for composite steel and concrete girders operated in combination with the hollow-concrete ceiling slabs, subject to the conditions that provide strength of the support areas of slabs. The researches carried out with regard to this design solution for composite steel and concrete girders demonstrate that it results in high load-bearing capacity and can be successfully applied for many various civil buildings.

The new structural system on top of already mentioned fields of applications, can be used for construction of prefabricated dwelling and public buildings on sites remote from the production basis of the construction, for example in oil- and gas extraction regions, geographic regions with short warm season, severe construction conditions.

REFERENCES

Бетонные и железобетонные конструкции: СНБ 5.03.01-02. - Введ. 01.07.2003. - Минск: Минстройархитектуры Республики Беларусь, 2003. - 144с. [Concrete and Reinforced Concrete Structures: Construction Norms of Belarus, SNB 5.03.01-02. - Introduction 01.07.2003. - Minsk: Ministry of Architecture and Construction of the Republic of Belarus. 2003. – 144 p.]

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Clay Based Poultices for Desalination of Building Materials

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EXTENDED ABSTRACT

One of the major threats affecting the lifetime of cultural monuments and residential buildings are the water-soluble salts raising the necessity for desalination activities. Different methods are available for this purpose depending on particular environmental conditions, physical and chemical properties of the contaminated object as well as its historical background [1]. The most common desalination technique is a use of desalination poultices made of a mixture of clay minerals (zeolite, kaolinite or bentonite), sand and cellulose. Mechanism of this method presumes that salts migrate from the salinated substrate into the poultice by diffusion or advection [2]. Even though this method is attractive due to its simplicity, effective desalination and use of locally available raw materials, more explicit examination of desalination mechanisms is necessary.

The current study has been elaborated in two stages: selection and examination of clay-based desalination compositions and control of desalination process.

Three clay-based compositions have been studied by varying binder (clay) to filler (sand and cellulose) ratio as follows: clay to sand mass ratio 1:2, 1:5 and clay/sand/cellulose mass ratio of 1:4,5:0,5. The quaternary clay from Broceni (Latvia) was used for experiments.

The experimental examination of desalination compositions included determination of density, drying shrinkage, pore size distribution using mercury porosimetry before and after exposure to the solutions of water soluble salts.

In order to control desalination process quantitative and qualitative analysis of ions of soluble salts (distribution profiles of nitrate, chloride and sulphate ions as well as crystalline phases of the samples by using chemical and XRD analysis) in both material – poultice, as well as salinated building material have been performed.

The results obtained in the following study have shown that the main parameter determining salt transport mechanisms and desalination efficiency is pore size distribution of the substrate and poultice as well as nature and ratio of the binder and filler.

It has been concluded that the compositions with higher binder to filler ratio exhibit broader pore size distribution and higher desalination efficiency.

Based on obtained results clay based application with clay/sand/cellulose ratio of 1:4,5:0,5 and clay/sand ratio of 1:5 can be recommended as effective desalination compositions.

Obtained experimental data can be used for further research for desalination of different construction materials as well as planning of practical restoration activities in environments with high concentration of water-soluble salts.

Keywords: clay-based poultices, building materials, desalination.

ACKNOWLEDGEMENT

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REFERENCES

Carretero, M. I., Barnabé, J.M., Galán, E. (2006). Application of sepiolite-cellulose pastes for the removal of salts from building stones. Applied Clay Science, 33, 43-51.

Lubelli, B., van Hees, R.P.J. (2010). Desalination of mansonry structres: Fine tuning of pore size distribution of poultices to substrate properties. Journal of Cultural Heritage, 11, 10-18.

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Crack Opening Width Calculation Method for Non-Pressure Reinforced-Concrete Pipes

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Abstract. The method is proposed for calculation of crack opening width in non-pressure reinforced-concrete pipes. The method is based on 3D finite element model. The calculation model of a pipe is developed as an array consisting of volume and bar finite element, simulating the concrete and the reinforcement respectively. Iteration method is used for calculations, and the concrete and steel deformation diagrams are applied. Cracking is taken into consideration by exclusion of concrete element chains in which the deformation reaches the concrete ultimate tensibility.

Keywords: reinforced-concrete pipes, crack opening width, finite element model, experimental research.

INTRODUCTION

The scope of research includes non-pressure reinforced-concrete pipes, 1000 mm and 2000 mm diameter, for sewages.

The purpose of this work is to determine the factors influencing the crack formation and opening process in non-pressure reinforced-concrete pipes, and to develop the proposals for calculation of crack opening width in these structures.

The comparative analysis is carried out, covering the numeric values of (normal) crack opening width resulting from the standard procedures (described in Construction Norms and Rules (SNiP) and Construction Norms of the Republic of Belarus (SNB)), from experiments and from the finite element model.

METHODS

Pipe design calculation and test results

Many publications exist covering the research of the processes of normal crack formation and opening in non-pressure reinforced-concrete pipes. According to (Бондаренко В. М., 2004), the methods practically applicable for calculation of crack opening width can be subdivided into four groups.

The first group includes methods based on provisions of V.I. Murashov's theory (Мурашов В.И., 1950). In accordance with this theory, the crack opening width, a_{crc}, shall be calculated as follows:

$$A_{crc} = (\mathcal{M}_{sm} - \mathcal{M}_{bt,m})\, l_{crc} \tag{1}$$

where l_{crc} is the distance between cracks, $\mathcal{M}_{bt,m}$ and $\mathcal{M}_{sm}$ are relative elongations of tensile zone of concrete and reinforcement (respectively) between cracks.

Distances between cracks, l_{crc}, shall be calculated assuming that at the time of crack formation the difference between reinforcement tensile forces in the section containing a crack and in the section between cracks is balanced by forces of bond existing between the reinforcement and the concrete. Meanwhile, crack opening width depends significantly on the stress of bond between the reinforcement and the concrete and on the bond stress distribution diagram filling factor.

The methods comprising the second group are based on empirical and semi-empirical relationships found experimentally. This group includes the procedure stipulated in SNiP 2.03.01-84 (ЦИТП Госстроя СССР, 1985), according to which, the normal crack opening width shall be calculated as follows:

$$a_{crc} = \Omega \cdot \mathcal{T}_l \cdot \mathcal{M} \cdot \frac{\sigma_s}{E_s} \cdot 20 \cdot (3{,}5 - 100 \cdot \mathcal{O}) \cdot \sqrt[3]{d} \tag{2}$$

where Ω, $\mathcal{T}_l$ and $\mathcal{M}$ are the factors depending on the force application type, load application duration and the effective reinforcement shape;

σ_s are E_s are, respectively, the reinforcement stress and modulus of elasticity;

Ω and d are, respectively, the section reinforcement ratio and the effective reinforcement diameter.

As a rule, normal crack opening widths in flexural reinforced-concrete members calculated by (2) match with the experiment results well (for flat members).

The third group of methods includes the procedure stipulated in SNiP 2.05.03-85 (ЦИТП Госстроя СССР, 1985), based on O.Ya. Berg's assumption. In accordance with this procedure, the so-called reinforcement radius R_r, used to consider the interaction between reinforcement and concrete, shall be included in the equation for normal crack opening width calculation:

$$a_{crc} = \frac{\sigma_s}{E_s} \cdot \Omega \cdot \sqrt{R_r} \tag{3}$$

This procedure is applied for the bridge structure design purposes. Its results match well with the experimental data for pre-stressed flexural members. However, the key parameters of this procedure are not related to the interaction between the reinforcement (tangential stress parameters) and the concrete.

The methods comprising the fourth group are based on Thomas's hypothesis defining the crack opening width as a total of mutual displacements of reinforcement and concrete within the zone between the cracks. To implement these methods, the information is required about the relation between relative displacements and tangential stresses in a zone between the cracks. M.M. Kholmyansky (Холмянский М.М., 1997) has proposed the method for determination of this function for centrally-tensile reinforced-concrete members.

In the procedure used in SNB 5.03.01-02 (based on V.I. Murashov's theory backgrounds), the design normal crack opening width w_k is calculated as follows:

$$w_k = \delta \cdot s_{rm} \cdot \varepsilon_{sm} \tag{4}$$

where δ is the factor depending on the section dimensions;

ε_{sm} and s_{rm} are mean relative deformation of the reinforcement and mean distance between cracks respectively (the semi-empirical relationships (СНБ 5.03.01-02, Минстройархитектуры, 2003) are used to determine these values).

The analysis of these methods and procedures demonstrates that they have quite different backgrounds and this difference affects calculation results. As for the calculation of crack opening width in non-pressure reinforced-concrete pipes, SNiP 2.03.01 procedure was applied for this purpose before SNB 5.03.01 came into force.

See Table 1 for the results of calculation of crack opening width in unsafe sections of non-pressure reinforced-concrete pipes (ГОСТ 6482-88, Издательство стандартов, 1989). Several various calculation procedures were used to obtain these results. The pipes, in accordance with the design, were made of heavy concrete, C25 class, and reinforced by the cylindrical cage, with its spiral (effective) reinforcement made of wire, Vr-1 class, 5 mm diameter, or rods, AIII class, 6 mm and 8 mm diameter. The reinforcement cage is mounted in a way to provide the required design section height (d) in the pipe apex and bottom, with the pipe wall thickness h.

Table 1. Calculation of crack opening width according to various calculation procedures

Pipe grade	M_{sd}, kN·m/m	M_{crc} kN·m/m	h/d, mm	Reinforcement diameter and pitch, mm	Crack opening width, mm		
					SNiP 2.03.01-84	SNiP 2.05.03-85	SNB 5.03.01
TB50.50-3	2.655	1.677	60/35	5/60	0.118	0.138	0.134
TB60.50-3	3.192	1.918	60/35	5/50	0.121	0.141	0.136
TB80.50-3	6.236	2.981	80/45	6/45	0.089	0.139	0.128
TB100.50-3	9.249	4.657	100/59	8/70	0.096	0.166	0.150

The standard bending moment, M_{sd}, arises in the pipe apex, resulting from the effective vertical load, P (crack resistance test load). The pipe wall section crack resistance, M_{crc}, was calculated for R_{btn} = 1.6 MPa.

The values calculated in accordance with SNB 5.03.01 and SNiP 2.05.03 procedures differ only slightly (see Table 1), but they are significantly (up to 60%) higher than those resulting from SNiP 2.03.01 procedure. However, as a rule, the real crack opening width (in tests) under the standard load (the crack resistance test load) was within 0.05… 0.1 mm for 500…1000 mm diameter pipes. It means that the calculation results differ significantly from the experimental data.

In our opinion, these differences (especially for small-diameter pipes) result from the initial curvature of the structures, affecting the reinforcement/concrete interaction (bond). The more is the structure curvature, the

higher is the reinforcement/concrete bond force; however, this fact is not taken into consideration in the existing calculation procedures.

Now, radial pressing and vibration pressing processes are applied in the Republic of Belarus for non-pressure reinforced-concrete pipes manufacturing. The design solutions for these pipes are developed by the Institute BelNIIS RUE. The load tests, carried out for sample pipes, demonstrate that the crack resistance test loads does not result in any cracks in unsafe sections, or, if these cracks arise, their opening width is much less than the permissible limits. For standard pipes (second and third group, in terms of their load bearing capacity), the strength calculation is critical; however, for the fourth and fifth group, the load bearing capacity calculation is critical, and for pipes intended for operation in corrosive environment, the crack resistance calculation is also of great importance.

Thus, in our opinion, new procedures must be developed for calculation of crack opening width or the existing procedures must be corrected with regard to non-pressure reinforced-concrete pipes and other flexural members having initial curvatures.

RESULTS

Applying the finite-element model for calculation of crack opening width in reinforced-concrete pipes

In our opinion, this problem can be solved more precisely by numerical simulation methods. Taking into consideration that a pipe (both in operation or during a load test) is subject to plane deformation, this simulation problem can be easily resolved, e.g. by finite element calculation model. The similar approach was applied for reinforced-concrete half-ties design (Шепелевич Н.И., 2006).

See Figure 1 for a part of the finite-element calculation model of the non-pressure reinforced-concrete pipe, 1000 mm diameter, fifth group (in terms of load-bearing capacity), 130 mm wall thickness. The pipe is reinforced by two cylindrical cages made of effective (spiral) reinforcement, 8 mm diameter, class S500, 80 mm winding pitch. The concrete design class is C25/30.

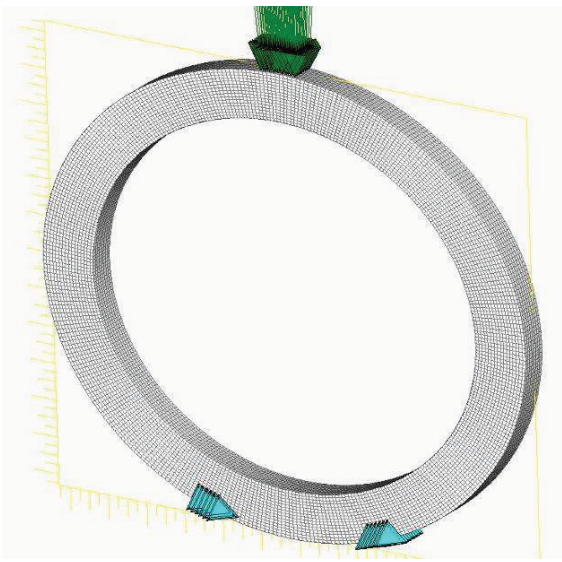

Figure 1. Finite-element pipe model, Ø1000 mm and Ø2000 mm (MSC/Nastran)

Pipe and reinforcement cage dimensions are used as basic data for the development of the finite element model. For concrete simulation, 10x10x10 mm volume elements rigidly coupled with each other are used; for reinforcement simulation, bar elements, 10 mm length, rigidly coupled with each other and with volume elements (in nodes) are used, see Figure 2. The elements deformation characteristics are specified by the concrete and reinforcement deformation diagrams.

The external load was given as vertically concentrated forces applied in the model nodes within the spiral pitch. Fastening conditions were simulated by hinged movable supports and hinged supports located in accordance with the pipe load test layout.

The load was applied step by step, in accordance with step values used for the pipe test. At each loading step, concrete elements were removed if their tensile deformation exceeded the limit value, ≈0.15‰ (this value was determined in experiments), and recalculation was carried out in such a case.

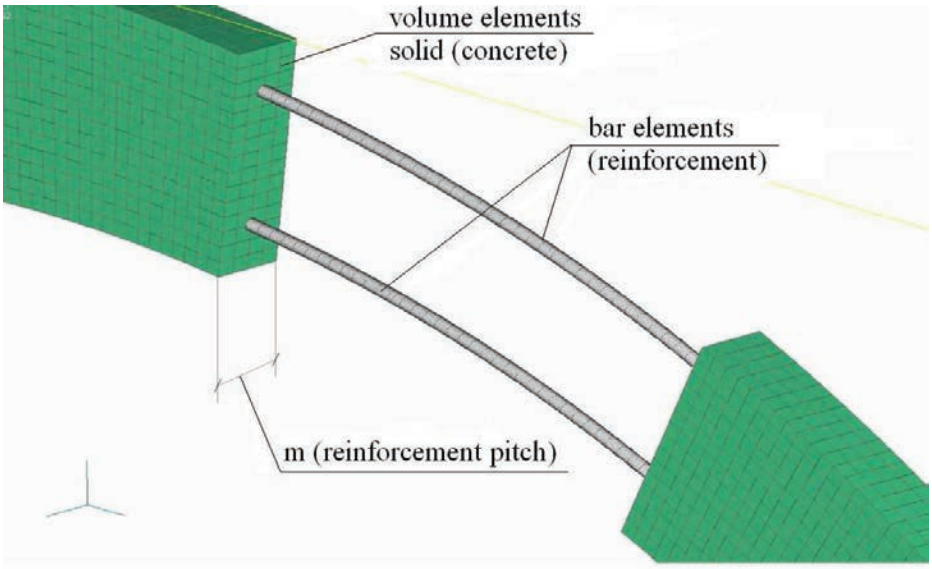

Figure 2. Pipe simulation: volume and bar elements location

For the illustration of stresses arising in unsafe (longitudinal) sections of the pipe apex at various loading steps, see Figure 3.

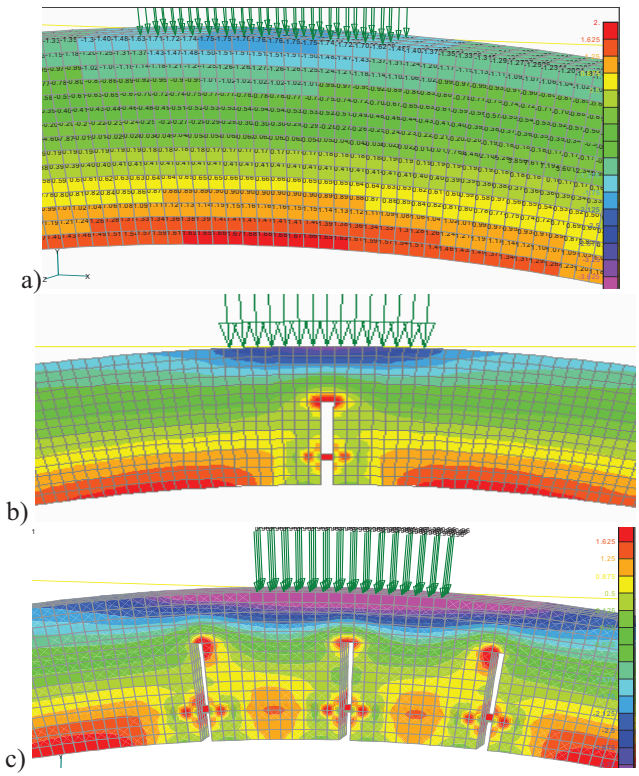

Figure 3. Stresses in the unsafe section (apex) of a pipe, Ø2000, for various loads:
a) before crack formation; b) single crack; c) three cracks

For the purposes of comparative analysis, the strength test and crack resistance test results are given for the samples of reinforced-concrete pipes, 1000 mm and 2000 mm diameter. The pipes were reinforced by two spiral-type longitudinal cages. Class S500 reinforcement was used as the effective (spiral) reinforcement. The pipes were tested by loading in accordance with the three-line pattern (see Figure 4 for photo). The load was applied step-by-step. At each loading stage, measurements were carried out, including vertical and horizontal pipe diameter and crack opening width at the pipe apex (the most loaded section); see Figure 5 for photo.

Figure 4. TB 100.25-5 pipe test

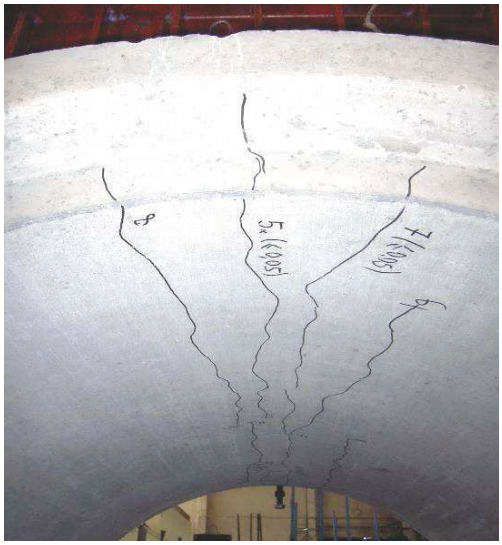

Figure 5. Crack formation in the pipe apex

The tests have demonstrated that, for all sample pipes, the first cracks arose in the pipe apex under loads exceeding the crack resistance test load, due to high tensile strength of the vibration-pressed concrete.

See Table 2 for the results of calculations (by various procedures) and experimental values of crack opening width in the unsafe section (apex) of non-pressure reinforced-concrete pipes, Ø1000 mm and Ø2000 mm, at various loading stages. For pipe specifications, see Table 3.

Table 2. Comparison of experimental values of crack opening width under various procedures

Load, kN/m	Crack opening width determined by various procedures				
	SNiP 2.03.01-84*	SNB 5.03.01-02	SNiP 2.05.03-84	Experiment	Calculation model
TB 100.25-5 pipe					
100	0.19	0.20	0.23	0.1	0.12
120	0.23	0.25	0.26	0.2	0.21
140	0.32	0.36	0.37	0.28	0.30
TB 200.25-3 pipe					
110	0.12	0.13	0.13	0.08	0.09
130	0.27	0.29	0.29	0.2	0.23
150	0.49	0.55	0.56	0.42	0.44

Table 3. Pipe specifications

Pipe grade	h, mm	d, mm	Reinforcement diameter and pitch, mm	Concrete strength, MPa	Crack resistance test load (P), kN/m	Calculated value a_{crc}	P, kN/m, for $a_{crc} = 0.2$ *mm*
TB100.25-5	130	95	8 x 80	37.8	87.8	0.19	120.0
TB200.25-3	150	120	8 x 45	38.3	104.5	0.22	130.0

CONCLUSIONS

Thus, the procedure proposed for calculation of crack opening width in non-pressure reinforced-concrete pipes, based on 3D finite element model, gives the best results in terms of matching the experimental data and, therefore, may be recommended for application in pipe design.

REFERENCES

Бетонные и железобетонные конструкции: СНБ 5.03.01-02. – Минск: Минстройархитектуры. 2003. [Concrete and Reinforced Concrete Structures: SNB 5.03.01-02. - Minsk: Ministry of Architecture and Construction of the Republic of Belarus. 2003].

Бетонные и железобетонные конструкции: СНиП 2.03.01-84. – М.: ЦИТП Госстроя СССР, 1985. [Concrete and Reinforced Concrete Structures: SNiP 2.03.01-84. – Moscow: Central Institute of Standard Projects, State Committee for Construction of the USSR, 1985].

Бондаренко В. М. Расчетные модели силового сопротивления железобетона/ М.М.Бондаренко, В.И.Колчунов. — М.: Издательство АСВ, 2004. — С. 40-64. [Bondarenko V.M. Reinforced Concrete Force Resistance: Calculation Models / M.M. Bondarenko, V.I. Kolchunov. – Moscow: ASV Publ., 2004. – p.40-64].

Мосты и трубы: СНиП 2.05.03-85. – М.: ЦИТП Госстроя СССР, 1985. [Bridges and Pipes: SNiP 2.05.03-85. – Moscow: Central Institute of Standard Projects, State Committee for Construction of the USSR, 1985.]

5Мурашов В.И. Трещиностойкость, жесткость и прочность железобетона.- М.: Машстройиздат, 1950. – 268 с. [Murashov V.I. Crack Resistance, Stiffness and Reinforced Concrete Strength. – Moscow: Mashstroyizdat Publ., 1950. – 268 p.].

ГОСТ 6482- 88 Трубы железобетонные безнапорные. Технические условия. – М.: Издательство стандартов, 1989. [GOST 6482- 88. Non-pressure Reinforced Concrete Pipes. Specifications. – Moscow: Standards Publ., 1989].

Холмянский М.М. Бетон и железобетон: Деформативность и прочность / Холмянский М.М. – М.: Стройиздат, 1997. – С. 391-397. [Kholmyansky M.M. Concrete and Reinforced Concrete: Deformability and Strength / Kholmyansky M.M. – Moscow: Stroyizdat Publ., 1997. – p. 391-397].

Шепелевич Н.И. Расчет коротких изгибаемых элементов на прочность и трещиностойкость с использованием конечно-элементной модели/ Н.И.Шепелевич, А.Н.Бугаев// Архитектура и строительство. – 2006. – № 4. – С. 102-104. [Shepelevich N.I. Strength and Crack Resistance Calculation for Short Flexural Members: Finite Element Model Application / N.I. Shepelevich, A.N. Bugaev // Architecture and Construction (Journal). – 2006. – No.4. – p.1020104].

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Post-Tensioned Cast-in-Situ Flat Slabs. Specific Details of Calculation and Design

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Abstract. This article deals with the most important specific details applicable to the design of cast-in-situ post-tensioned ceilings. The key parameters assignment stage is analyzed (including the key design parameters of ceiling, pre-stress values, concrete class, stressed members placement etc). The specifications of various types of cast-in-situ post-tensioned ceilings are specified.

Keywords: Post-tension, flat slab, unbonded tendon, deflection, concrete class.

INTRODUCTION

The current trend in the world practice of high-rise building construction includes wide application of pre-stressed cast-in-situ ceiling slabs. For these purposes the two-way slabs are predominantly used; these slabs are pre-stressed with unbonded tendons (strands, wires). It should be noted that structural solutions based on this type of ceilings, roof slabs, foundation slabs etc. are especially popular in the USA.

By now (PCA, 2005), more than 70 million m^2 of post-tensioned slabs are already erected in the USA only. As a result of pre-stress systems design and improvement, the structural systems of this type are widely applied in France, Germany, the Netherlands, Switzerland and Australia. Practically in all cases for which the relevant information is available, the pre-stress was applied by unbonded tendons.

Assigning the key design parameters for flat post-stressed slabs

Post-tensioned cast-in-situ slabs with tendons not bonded with concrete have several advantages that shall be taken into consideration in high-rise building design.

The key advantages are as follows:

-improved economic parameters, including the reduced consumption of materials as compared with the standard reinforced-concrete structures;

- long spans can be built, with the ceiling stiffness meeting all requirements. Also, it should be noted that, due to larger span dimensions, the ceiling layout design becomes more flexible;

- the buildings can be designed to be more expressive in architectural terms. Free placement of tendons along a force flow trajectories (lines of supports) makes it possible to use structural systems involving irregular location of supports (such as walls and columns). Also, the structural system may include openings and console-type parts of slabs;

- ceiling's dead load is reduced, resulting in favorable effects for the columns loaded most severely (the columns of lower stories and foundations);

- redundancy in terms of strength is provided if additional inner horizontal braces are used, improving the structural system's reliability and protection against progressive failure;

- high local shear strength (for punching shear), if tendons are placed appropriately;

- reduction of term of construction.

Several available publications were used to collect the key technical and economic specifications (see Table 1) for ceilings based on various design solutions, with the rated design load 5 kPa (not including the own weight of the slab).

Table 1. Various structural solutions for ceilings: key technical and economic specifications [1)]

Slab type	Slab span (mm)	Slab thickness (mm)	Girder height (mm)	Span / thickness	Reinforcement consumption	
					stressed, per 1 m, (pcs) [2)]	non-stressed [3)] (kg/m²)
Solid flat slabs	6.0	200	-	30	1.4 [4)]	8.5
	8.0	250	-	32	2.3	12.0
Solid slabs exerting force in one direction and provided with girt strips	6.0	150	300	40/20 [5)]	3.2	6.5
	8.0	200	375	40/21	3.0	7.5
	12.0	300	550	40/22	3.0	9.4
Girder ceilings	8.0	-	300	27/1	2.5	10.0
	12.0	-	450	25/1	2.5	10.
	15.0	-	575	25/1	3.8	17.5

Notes:

1) data in the table are given for the useful load 5 kPa (not including the own weight of the slab);
2) stressed reinforcement consumption is specified for strands, ∅15.7 mm, 265 kN limit force;
3) consumption of non-stressed reinforcement, class S500;
4) in each direction;
5) for slabs / for girders.

For flat ceiling design, the column grid geometry selection is critically important. See Figure 1 for optimal dimensions of spans intended for flat ceilings with the square column grid and the rated design load 5 kPa.

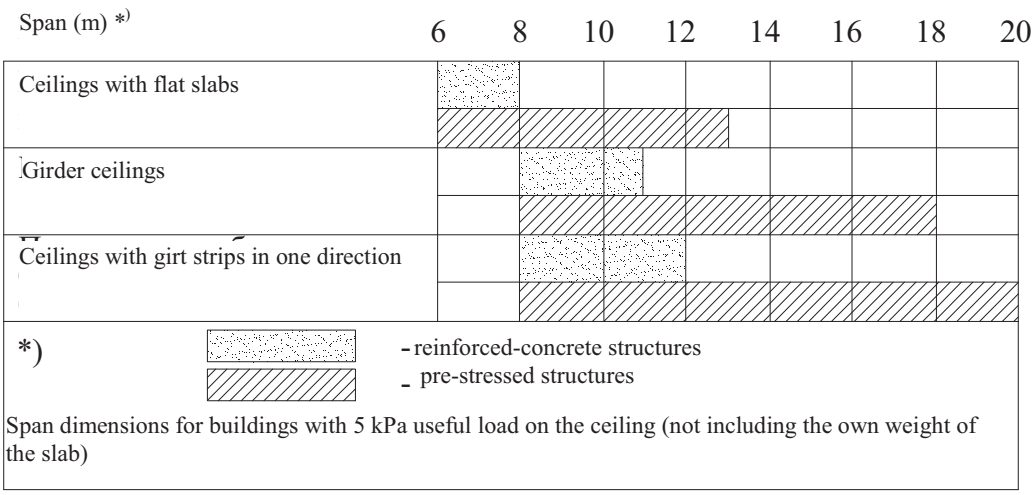

Figure 1. Optimal dimensions of spans for various structural solutions intended for ceilings (stiffness requirements are met) (Stevenson, 1994)

Here, the approaches for flat ceiling structure are briefly described, with the deflection limitation criteria emphasized.

Before the beginning of the static calculation, the designer must specify the required slab thickness.

For reinforced-concrete slabs, the criteria for the selection of the ratio value, (*l/h*), are well defined and even included in standards in several countries.

For post-tensioned slabs, the problem of criteria assignment for the preliminary design becomes more complex. In these structures, the slab deformability depends not only on flexibility (*l/h*), but also on several other important parameters, such as the value (or rate) of pre-stress and the variable load level. Great variability and wide range of these important parameters makes difficult to formulate simplified rules for the deflection limitation in post-tensioned slabs, and some preliminary calculations are necessary for this purpose.

Table 2 shows some recommended values of flexibility (*l/h*) for post-tensioned slabs in accordance with the requirements of the U.S. and European design standards (ACI 318 M, 2002; CSA A 23.3, 2001; Almeida, 2001, Stevenson, 1994; ACI-ASCE, 1974).

It should be noted that it is emphasized in standards (ACI 318 M, 2002; CSA A 23.3, 2001; Almeida, 2001, Stevenson, 1994; ACI-ASCE, 1974) that the valued specified in these standards are for reference only, and they must be verified by calculations for the specified pre-stress level and for the forces resulting from loads.

Table 2. Recommended ratios (*l/h*) for post-tensioned slabs

Document	*l/h*	
	Ceiling	Roof
ACI – ASCE	40 … 45 or 48*	45 … 48 or 52*
FIp Recommendations	42 or 48*	48 or 52*
Concrete Society Techn.Rep№25	34 … 42 or (28 … 36)**	40 … 48
ACI 318 – 89	42 … 48*	48 … 52*
Notes: *) including the requirements for flexibility; **) for heavily loaded ceilings.		

Flat slabs with unbonded tendons are applied predominantly in the structural systems for which strict requirements are prescribed in terms of deflection limitations.

The permissible slab deflections are specified in accordance with the set of requirements, including technological, aesthetical and psychological, physiological, structural ones. As for the latter, the excessive deflections must not result in damage for structural and non-structural members, seam opening, excessive cracking etc. For the purposes of assessment in terms of structural limitations, only the part of the deflection that appears after the construction of the potentially damageable members shall be taken into consideration. In accordance with these reasons, the limitations for slab deflections stipulated by the U.S. and European standards are as follows:

- maximum deflection under the quasi permanent load must not exceed *l*/250;
- maximum deflection that arises after the construction of partitions, for frequent load, must not exceed min{*l*/500; 15 mm}.

The reference thicknesses of two-way pre-stressed slabs are given in the articles of German researches (Morgen *et al.*, 2004) as l/h ratios for various ratios of variable load intensities *q* to permanent loads *g* and for various spans (see Table 3). It should be noted that this table is cited from the practical recommendations for DIN 1045, and it does not include any descriptions of the pre-stressing process (i.e. it is not clear whether the stressed tendons are bonded or not).

Table 3. Recommended limits for l/h ratio in two-way pre-stressed slabs in accordance with (Morgen, 2004)

Full / dead load ratio $(q+g)/g$	Span (m)			
	7.5	10.0	15.0	20.0
1.0	45	42	33	27
2.0	41	34	26	20
3.0	35	29	22	16

In the most of standards, there are no limitations for the thickness of pre-stressed ceiling slabs with the stressed reinforcement pulled on the concrete. Maybe, there is only one exception, German code DIN 4227, that includes the general requirement $l/h \leq 40$ for the pre-stressed slabs with unbonded tendons. This recommendation, however, is only for ceilings with uniform distribution of stressed strands in the span. As for the ceilings with strands concentrated in strips between the columns, this case is not considered.

There are some more requirements and recommendations with regard to the thickness of pre-stressed ceiling slabs in DIN 1045-1. The minimum thickness of the pre-stressed slab is recommended to be at least 200 mm. Also, general recommendations are given with regard to the slab flexibility. With the deflection limitation specified as ($a_f \leq l_{ef}/250$), the slab's minimum effective section height is described as $d=l_{eff}/35$, resulting, for standard cases, in $l_{eff}/h=35 \div 40$.

These DINs are used by authors of the above mentioned (Morgen *et al.*, 2004) to specify the thicknesses of flat ceiling slabs made with or without pre-stress. Summary of these recommendations are given in Table 4.

Deflection limitations are considered for the end spans. If the end spans are smaller than the intermediate spans, the criteria shall be tested for intermediate spans also.

For the preliminary selection of thickness of flat ceiling slabs, *fib* recommendations (see Table 5) can also be useful.

It is common that the structural solutions for the high-rise buildings are designed in accordance with the concept assuming that the main usable (i.e. being in operation) areas of ceilings are concentrated around the stiff central core (Aalami, Jurgens, 2003). In these buildings, as a rule, the slab span is at least 9 m (the most common length is 12 m). For pre-stressed slabs with unbonded tendons, commonly applied slab thickness is 200 … 240 mm, depending on the span size (VSL, 1985).

Table 4. Recommended slab thicknesses for flat ceilings with unbonded tendons (Morgen *et al.*, 2004)

Permissible deflection	Span, l (m)	Slab thickness, h (mm)
Standard limit $a/l_{eff} \leq 1/250$	6	200*
	8	220
	10	270
	12	310
Strengthened limit $a/l_{eff} \leq 1/500$	6	200*
	8	240
	10	350
	12	480
Note: * minimum thickness in accordance with DIN 1045-1		

Table 5. Comparative recommendations for solid slabs span/thickness ratio (flat reinforced-concrete slabs and pre-stressed slabs in ceilings) (FIP Recommendations, 1980)

Slab sides ratio	Live load (kPa)	Slab thickness (mm)	Maximum (reasonable) reinforced-concrete slab span (m)	Maximum (reasonable) pre-stressed slab span (m)
1:1	2.25	200	6.5	7.5
		300	8.6	10.2
	4.50	200	5.8	6.8
		300	7.8	9.5
1:1.5	2.25	200	7.2	8.8
		300	9.2	12.0
	4.50	200	6.0	7.8
		300	8.1	10.8

As described before, thinner slabs result in reduction of columns sections (especially for the ground storey) and in reduction of loads transmitted to the foundation. Moreover, reduction of loads resulting from the ceiling slabs' self weight provides significant benefits for high-rise buildings design in terms of wind and seismic loads.

For buildings with irregular location of columns in plan view (see Figure 2), post-tensioned slabs are especially beneficial. In such a case, stressed reinforcement members are relatively simply placed along the force trajectories, resulting in conditions appropriate to pre-stress effectively not only the span members of the slab, but also its console members.

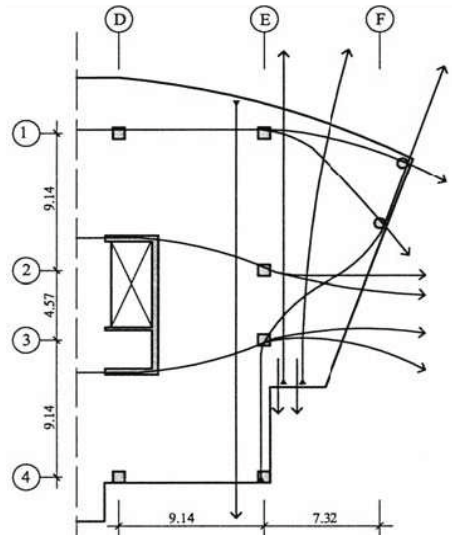

Figure 2. Example of placement of stressed members along the force trajectories (Albrecht, Raynard)

Assigning the pre-stress value

The calculation criteria applied to assign the pre-stress value in post-tensioned slabs are determined predominantly by the deflection limitations. The required pre-stressing force is specified in accordance with the pre-stress rate κ, calculated as a ratio between the maximum hog, a_{sp}, resulting from the effective pre-stressing (taking into consideration the appropriate losses), and the deflection resulting from quasi permanent load, a_e ($k = a_{sp} / a_e$) (Almeida, Appletion, 2001). In practical design cases, the pre-stress rate κ is within 0.6 … 1.0, depending on technical requirement, stipulated by standards, and economic considerations. For example, for $k \cong 1$, assessments in terms of deformability can result in relatively small slab thicknesses. In such a case, slab thickness shall be checked, for the purpose of its safety in a limit state, in terms of strength, flexibility limitation and fire resistance. Taking these requirements into consideration, recommendations are given in U.S. design standards (ACI 318 M, 2002; ACI-ASCE, 1974) to limit the average compressive stresses in the concrete resulting from the effective pre-stressing.

For flat slabs, compressive stresses in concrete are recommended to assign within 1…3 MPa.

See Figure 3 for the curves used to determine the flexibility (*l/h*) as a function of pre-stress rate (*k*=0.8) and load level. These curves are plotted in accordance with deflection limitations (Almeida, Appletion, 2001).

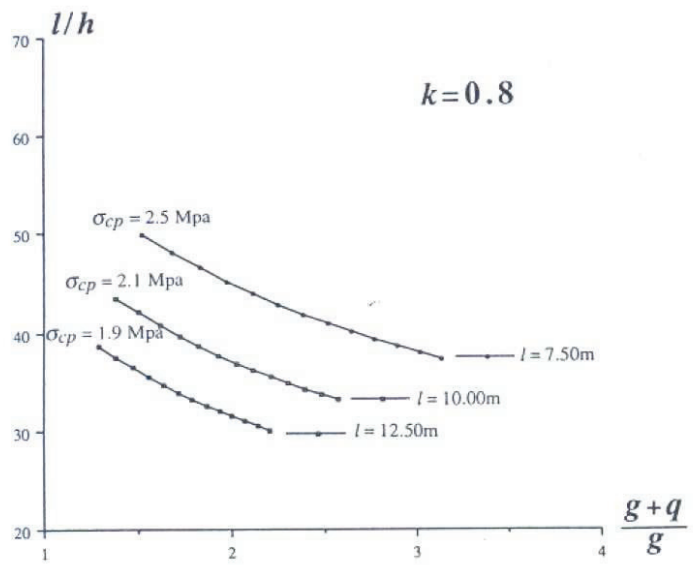

Figure 3. Curves for determination of *l/h* as a function of pre-stress rate $k=a_{sp}/a_e$

If mean compressive stresses in a slab concrete are less than 1 MPa, these structures, as a rule, shows low technical and economic characteristics. However, mean stresses in a slab assigned higher than 3 MPa may cause slab's shortening.

Calculating the necessary amount of non-stressed reinforcement in post-tensioned structure with unbonded tendons

There is one more important property of the post-tensioned structures with unbonded tendons: non-stressed reinforcement must be inserted in the section of this structure.

As a rule, in accordance with the U.S. and European standards (СНБ 5.03.02-02, 2003; DIN 4227, 1999; DIN 1045-1, 2002; EN 1992-1-1, 2005; ACI 318M, 2002), the design of post-tensioned slabs with unbonded tendons must include, in combination with the stressed reinforcement members, non-stressed reinforcement.

For this purpose, the required ratio between the amounts of stressed and non-stressed reinforcement in design sections depends significantly on the concrete stressing (i.e. on the pre-stress rate).

Neither of European standards, including СНБ 5.03.01, contains any special requirements with regard to stresses limitation in the tensioned concrete of slabs; as a result, crack formation and limited opening is considered to be permissible. However, if this is the case, these standards require the structure to be checked for limit states to avoid any reduction of its serviceability and service life.

As a result, for the design of pre-stressed structures consisting of slabs, with unbonded tendons, the situation is as follows. On the one hand, compressive stresses in the concrete must be set to ensure that the structure meets the requirements in terms of crack resistance and stiffness for the existing loads. On the other hand, higher concrete stressing results in a risk of brittle failure of the structure and, therefore, greater amount of non-stressed reinforcement must be inserted. Thus, minimum amount of non-stressed reinforcement must be determined to meet the requirement of avoidance of brittle failure.

In accordance with DINs (DIN 4227, 1999; DIN 1045-1, 2002), necessary amount of non-stressed reinforcement shall be calculated in accordance with the crack formation moment (M_{cr}); this moment, in turn, shall be calculated in accordance with the concrete tensile strength. This approach is quite conservative, because it is assumed that, after the crack formation, only non-stressed reinforcement bears the tensile force.

In accordance with the Canadian standard CSA A23.3, in the one-way slabs exerting force with unbonded tendons non-stressed reinforcement must carry the tensile force created by the moment as high as the dead load is, and 25% of the design liveload applied to the ceiling or roof (see Figure 4).

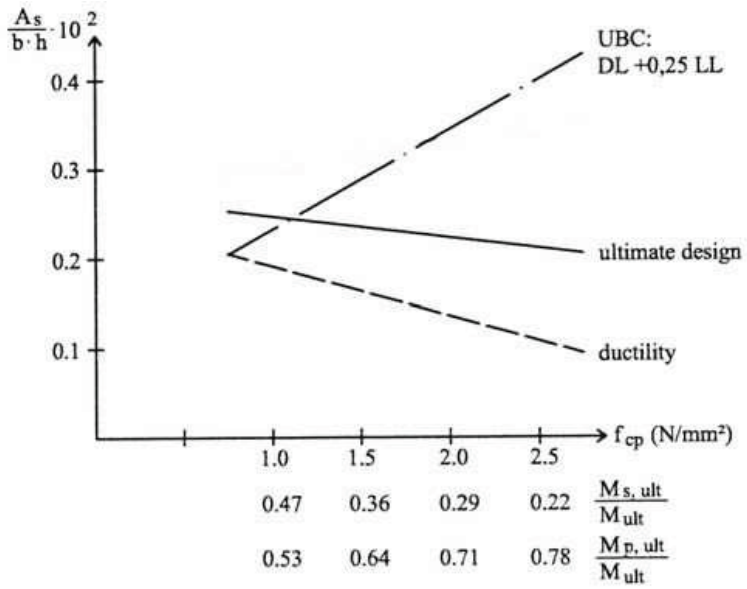

Figure 4. Mild reinforcement, required for one-way slab (Albrecht, Raynard)

In accordance with the Canadian standards the part of the limit moment born by the stressed reinforcement is recommended to be assumed $0.5 \le \alpha \le 0.6$ ($\alpha = M_{p,ult} / M_{ult}$) because the non-stressed reinforcement provides strength redundancy; in other words, 50 - 60% of the limit design force existing in the section must be carried by the stressed reinforcement and other 40 – 50% must be carried by the non-stressed reinforcement

bonded with the concrete (see Figure 5). However, the percentage of reinforcement for the non-stressed reinforcement ($\rho_{s,\min}$) resulting from the preliminary calculation must meet the existing standards.

Thus, the pre-stressed slabs with unbonded tendons are sensitive to the effective pre-stressing of the concrete. Strength redundancy shall be provided in these slabs by reduction of the effective stressing and/or by increasing the number of non-stressed reinforcement members bonded with the concrete.

Assigning the concrete class

For the design of slabs to be used in pre-stressed flat ceilings, the elastic properties of concrete and the rheological characteristics (shrinkage and creep) are of great importance. The modulus of elasticity of the concrete influences the deflection (in case of short-term loading) and reduction of pre-stress losses. The shrinkage deformation affects both the pre-stress losses and the changes of inner forces throughout the structural system consisting of slabs and columns. The creep coefficient has a significant influence on the long-term deflections and the pre-stress losses during operation. Therefore, these parameters of the concrete shall be carefully selected for the design of pre-stressed flat structures.

The lowest concrete class, in terms of compressive strength, shall be selected in accordance with the applicable standards (СНБ 5.03.01-02, 2003) for pre-stressed structures and it shall be C $25/30$ or better. Also, the requirements of technical recommendations for particular pre-stressing systems shall be taken into consideration; as a result, the concrete class higher than the lowest one may be necessary in anchorage zones.

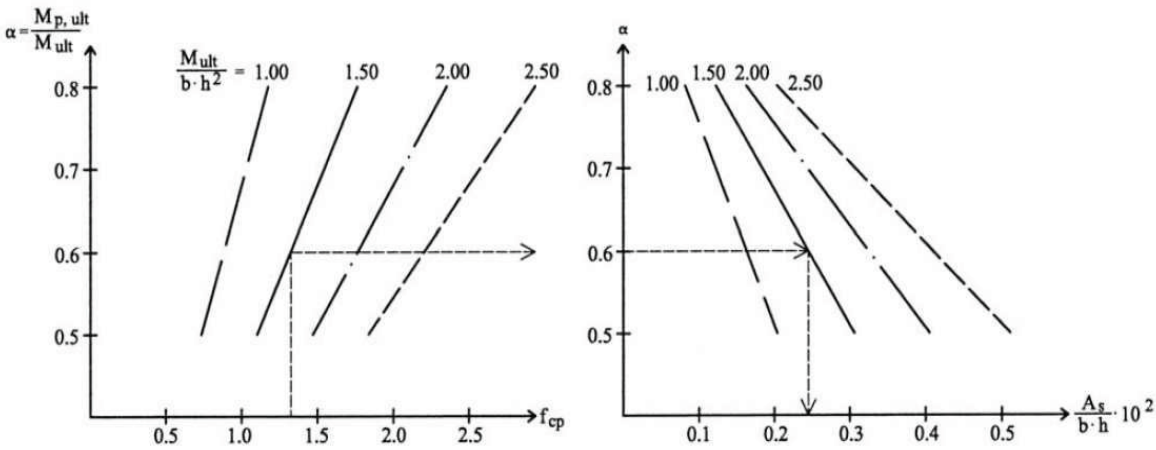

Figure 5. Average compressive stress and non-prestressed reinforcement depending on proportion of ultimate moment, covered be pre-stress (in accordance with the Canadian design standards)

As a rule, the concrete of higher class (in terms of strength) demonstrates higher modulus of elasticity (with the same concrete aggregate) resulting in reduction of deflections and saving the stressed reinforcement consumption. However, it should be noted that the processes used for making the high-strength concretes are different from the standard processes and growth of strength achieved by way of increasing the amount of the bonding agent always results in growth of shrinkage deformations (predominantly autogenous).

Arrangement of tendons

Figure 6 demonstrates several typical cases of placement of stressed members in a plan view for the ceiling with a regular (near-rectangular) column grid.

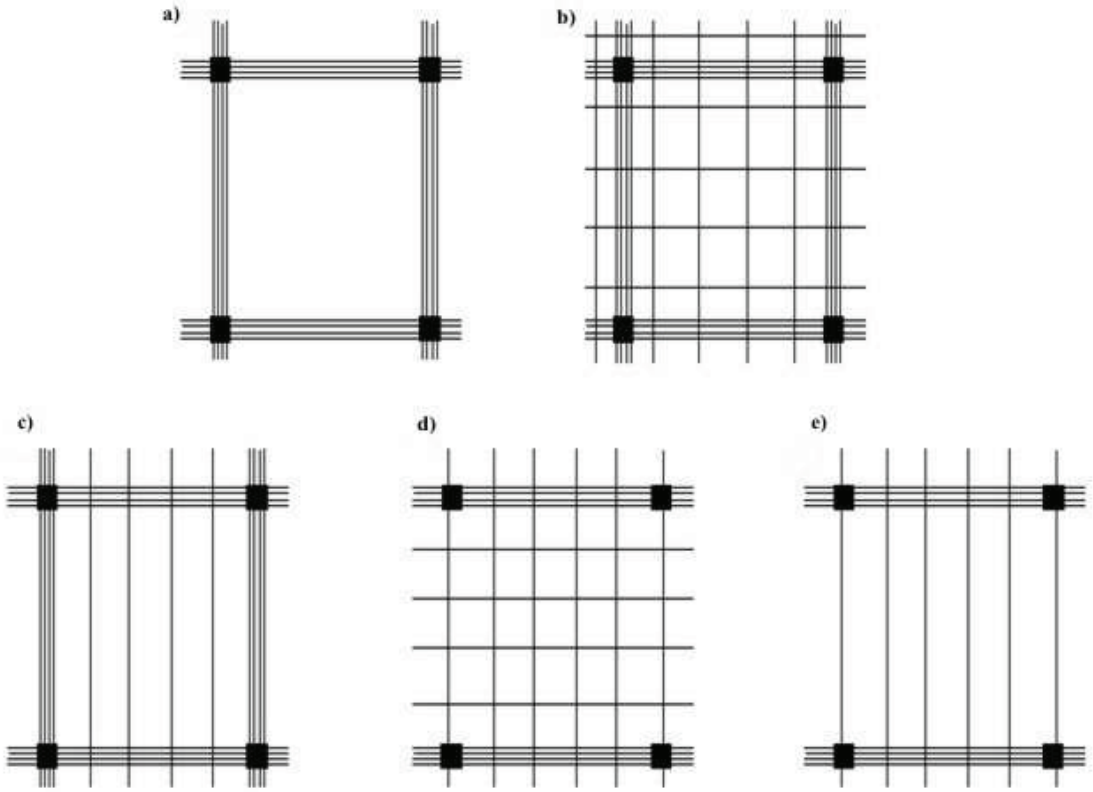

Figure 6. Typical patterns of tendons arrangement (ceiling plan view), for regular grid of columns

In ceilings with long spans, when the slabs are rather thick (about 300 mm), pre-stressed members are uniformly distributed along the slabs in both directions or, alternatively, they are concentrated in a column strip (see Figure 6a). Theoretically, the placement pattern shown on Figure 6b shall be considered as the most favorable one. However, patterns (c), (d) or (e) can be more effective for smaller thicknesses in terms of practical implementation.

The pattern (a) is especially useful in terms of increase of local shear strength (bursting strength) and reduction of deflections; however, it requires higher amount of non-stressed reinforcement in spans (similar to a slab supported along its four sides).

For slabs with crosswise stressed reinforcement, it should be noted that the effective height of slabs is different in two directions. Therefore, small-diameter strands are recommended for pre-stressing. For these strands, "free placement" of stressed bars in a span is recommended when they are placed on the non-stressed reinforcement.

CONCLUSION

The cast-in-situ slabs for ceilings or roofs, made by pulling the stressed reinforcement on the concrete at the construction site, aka post-tensioned structures, have several advantages, resulting in their high share in the world practice of construction. Application of post-tensioned ceiling slabs in cast-in-situ frames results in significant saving of reinforcement and concrete. For example, if the slab span length is 6 m, savings resulting from the reduction of the slab section height can be as high as 40% for non-stressed reinforcement and 30% for concrete.

It should be noted that the design of cast-in-situ post-tensioned slabs includes several details making this procedure different from that for the design and calculation of standard pre-stressed structures. Special attention must be paid to the assignment of the preliminary stressing rate and to the calculation of the necessary amount of non-pressed reinforcement.

REFERENCES

Aalami, B. O. Nonprestressed bonded reinforcement in post-tensioned building design/ ADAPT Technical Publication, P2 – 01, February 2001 – p. 1 – 12.

Aalami, B. O. Structural modeling and analysis of concrete floor slabs/ Concrete International, December, 2005 – p. 39 – 43.

Aalami, B. O., Gail, S. E., Kelly, P. E. Design of concrete floors with particular reference to post-tensioning/ PTI Technical Notes/ №11, January, 2001 – p. 1 – 17.
Aalami, B. O., Jurgens, J. B. Guidelines for the design of post-tensioned floors/ Concrete International, March, 2003 – p. 77 – 83.
ACI 318 M – 02/318 RM – 02 Building Code Requirements for Structural concrete (ACI 318M – 02) and Commentary (ACI 318M – 02), American Concrete Institute, Farmington Hills, 2002.
ACI-ASCE committee 423. "Tentative Recommendations for prestressed concrete flat plates"// Journal of the American Concrete Institute, v. 71, №2, February, 1974.
Ajdukiewicz, A., Golonka, K. Plaskie stropy sprężone kabllami bez przyczepności – specifika proektowania/ Inżynierija i Budownictwo, №6, 2007 – s. 300 – 309.
Albrecht, U., Raynard, G. Structural safety and reliability of post-tensioned floor slabs.
Almeida J. F., Appletion A. S. Control of deflections in post-tensioned slabs// Journal of Structural Engineering, №7 vol. 32; 2001 – p. 14 – 17.
Concrete Society Technical Report №25 "Post-tensioned flat slab design handbook", Concrete Society, London, 1984, 43 p-p.
CSA A 23.3 – Design of concrete structures: Canadian Structure Association – Toronto, 2003.
DIN 1045-1 Tragwerke aus Beton, Stahlbeton und Spanbeton – Teil 1: Bemessung und konstruktion, Juli, 2002.
DIN 4227 Tiel 6: Spaunbeton – Bateile mit Vorspannung ohne Verbund. Augabe Mai 1982 BK 1999 II/
EN 1992-1-1 (December 2005) Eurocode 2: Design of concrete structures – Part 1: General rules and rules for buildings, CEN, Brussels, March, 2005.
FIP Recommendations for the Design of flat slabs in post-tensioned concrete, Cement & Concrete Association, Wexham Springs, 1980, 21 p-p.
Morgen, K., Nolting, D., Wollrab, E. Flachdecken mit Vorspaunung ohne Verbund nach DIN 1045-1 . Beton und spanbetonban., Vol. 99, №11, 2004.
Partially prestressed composite beams under sustained and cyclic loads/ R. Z. Al-Zaid [et al.]// Journ. Of Struct. Engrg. – 1988. – Vol. 114, №2. – P.269-291.
Post-tensioned slabs – VSL international LTD., 1985 – 42 p.
Post-tensioning for two-way flat plate constructions, Professional Development Series/ PCA, October, 2005 – 6 p.
Stevenson A. M. Post-tensioned concrete floors in multi-storey buildings/ Reinforced concrete. British Cement Association, 1994; 22 p-p.
Teo, T. P. Experimental study of the behavior of simply supported unbounded post-tensioned one-way slabs/ T. P. Teo// MSc thesis/ University of Waterloo – Waterloo, Canada, 1975. – 273 p.
Harajli M. H. Evalution of the ultimate steel stress in partially prestressed concrete members/ M. H. Harajli, S. Hijazi// PCI Journ. – 1991. – Vol. 36, №1. – P.269-291.
Образцов, Л. В. Исследование железобетонных предварительно напряженных балок без сцепления арматуры с бетоном на действие изгибающего момента и поперечной силы: дис. … канд. техн. наук: 05.23.01/ Л. В. Образцов. – Брест, 1980. [Obraztsov L.V. Reinforced-concrete pre-stressed girders with the reinforcement not bonded with the concrete: Study of the behavior under bending moment and lateral force: Thesis for the degree of the Candidate of Technical Sciences: Specialty Code 05.23.01 / L.V. Obraztsov. – Brest, 1980].
СНБ 5.03.01-02. Бетонные и железобетонные конструкции – Минск: Минстройархитектуры РБ, 2003. – 146 с. [SNB 5.03.01-02. Concrete and reinforced concrete structures – Minsk: Ministry of Architecture and Construction of the Republic of Belarus, 2003. – 146 p.].
ТКП/ОР/45-5.01-2006 Проектирование железобетонных конструкций без сцепления арматуры с бетоном. [TKP/OR/45-5.01-2006 Design of reinforced concrete structures with the reinforcement not bonded with the concrete].
Тур, В. В., Образцов, О. Л. Комбинированно преднапряженные железобетонные конструкции с напрягаемой арматурой, не имеющей сцепления с бетоном// Строительная наука и техника, №2, 2007 – с. 17 – 31. [Tur V.V., Obraztsov O.L. Reinforced-concrete structures pre-stressed in combination, with the stressed reinforcement not bonded with the concrete // Construction Science and Engineering Journal, No.2, 2007 – p.17-31].

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The Research on the Width of Vertical Cracks in Reinforced Concrete Box-Girder Viaducts

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EXTENDED ABSTRACT

Very common defect in the old (operated for 20-30 years) stressed reinforced concrete box girder bridges in Lithuania is the cracking of girder webs shear and vertical sections. The experimental research on dynamic and static deflections of road pavement roughness of the three viaducts (Babtai, Gėluva and Pareizgupis) showed that dynamic deflection and coefficient depended greatly on road pavement roughness. Dynamic coefficient of the viaducts with uneven roadway surface was 20-30% higher than that of the viaducts with even roadway surface.

During the inspection of the Pareizgupis viaduct structure it was found out that stressed tendons were highly affected by corrosion and some wire bunches were broken in the 5th segment of girder "B". It was determined that 2,5 wire bunches were broken and 2 wire bunches were greatly subject to corrosion and were released. In order to examine the effect of dynamic loads on the viaduct deck, the changes in width of vertical cracks under the loads of heavy weight vehicles moving over a deck have been measured experimentally. The changes in width of vertical cracks were measured in the place of stressed reinforcement by sensors. By evaluating the corrosion of prestressed reinforcement, the width of vertical crack and stresses in stressed tendons were calculated theoretically. The long-term width of a vertical crack (not evaluating cyclic and dynamic loads) is equal to ~0,17 mm, i. e. almost two times less than it was obtained during the inspection. On the ground of practical research experience, it can be accepted that around 20% of load on one girder move to the adjacent girder over a diaphragm. In this case, the crack of mentioned size would be formed when ~4-5 wire bunches are not operating.

Having performed the experimental measurements of the changes in width of vertical cracks of the Pareizgupis viaduct under the loads of moving heavy weight vehicles, it was found out that the crack width increased by around 0,066 mm. It is not possible to evaluate the potential level of prestressed reinforcement corrosion based on the width of long-term vertical crack determined experimentally because cyclic and dynamic loads are of great importance in this case. On the ground of the width of short-term vertical crack determined experimentally, the potential level of prestressed reinforcement corrosion was calculated theoretically. It was obtained that, after evaluating the possible effect of a diaphragm in the section, 4-5 wire bunches do not operate, which was found out during the inspection.

Keywords: stressed reinforced concrete, crack width, stresses, precompression, elastoplastic deformations.

REFERENCES

Augonis, M., Zadlauskas, S., Rudžionis, Ž., Pakalnis, A. 2012. The analysis of reinforced concrete box-girder viaduct defects and their estimation. The Baltic Journal of Road and Bridge Engineering 7 (1), 13-21.

Bruni, S., Beretta, M., Simulation, S. 2003. Simulation of bridge heavy road vehicle interaction and assessment of structure durability. International Journal of vehicle design 20 (1), 70-85.

Gomez Navaro, M., Lebet, J. – P. 2001. Concrete cracking in composte bridges: Tests, models and design proposals. Struct. Eng. Int. (IABSE, Zurich, Switzerland), 11 (3), 184-190.

Li, C. Y. 1996. Bridge vibration and impact under moving vehicles. In Proceedings of the 1996 3rd joint conference on engineering systems design and analysis 81 (9), 17-23.

Sasaki, K. K., Peret, T., Araiza, J. C., Hals, P. 2010. Failure of concrete T-beam and box-girder highway bridges subjected to cyclic loading from traffic. Journal of Engineering Structures (32), 1838-1845.

Zadlauskas, S., Augonis, M. 2012. The infuence of dynamic loads on prestressed concrete box-girder viaduct deflection. In Proceeding of 17th Internanional Conference, Mechanika 2012, 345-350 p.

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Analysis of Stress Concentration Area about the Brace of the Concrete Wall at Early Age

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EXTENDED ABSTRACT

Scientists recently focus on concrete's hardening early age and its influence to solidity of a structure. Because of complex physical – chemical processes and developed strains, stresses appear in concrete and after they exceed tensile strength of concrete - develops cracks.

So it is important to assess impact from concrete shrinkage and to suppose possible areas of stress concentration. The importance of stresses caused by concrete shrinkage significantly increases in places where a cross-section shifts. One of the stress concentration areas is around the formwork's transverse brace and stresses due to autogeneous shrinkage are solved. Since the structure is restrained by formwork, concrete shrinkage caused by moisture loss is not considered, but the autogenous shrinkage is proceeded.

Concrete parameters used for calculations were obtained by means of an industrial experiment, while its tensile strength and modulus of elasticity were calculated using the corresponding formulas and EC2 regulations.

To define stresses, analytical and finite element methods are used. The numerical problem solution allows calculate the stress distribution around the transverse braces at any angle θ and the radius of the hole, the results obtained are exhaustive and it allows to get a clearer picture of stresses. Equivalent stresses are calculated according to Mises formula.

An area of stress concentration round the transverse bracing of the formwork, there the value of equivalent stresses is three times as big as the acting stresses appearing due to autogenous shrinkage of concrete in early age.

The equivalent stresses exceed concrete's tensile strength during the early days of concrete hardening and cause the opening of a crack.

To improve the quality of monolithic reinforced concrete structures as well as the reliability of exploitation, it is necessary to assess all the factors that influence strain-stresses behavior: when concrete mix is poured, when it hardens inside the formwork, when the formwork is removed and during the subsequent stages of hardening at surrounding environment.

Keywords: Autogenous shrinkage, cracks, early age, stress concentration area, finite element method.

REFERENCES

Holt, E.; Leivo, M. 2004. Cracking risks associated with early age shrinkage. Cement and Concrete Composites 26(5) : 521-530. doi: 10.1016/S0958-9465(03)00068-4.

Rees, D.; Taylor, B. 2012.Stress Concentrations for Slotted Plates in Bi-Axial Stress. Engineering 4(2): 69-75. doi:10.4236/eng.2012.42009.

Tazawa, E.; Miyazawa, S. 2002. Autogenous shrinkage: present understanding and future research. Control of Cracking in Early Age Concrete,-Mihashi and Wittmann (eds.). Swets and Zeitlinger, Lisse:165-176.

Žiliukas, A.; Surantas, A.; Žiogas, G. 2010. Strength and fracture criteria application in stress concentrators areas. Mechanika. Kaunas University of Technology, Lithuanian Academy of Sciences, Vilnius Gediminas Technical University. Kaunas:Technologija, nr. 3(83): 17-20.

Žiogas, V,A.; Juočiūnas,S.; Žiogas, G. 2007. Kauno nuotėkų biologinio valymo įrenginių statybos technologiniai sprendimai ir kokybės vertinimas. Mokslinio tyrimo darbo ataskaita (sutartis Nr.8364).Kauno technologijos universitetas. Kaunas 2007: 128 .[Decisions of construction technologies and estimation quality of Kaunas biological wasterwater treatment plant. Report of research work (contract No. 8364), Kaunas University of Technology]

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Lightweight Concrete with Aggregates Made by Using Industrial Waste

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EXTENDED ABSTRACT

The disposal and treatment of solid and hazardous industrial waste is quite expensive for any industry; therefore it brings challenges to find a solution that permits to obtain new, usable products by waste utilization in a technically and economically sustainable as well as environmentally friendly way.

The production of lightweight concrete by using aggregates made by industrial by-products and hazardous solid waste such as expanded fly ash, slag, sludge etc. is well known. This research provides possibilities to reuse waste called non-metallic product (NMP) from aluminium scrap recycling factories for the manufacturing of lightweight expanded clay aggregates and lightweight concrete. Characterization of NMP is described in the preliminary publications (Bajare et al. 2012).

The manufacturing cycle of lightweight expanded clay aggregates were simulated in laboratory by sintering the clay - waste mixes in the rotary furnace up to 1200°C. Lightweight expanded clay aggregates with rather different pore structure were obtained due to slight variations of mixture composition and sintering temperature. Produced aggregates were with bulk density from 320 kg/m^3 to 620 kg/m^3. Different types of lightweight aggregates were used to produce lightweight concretes. Mechanical, physical and thermal conductivity tests were performed for hardened concrete specimens according to standard procedures.

Keywords: Lightweight concrete, expanded clay aggregate, industrial waste.

CONCLUSIONS

Lightweight aggregate with different density (from 320 kg/m^3 to 620 kg/m^3) and crushing strength (from 0.8 MPa to 4.2 MPa) can be produced by using laboratory rotary kiln with the identical sintering temperature of 1180°C and regime, but changing NMP amount in composition of raw materials. They can substitute commercially available lightweight aggregates in low and high strength lightweight concrete.

Laboratory sintered aggregates LA and LB are with significantly lower water absorption up to 12% compared with the commercially available aggregates A1 and A2 (~18%). The water absorption for laboratory sintered aggregates is equivalent to high strength aggregates B1 (~12%).

Obtained concrete bulk densities ranged from 1600 kg/m^3 to 2020 kg/m^3. Hardened concrete bulk density for CLA, CA1 and CA2 was from 1550 kg/m^3 to 1600 kg/m^3, therefore it was declared as lightweight concrete. High strength lightweight concrete CLB, CB1 and CCLB samples showed bulk density under 2000 kg/m^3, but concrete composition CCB1 showed result 2020 kg/m^3.

Concrete made with lightweight aggregates with lower crushing strength and bulk density showed lower mechanical properties. Low strength lightweight concrete specimens CLA, CA1 and CA2 showed similar results in compressive strength after 28 days ranging from 20 to 24 MPa, and in flexural strength ranging from 4 to 5 MPa. Compressive strength of high strength lightweight concrete CLB and CB1 were 32 and 54 MPa after 28 days, and flexural strength were 5.5 and 6.7 MPa, respectively. Additional SF and admixture improved the mechanical properties of CCLB and CCB1, where compressive strength after 28 days were 43 and 62 MPa, and in flexural strength 6.9 and 7.6 MPa.

REFERENCES

Bajare D., Korjakins A., Kazjonovs J., Rozenstrauha I. Pore structure of lightweight clay aggregate incorporate with non-metallic products coming from aluminium scrap recycling industry. Journal of the European Ceramic Society 32 2012, 141-148 p.

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Investigation of Physical and Chemical Properties of Low-Temperature Hydraulic Binder from Latvia's Raw Materials

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EXTENDED ABSTRACT

One of historically widely used low-temperature binders has been romancement. During 19th/20th century it was the main hydraulic binder applied for the construction of buildings. Historical romancement was produced by firing marl (mineral composed from 60-75 % calcite or dolomite and 25-40 % clay) below its' sintering temperature (800-1200°C) and grinding. Romancement distinguished itself from other hydraulic binders by short setting time (usually 7-20 min), warm brown color and good durability.

In Latvia, in contrast to other parts of Europe, dolomitic romancement was used. However since the middle of 20th century its production has been stopped. At the same time, there is a great necessity for compatible materials for restoration purposes. Thus the aim of given research was to synthesize a hydraulic binder with chemical and mineralogical composition close to historical dolomitic romancement.

Low temperature hydraulic binder or so called dolomitic romancement synthesis of mixture composed from local clay and dolomite (both in powder state) is discussed. The chemical composition of the raw materials was analyzed. Specimens were prepared by homogenizing the mixture of requisite amounts of clay and dolomite in dry state and pressing plate samples. After firing at temperatures between 650 and 1050°C crystalline phases formed in samples were determined by XRD and chemical analyses. Natural dolomitic marl was treated at the same conditions in order to compare the crystalline phases formed in naturally and artificially made binders.

Hydraulic hardening could not be achieved without formation of cement minerals. Tricalcium aluminate provides quick setting (characteristic to romancement), but dicalcium silicate – gradual growth of strength which is important for longevity of mortar. It was determined that the formation of cement minerals is possible just after the dissociation of dolomite, when free CaO is released. Accordingly to data obtained by DTA analysis, it occurs at 777°C temperature. This is approved by XRD analysis, which detects dicalcium silicate and tricalcium aluminate crystalline phases present already at temperatures above 800°C.

Crystalline phases of artificially synthesized composition (24 % clay and 76 % dolomite) after firing are equal to crystalline phases in dolomitic marl fired at the same temperatures. Mineralogical composition of mixture closely conforms with natural marl's composition. Difference is notable in free CaO content - there is more of it in synthesized composition than in marl after firing.

Keywords: Low-temperature binder, clay, dolomite, crystalline phases, compatibility.

ACKNOWLEDGEMENT

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REFERENCES

Grosvalds, I., Lagzdina, S., Sedmalis, U. Dolomitic romancement – low temperature hydraulic binder. In: Abstracts of 10th International Congress on the Chemistry of Cement, Gothenburg, Sweden, 1997, Vol.2, 52-55.

Hughes, D.C., Jaglin, D., Kozłowski, R., Mucha, D. 2009. Roman cements — Belite cements calcined at low temperature. Cement. Concr. Res., 39 (2), 77-89.

Kozlowski, R., Adamski, G., Mucha, D. 2004. Roman cements – key materials in effectively restoring the built heritage of the 19th century/early 20th century. In: Scientific Journal of Riga Technical University, Material Science and Applied Chemistry, Riga, Latvia, 2004, Vol. 8, 102-109.

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Correlation Between Mechanical and Thermal Properties of Lightweight Concrete Made from Expanded Glass

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EXTENDED ABSTRACT

Lightweight concrete has become a popular construction material because of several advantages it holds over conventional concrete. Lightweight concrete is characterized by good compressive strength, durability and the most important advantages – low density and improved properties of thermal conductivity.

The aim of the study is to identify a correlation between mechanical and thermal properties of the lightweight concrete made from expanded glass aggregates. Six different concrete mixes with different amount of expanded glass granules and quartz sand were produced. Properties of fresh concrete like density and flow table test were tested. Flexural and compressive strength as well as density, water absorption and porosity were determined for 28 days old lightweight concrete samples. Thermal conductivity of lightweight concrete was determined and correlation between thermal and mechanical properties was identified.

Producers of lightweight expanded glass granules indicate the compressive strength from 0.45 −0.55MPa. By incorporating such material in cement matrix concrete compression strength could be limited due to the expanded glass granule compressive strength. Lightweight aggregate outer shell thickness, macroporosity and broken grains percentage all affect the aggregate strength (Y.Ke *et al.* 2009).

The materials used in this study were commercially available raw materials, cementitious materials and admixtures. Physical and mechanical properties of the expanded glass granules were determined.

The identified lightweight concrete properties were affected by quantity of expanded glass granule and sand content in mixture design. The compressive strength of lightweight concrete with expanded glass granules and sand could vary from 3.2 to 5.8MPa. Thermal conductivity decreases with the increasing amount of expanded glass granules (from 0.163 to 0.140 W/(m·K)) and increases with sand incorporation in lightweight concrete mixture (from 0.138 to 0.177 W/(m·K)).

Keywords: Expanded glass granules, Lightweight concrete, Mechanical and thermal properties.

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REFERENCES

Jasaitiene, J., Ivanauskas, E., Dauksys, M. 2010. Investigation of Lightweight Concrete with Porous Aggregates. In: Preceeding of the 2nd International Conference Advanced Construction, Lithuania, 2010.

Jennings, H., Thomas, J. J. 2009. Materials of cement science primer. A final report submitted to the Infrastructure Technology Institute for TEA-21 funded projects designated A474 Northwestern University, Evanston.

Ke, Y., Beaucor, A.L., Ortola, S., Dumontet, H., Cabrillac, R. 2009. Influence of volume fraction and characteristics of lightweight aggregates on the mechanical properties of concrete. In: Construction and Building Materials 23. P.2821-2828.

Kralj, D. 2009. Experimental study of recycling lightweight concrete with aggregates containing expanded glass. In: Process Safety and Environmental Protection 87, P.267-273.

Nemes, R. 2006. Lightweight concrete made with expanded glass aggregate. Budapest University of Technology and Economics, Budapest.

Tommy Y.Lo, Tang, W.C., Cui, H.Z. 2007. The effects of aggregate properties on lightweight concrete. In: Building and Environment 42.

US Patent 7695560. Strong, lower density composite concrete building material with foam glass aggregate. 2011.

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Mathematical Modelling of Ceramic Block Heat Transfer Properties

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Abstract. There are many methods for estimation of heat transfer properties for building materials. It is clear, that it is impossible to replace the experimental methods for determination of heat conductivity for basic materials. Experiments carried out show that heat conductivity of each particular material is dependent on different factors that could not be easily calculated. One of the possible alternatives to experimental methods is use of mathematical modelling in case when heat conductivity of basic materials is experimentally measured and building structure is combined of such materials or only geometry of macroscopic domains is changed in material. The advantages of this method are as follows: low cost - since no experimental equipment is needed; ability to virtually modify the structure of the material for maximizing its performance efficiency for a given task; and capability to handle geometrically complex materials when no explicit analytical approach is applicable. This research is developed to reveal dependences of heat conductivity of ceramic building materials from clay mineralogical composition, porosity, structure of geometrical cavities and influence of different heat transfer mechanisms and moisture for ceramic building materials with different macroscopic air domains and different filling materials.

Keywords: mathematical modelling, building materials, ceramics, heat transfer, thermal conductivity.

INTRODUCTION

Applying of ceramic materials has key position in building industries. This is because of ceramics properties – hardness, building convenience and high resistance on environment influence and microorganisms. Thanks to their ability to control humidity, ceramic building materials provide a favorable microclimate in rooms. But traditional ceramic materials have high thermal conductivity. Thus decreasing thermal conductivity of ceramic material was always actual question.

Thermal conductivity of ceramic building products depends on thermal conductivity of main ceramic body and on number and configuration of perforation or cavities exist in the ceramic material. It is possible to experimentally measure the properties of different clays, but in order to estimate the total heat transfer properties for the whole construction including cavities, the best way is to develop mathematical model and to perform numerical calculation series varying geometry or filling properties. This significantly speeds up the development process and allows optimizing of the product properties before production.

METHODS

1. Thermal conductivity of ceramic body

1.1. Dependence of thermal conductivity from clay mineralogical content

To determine dependence of thermal conductivity from mineralogical content of ceramic clays of bigger Latvian deposits and heat conductivity properties of ceramic received from these clays were investigated. Experiments carried out in the laboratory showed that thermal conductivity of ceramic body depends on mineralogical content of clay. High quartz content, low carbonate content and low clay mineral content increases heat conductivity of ceramic body (Table 1 and Fig. 1).

Table 1. Properties of ceramic body for different clays fired at 1000°C

Deposit name (in Latvia)	Heat conductivity λ, W/m·K	Density ρ, g/cm^3	Clay particles <0.005 mm, %	Sand >0.05mm, %	SiO_2, %	CaO+MgO, %
Progress	0.33	1.53	60.9	4	50.5	12.6
Apriķi	0.38	1.50	85.8	2.5	49.5	9.7

Līvāni	0.40	1.62	66.6	6.1	49.8	10.5
Kaiģi	0.41	1.50	34.7	4.3	54.6	14.9
Liepa	0.59	2.00	42.5	18.6	68.4	2.3

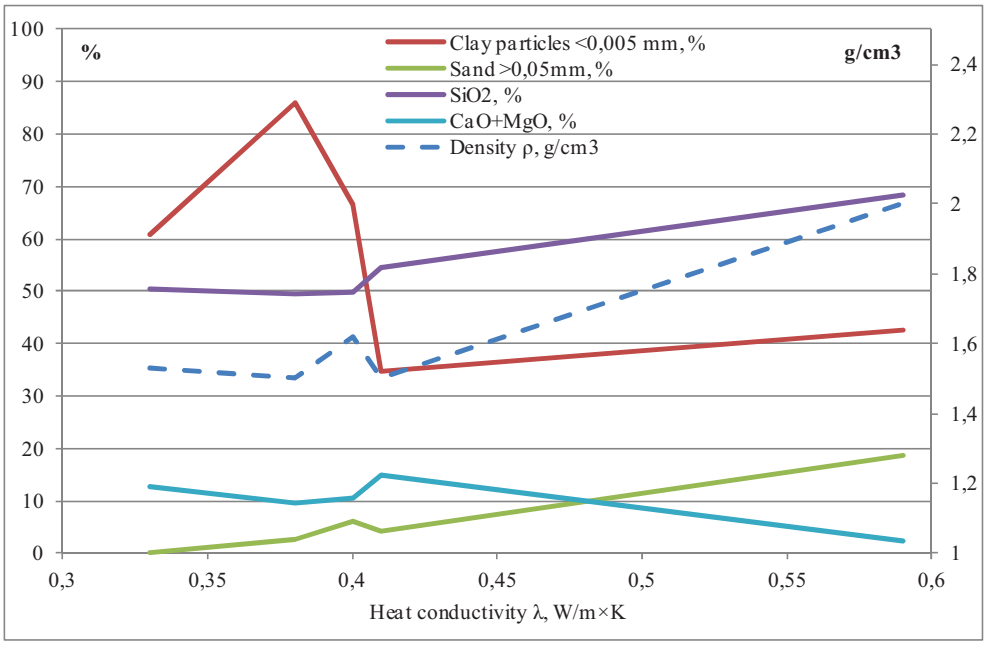

Figure 1. Factors influencing thermal conductivity of ceramic body

1.2. Dependence of thermal conductivity from ceramic density

The main factor influencing thermal conductivity of ceramic body is mineralogical content of the clay and it could not be changed significantly. But it is possible to decrease thermal conductivity of ceramic by decreasing its density – to archive this different organic and inorganic pore forming additives are utilized. Data summarized in Tables 2 and 3 shows influence of pore forming additives on thermal conductivity, density and compressive strength of ceramic. It is possible also to decrease thermal conductivity of ceramic body by adding pore forming additives. Quite big amount of additives should be added to achieve a considerable effect and appropriate thermal conductivity (<0,20 W/m·K) even in this case would not be achieved. Widely used solution is to use the main ceramic body with appropriate porosity and compressive strength with technological cavities. Thermal conductivity of ceramic building material would be influenced by quantity, shape, and filament of cavities.

Table 2. Ceramic produced from different clays with the same saw dust content properties

Name of deposit	Spartaks	Apriķi	Līvāni
Clay	95	95	95
Saw dust	5	5	5
Heat conductivity λ, W/m·K	0,32	0,36	0,34
Density ρ, g/cm^3	1,37	1,43	1,42
Compressive strength, N/mm^2	17,3	17	18

Table 3. Thermal conductivity of ceramic on base of clay from Līvāni from additive content

Name of additive	Content in mass %								
Clay Līvāni	100	95	90	80	75	85	80	80	95
Saw dust		5	5		5	5	5	6	
Coffee			5			5	5	5	
Wood gridding dust								4	
Dolomite				20	20	5	10		

Crushed expanded clay								1	
Crushed ceramic								4	
Milled glass									5
Heat conductivity λ., W/m·K	0,40	0,34	0,33	0,37	0,33	0,30	0,30	0,26	0,36
Density ρ, g/cm^3	1,62	1,42	1,30	1,50	1,33	1,24	1,24	1,15	1,46
Compressive strength, N/mm^2	22,0	18,0	15,0	20,0	17,9	7,0	12,3	4,7	18,2

2. Calculation of thermal conductivity in ceramic building material

One of the possible alternatives to experimental methods and empirical calculations for determination of the physical properties of the building materials is mathematical modelling approach. The main advantage of this method is low cost since no experimental equipment is needed to modify the geometry of the blocks and to change the filling and the properties of the cavities. The results obtained from these models demonstrate good agreement with experimental data (Cepīte and Jakovičs, 2008; Grechenkovs *et al.* 2011) and thus can be used in practice.

Two blocks with different cavity structure (Fig. 2) were compared in this research - *Keraterm 44* with experimentally determined equivalent thermal conductivity coefficient λ_e=0,129 W/m·K presently produced in *JSC "LODE"* and block structure with experimental cavity combination properties of which are calculated using mathematical modelling approach.

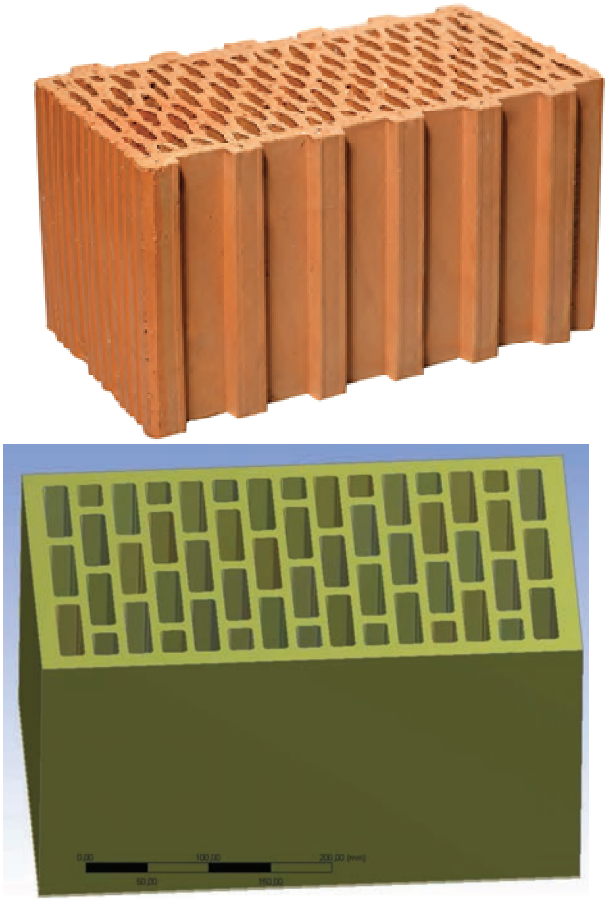

Figure 2. Building blocks *Keraterm 44* produced presently by *JSC „Lode"* (left) and modelled block with experimental cavity combination (right).

2.1. Physical quantities used for measurements

Heat transmittance U (W/m^{2}K) for the whole structure is defined as stationary heat flow Q (W) divided by the area S (m^2) and temperature difference ΔT (°C) on opposite surfaces (inner and outer walls):

$$U = \frac{Q}{S \cdot \Delta T} . \quad (1)$$

Heat transmittance can be determined experimentally by measuring heat flow through the object at constant temperature difference, for example using calibrated hot box apparatus (European Standard EN ISO 8990).

Heat transmittance characterizes the whole structure with fixed sizes including thickness. Often it is needed to describe the heat transfer properties of known configuration of many components independent on the structure thickness. For this reason equivalent thermal conductivity coefficient λ_e (W/m·K) is introduced, which describes the properties of the composite structure as for homogenous material; it can be calculated from heat transmittance U of the construction with depth d (m):

$$\lambda_e = U \cdot d . \quad (2)$$

As one can see from this equation, equivalent thermal conductivity is less for the structure with the same heat transmittance but smaller thickness.

2.2. Heat transfer equations for mathematical modelling

Mathematical modeling of the physical processed within the building blocks was made using commercial computational fluid dynamics software ANSYS CFX (Ansys Inc., 2012). The main equations solved using finite volume method (Versteeg & Malalasekra) are as follows (Incropera and DeWitt, 2001):

- The heat transfer in solid materials is determined by Fourier's law:

  $$\vec{q} = -\lambda \nabla T$$

  where $\vec{q}$ is the heat flux density, λ is the heat conductivity and T is temperature.
- The thermodynamic balance for fluids is given by a more complex equation:

  $$\rho c_p \left(\frac{\partial T}{\partial t} + (\vec{v}\nabla)T \right) = \lambda \nabla^2 T \quad (3)$$

  where ρ is the density, c_p – heat capacity and $\vec{v}$ – velocity of the medium. Term $(\vec{v}\nabla)T$ stands for convection and therefore can be neglected for solids.
- The motion of fluid is given by Navier–Stokes equation in the Boussinesque approximation:

  $$\begin{cases} \frac{\partial \vec{v}}{\partial t} + (\vec{v}\nabla)\vec{v} = -\frac{1}{\rho}\nabla p + \nu\left(\nabla^2 \vec{v}\right) + \vec{f} - \vec{g} \\ \nabla \vec{v} = 0 \end{cases} \quad (4)$$

  with the buoyancy force $\vec{f}$ to be derived from the equation:

  $$\vec{f} = \beta(T - T_0)\vec{g} \quad (5)$$

In these equations $\vec{g}$ is the gravitational acceleration, p – the pressure, ν – kinematic viscosity, β – thermal expansion coefficient, T_0 – reference temperature. Since only steady state solutions are found, the terms containing time derivatives could be neglected.

Discrete heat transfer radiation model (Lockwood and Shah, 1981) is selected for the radiation heat transfer calculations, and the equation for the change of radiant intensity dI along a path ds can be written as:

$$\frac{dI}{ds} + \alpha I = \frac{a\sigma T^4}{\pi} \quad (6)$$

where a is gas absorption coefficient and σ - Stefan-Boltzmann constant (5.672×10^{-8} W/m^{2}K^4). If a is constant along the ray, then $I(s)$ can be estimated as

$$I(s) = \frac{\sigma T^4}{\pi}\left(1 - e^{-as}\right) + I_0 \cdot e^{-as} \quad (7)$$

here I_0 is the radiant intensity at the start of the incremental path.

3. Model

One geometry (Fig. 2, right) of the experimental block with different cavity filling is modeled to analyze the influence of the potential possible filling on the thermal resistance properties of a whole block. Dimensions of a block is set 440×245×240mm. Fixed surface temperatures of 0°C and +20°C are set as boundary conditions on block's surfaces according to the construction inner and outer walls, adiabatic boundary conditions are set on all other surfaces excluding heat exchange between similar blocks in the wall. Discretisation mesh in the middle cross-section is shown on Fig. 3. Properties of the air and cavity filling materials are shown in the Table 4.

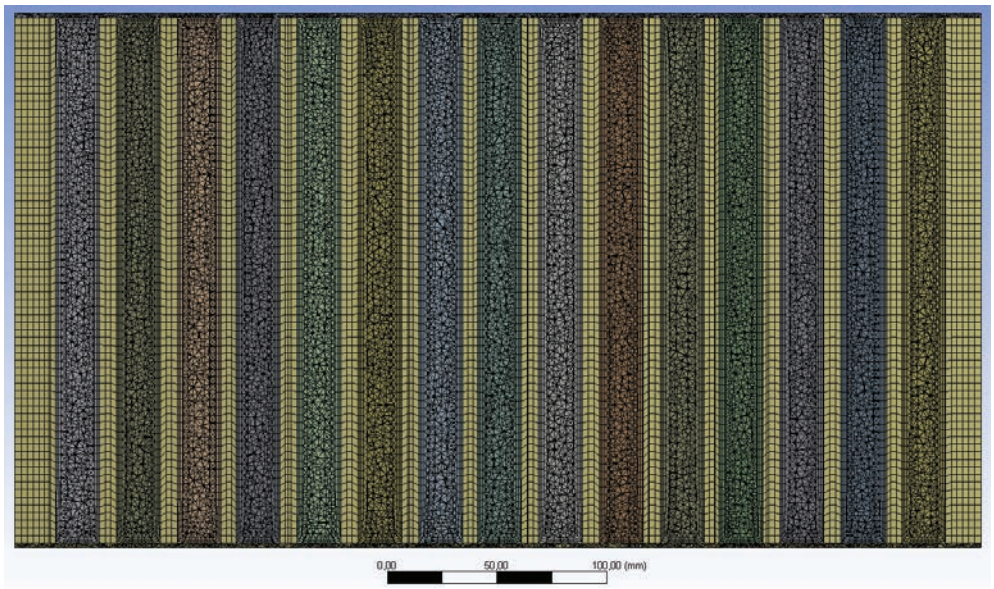

Figure 3. Discretisation mesh in the middle cross-section of a modelled experimental block

Table 4. Material properties used for mathematical modelling

Material	Density ρ (kg/m^3)	Specific heat capacity c_p (J/(kg·K))	Thermal conductivity λ (W/(m·K))
Ceramic	1460	920	0.278
Air	1.185	1000	0.0261
Mineral wool	220	2100	0.038
Polyurethane foam	40	1500	0.026

RESULTS

Due to structure of the block, which consists of ceramic material and cavities, different heat transfer mechanisms are included in the model – conduction, convection and radiation. Heat conduction is the only one heat transfer process for non-transparent solid ceramic part, convection and radiation are important only in case of gas filled cavities. In case when block has bigger cavities convection, transfer starts to play more important role in thermal conduction. This is confirmed by difference between equivalent thermal conductivity (Table 5) of real *Keraterm 44* block (Fig. 2, left) and experimental one (Fig. 2, right).

Table 5. Experimental data (*Keraterm 44*) and modelling results (A, W, P, A0.3)

Model	Cavities filling	Surface emission ε (-)	Heat flux Q (W)	Heat transmittance U (W/(m^2·K))	Thermal conductivity λ_e (W/(m·K))
Keraterm 44	Air	*Experimental measurements*			0.129
A	Air	0.9	0.4522	0.384	0.169
W	Mineral wool	0.9	0.2947	0.250	0.110
P	Polyurethane foam	0.9	0.2578	0.220	0.097
A0.3	Air	0.3	0.3159	0.268	0.118

Modelling results for experimental block with different cavity fillings are summarized in Table 5. As one can see, the equivalent thermal conductivity λ_e=0.169 (W/(m·K)) is estimated for the block model without any special filling (model A), it is higher value than for experimental *Keraterm 44* block with smaller cavities. The main reason for this difference is bigger size of internal air filled cavities which means more intensive convection.

Two different improvement of heat resistance for modelled block are investigated – cavity filling with the heat insulation materials (mineral wool – model W, polyurethane foam – model P) and the reducing of radiation heat transfer by decreasing of cavity surface emissions (model A0.3). The last one can be changed by coating the

cavity surface with special low emission material. As it is seen from results (Table 5), mineral wool filling reduces the equivalent thermal conductivity of the block to 0.110 W/(m·K), but with the polyurethane filling λ_e decreases to 0.097 W/(m·K).

Mechanical filling of cavities is very complicated process in terms of technical implementation, the easiest way is to spray the special low emission coating into the cavities, in this case (model A0.3) reduction of radiation heat transfer causes the reduction of equivalent thermal conductivity down to 0.118 W/(m·K), which is very close to the effect of mineral wool filling.

Figures 4 and 5 show the temperature contours on the top of the block and in the middle cross-section for variants with air and polyurethane filling. Due to convection, heat transfer of air filled cavities is more intensive than in cavities with solid polyurethane filling. Non-symmetrical temperature distribution in the lower part of the cavities (Fig. 5) demonstrates the influence of convectional air transfer with air movement.

The character of heat exchange is clearly seen also from the temperature data on one line in the middle of the block (Fig. 6) – as one can see, in case of air-filled cavities (red line) the temperature distribution in more homogenous than for case of polyurethane filling with greater temperature gradients in all domains. On the pictures shown on Fig. 7 velocity vectors in the air filled cavities are visualized – in the middle vertical part they are symmetrical, but in the upper part situation changes resulting also shift in temperature field seen in Fig. 5 (left).

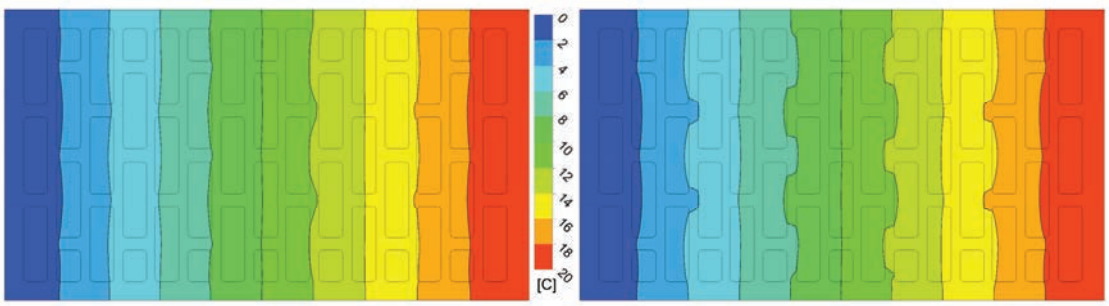

Figure 4. Temperature field on top of the block for model A (left) and model P (right).

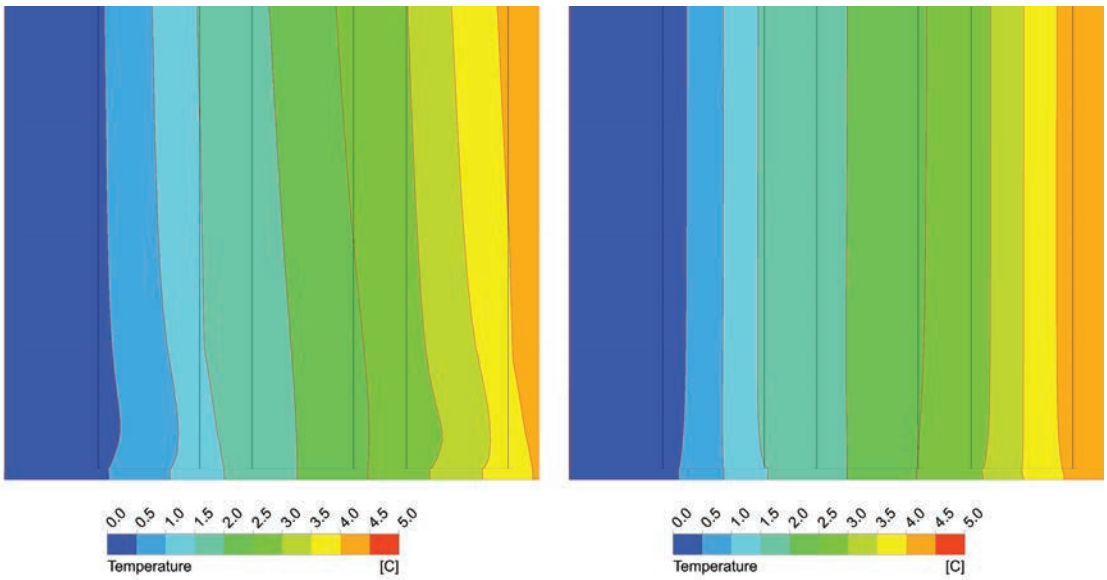

Figure 5. Temperature field on bottom part of vertical cross-section in the middle of block for model A (left) and model P (right).

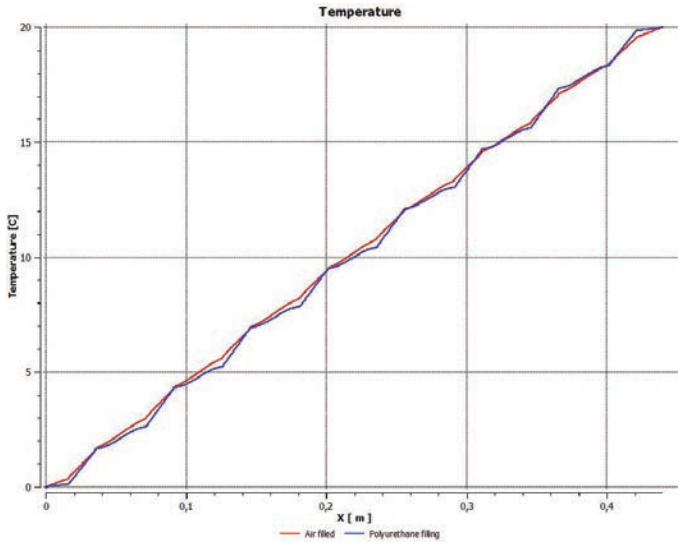

Figure 6. Temperature profile on the middle line (in direction of temperature gradient)

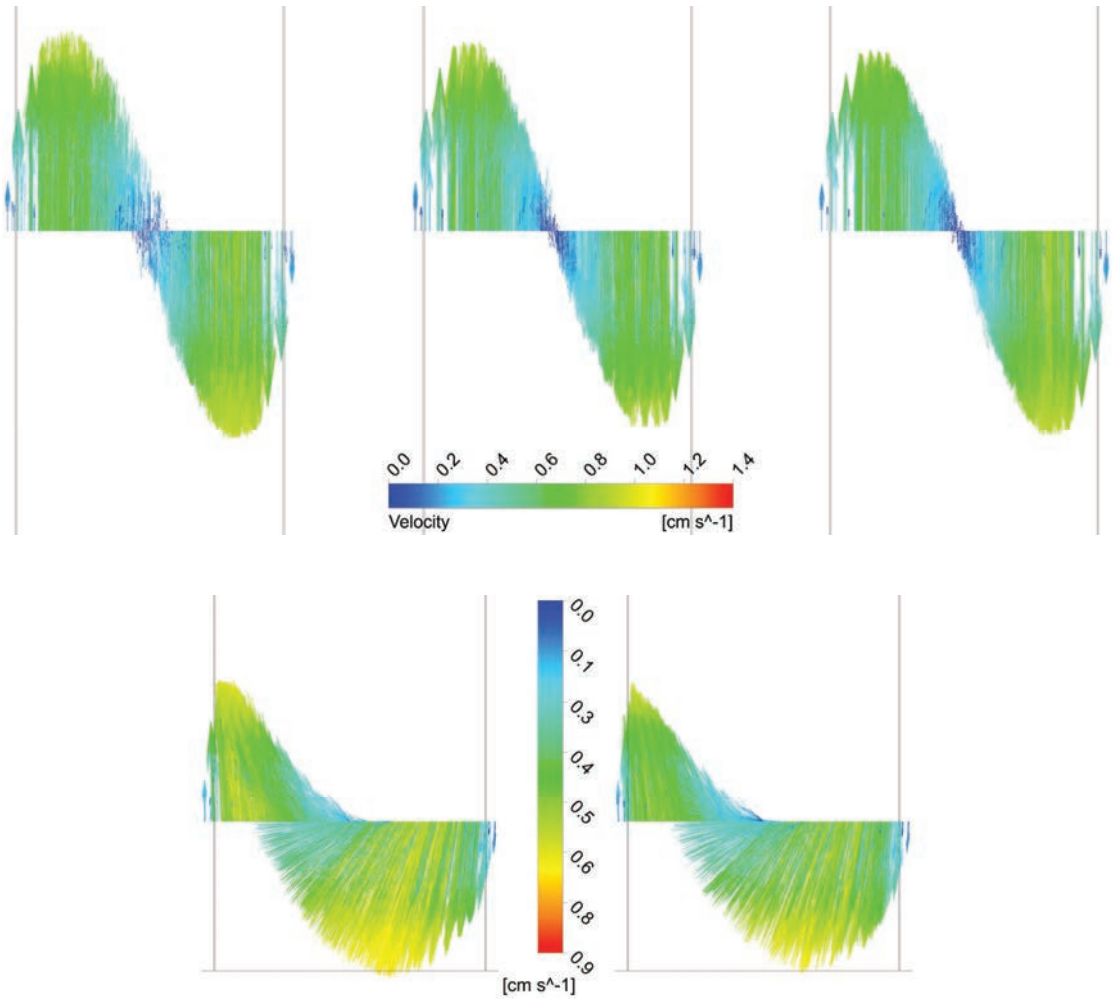

Figure 7. Velocity vectors in the middle part (above) and in the upper part of the cavities (below)

DISCUSSION

Numerical calculation of heat transfer properties for ceramics blocks with cavities need accurate input data. Thermal properties of basic materials (ceramics, solid filling etc.) and geometrical properties can be easily

found, but some other factors needs to be evaluated based on empirical data (e.g., real emissivity of the surfaces to correctly include the radiation heat transfer). Therefore it is very important to perform also the experimental research for some already modeled products to compare measured and calculated heat transport properties.

Other important mechanism for this kind of building structure is moisture transport due to low vapour resistance. It influences the heat conductivity of a ceramics, in this way increasing the heat transmittance for whole structure. Modelling for some observed ceramic blocks was carried out (e.g., Grechenkovs *et al.* 2011), but coupled heat and air moisture (HAM) transport modeling is needed to obtain more accurate results. Measurements carried out in the Laboratory for mathematical modelling of environmental and technological processes for such kind of ceramic blocks showed, that the difference in resulting *U* value can be more than 20% under different humidity conditions.

CONCLUSIONS

It is many possibilities to decrease thermal conductivity of ceramic material. Thermal conductivity of ceramic body could be decreased by modification clay mineralogical content and increasing porosity of ceramic body. This method could give some improvements but it is limited with compressive strength of material. The same limit has increasing amount of macro cavities in ceramic block.

Modelling pointed out that decreasing radiation inside cavities decreases thermal conductivity considerably. Additional improvement gives removing convection from heat transfer process. Previous researches showed a good agreement of mathematical modelling method with manufacturer data (Grechenkovs *et al.* 2011).

Therefore the method of mathematical modelling can be used to determine the heat transfer properties of the building materials in a quick and easy way. The usage of this method is both precise and cheap (especially considering the modern rate of the evolution of computers and computer software). The precision is achieved through inclusion of such physical processes as radiation heat transfer that cannot be introduced fully adequately by other methods. The obtained results provide ideas to the manufacturers how to improve thermal resistance of present materials by combining effects of physical and geometrical factors.

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REFERENCES

Cepīte, D., Jakovičs, A. 2008. Analysis of heat transfer in the structures with regularly arranged cavities. Latvian Journal of Physics and Technical Sciences, Volume 45, Number 4, 14-24.

Grechenkovs, J., Jakovich. A., Gendelis, S. 2011. 3D Numerical Analysis of Heat Exchange in Building Structures with Cavities. Latvian Journal of Physics and Technical Sciences, Volume 48, Number 1, 3-12.

European Standard EN ISO 8990, Thermal insulation – Determination of steady state thermal transmission properties – Calibrated and guarded hot box, 1996.

Versteeg, H., Malalasekra, W. 1996. An Introduction to Computational Fluid Dynamics: The Finite Volume Method Approach. Prentice Hall, New York.

Incropera, F. P., DeWitt, D. P. 2001. Fundamentals of Heat and Mass Transfer, 5th ed. New York: John Wiley & Sons.

Lockwood, F. C., Shah, N. G. 1981. A new radiation solution method for incorporation in general combustion prediction procedures. In: 18th Symposium on Combustion, The Combustion Institute, Pittsburgh, 1981, 1405–1414.

ANSYS Inc., ANSYS Release 14.0 Documentation, 2012.

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Studies on Formulation and Properties of Special Silicate Renders

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Abstract. In the work the conditions for development of special silicate renders were determined. Such renders were produced by correcting the quantities of the main components of silicate renders (modified binder, fillers, pigments) within the optimal limits and at the same time, significantly changing the main technological properties of renders and operational properties of their coatings, i.e. water and vapour permeability, mechanical strength of dry and wet coating. By correction of the universal composition of the silicate renders and changing its properties, the renders possessing certain extremely high-quality special properties were produced. When generating compositions of such renders the following provision was followed that in order to produce renders with a set special property, it is necessary to maximize (minimize) the content of a component affecting this property without infringing its optimal quantitative relations with the other components of the composition.

Keywords: silicate renders, special renders, formulation, properties

INTRODUCTION

Silicate render is a dispersive system which combines solid, liquid and gaseous phases. A solid phase means fillers, pigments comprising structural framework the pores of which are filled by fine-dispersive particles and liquid phase. Colloidal-chemical properties of this liquid phase cohering solid particles and the content in the system determine the density of a thickened structure. The structure density determines the strength of the thickened coating and permeability of water and water vapour (Ailer, 1982).

Based on the research of a series of authors it may be stated that the properties of liquid glass determine of properties of substances with potassium liquid glass (Korneev and Danilov, 1991; Lotov, 2007). Liquid glasses are alkaline silicate solutions and consist of $Si(OH)_4$ silicate ions, polysilicate ions and colloidal silicic acid particles. They have prevailing dynamic equilibrium which determines a structure and size of said particles. This equilibrium depends on liquid glass module (ratio of SiO_2 and K_2O clays), concentration, temperature, pH value, etc. Such solutions are thermodynamically unstable and due to dehydration they respond to condensate polymerization which leads to formation of primary colloidal SiO_2 particles. At pH >9 colloidal SiO_2 particles (sol) generate and grow fast – liquid glass coagulation is taking place. Subsequently, aggregation process – formation of viscous sols and gels – takes place.

The silicate render compositions generally contain non-organic pigments, carbonate, silicate, phosphate and sulphate fillers as well as stabilizing, dispersible and rheological additives (Margraf and Könner, 1998). An important component is fillers which not only have to ensure render consistency, spreading rate, operating properties of thickened coatings, but they may also increase the render efficiency (Wagner, 1993; Daunoravičius *et al*. 2010).

Was carried out analysis of silicate render properties and composition and determined optimal quantitative relations between the main components (Daunoravičius *et al.* 2011).

On the basis of the achieved results the following conditions for developing optimal compositions of silicate renders were defined:

potassium liquid glass has to be of around 1180 kg/m^3 of density and have the 3.5 – 4 silicate module. Its content (non-volatile substances) has to comprise 3.5 – 4 per cent of the total render mass;

dispersion content (non-volatile substances) has to comprise 3 – 3.5 per cent of the total render mass;

pigment and micro-filler mass ratio has to be within the limits of 1:5 – 1:2.5;

silicate binder (non-volatile substances of liquid glass and polymeric dispersion) mass ratio with the total pigment and filler mass has to be 1:11 –1:13. In order to produce the coatings possessing the increased mechanical strength, the binder content may be increased up to 1:10.

It has been determined that when changing the quantities of the main components of silicate paints (modified binder, fillers, pigments) within the optimal limits, it is possible to significantly change the main technological properties of paints and operational properties of their coatings, i.e. water and vapour permeability, mechanical strength of dry and wet coating and the strength of its cohesion with the surface (Daunoravičius *et al*. 2010). By analogical correction of the compositions of silicate renders and direct changing of their properties it is possible to produce not only universal compositions with all sufficiently high-value properties, but also the renders with the certain extremely high-quality special properties.

Special renders are used under complicated environmental and operational conditions. It is reasonable to finish buildings, containing premises of increased humidity and buildings which are endangered by microbiological pollution, air pollution and vibration, with such renders. The render for façade finishing is selected taking into account the structures of building partitions. If they are fabricated from materials which are water vapour-permeable then the render which is more vapour-permeable should be selected. When choosing a decorative render its price is not of the least importance. The price of silicate renders is not low; therefore it is necessary to find the ways to make them less costly by preserving their positive qualities. For instance, under milder operating conditions it is possible to use mechanically weaker but less expensive renders.

The aim of this work is by adjusting of the universal formulation of the silicate render and changing it properties, compose the renders possessing certain extremely high-quality special properties.

MATERIALS AND EXPERIMENTAL METHODS

Potassium liquid glass of 1260 kg/m^3 density and 3.5 silicate module was used during the tests. Liquid glass was modified by styrene/acrylic polymer dispersion Finndisp A 11, particle size 0.19 µm, pH 7.5-8.5, MFFT 14°C, content of non-volatile substances – 50 per cent. Due to the electrostatic effect of a carboxylic group this dispersion not only st abilizes the binder, liquid glass, but also reaglomerates pigments and fillers. The modifying dispersion was mixed not directly with liquid glass but it was poured into the render compositions which were nearly finished and stirred in these compositions for a while by necessarily adding an additional amount of antifoamer. The characteristics of mineral pigments resistant to alkaline and light used in these tests are provided in Table 1.

Table 1. Pigments used for renders and their characteristics

Title	Chemical composition	Colour	Medium particle size, µm
Red ferric oxide (hematite)	Fe_2O_3 (up to 95 %)	Dark red	0.17
Titanium dioxide	TiO_2 (rutile)	white	0.10

When selecting fillers their properties have to be taken into account. Some minerals – calcite, kaolin, baryta – may improve decorative properties of the coatings but degrade mechanical ones. The others (quartz, mica), on the contrary, improve physical-mechanical properties but degrade decorative ones. Therefore several types of fillers, for instance, 2-3 combinations of different fillers, instead of one type should be used. It is stated that talc improves all properties of the coatings (decorative, physical-mechanical, technological and operational) therefore it is to be used in all cases. The characteristics of micro-fillers used during the tests are provided in Table 2.

Table 2. Characteristics of micro-fillers used for renders

Micro-filler	Chemical formula	Shape of particles	Medium particle size, µm
Talc	$3MgO{\cdot}4SiO_2{\cdot}H_2O$	Plates	10
Calcite	$CaCO_3$	Spheres	6
Calcite	$CaCO_3$	Spheres	10
Fibre micro-filler	$(C_6H_{10}O_5)n$	Needles	200

Larger fillers are also necessary for the renders. They influence the thickness of the formed coatings and make their pattern. The marble granules of 1-2 mm thick were used during the tests.

The following additives ensuring the required technological and technical painting characteristics were used in the render compositions as well: glass stabilizers, viscosity converters, thickeners, dispergators, antifoamers and emulgators. These additives were not tested and their amounts were chosen based on the manufacturers' recommendations. The descriptive data of the additives used for the renders are provided in Table 3.

Table 3. Modifications of targeted additives of silicate renders and their impact on the render properties

Item No	Additive name	Range of Substances	Effect of Paint Properties
1	Liquid glass stabilizers	Substances characteristic of cationic or anionic molecular groups, e. g. quarterly ammonium compounds.	Stabilizing effect on SiO_2 anions impeding the increase of their dispersive particles. Ensure low and stable product viscosity when storing.
2	Thickeners	Carboximethylcellulose, hydroxyethylcellulose, xanthan rubber, bentonite	Increase viscosity of render mixtures, stabilize sedimentation of fillers and pigments, improve mixing characteristics, increase a possibility to cover edges, rims, increase a number of applications and facilitate this process
3	Dispergators	Polyphosphates, diphosphates, phosphonates, lignin sulphonates, naphthene sulphonate	Impact an area of the filler and pigment surface, eliminate electrostatic charges and determine a higher liquefaction of included suspensions.
4	Antifoamers	Silicone emulsions, fatty acid esters.	Prevent a substance against foaming
5	Emulgators	Anionic, cationic, non-ionic or amphoteric, surface active substances	Change tensions of the particle surfaces

Analysis of hardened render coatings:

- *abrasion-resistance of the render coatings* was determined according to LST EN ISO 7784-2:2006, by means of applying the Taber method using 10 mm thick concrete plate samples with formed and hardened render coatings.

- *cohesive strength by removing* renders coatings from concrete plates using device 58-C0215/T of the company *CONTROLS* was determined according to LST EN 1542:2002. Test renders were applied onto the dry standard concrete plates with the 2 mm layer.

- *water permeability* was determined according to LST EN 1062-3:2008, using 3 cm thick and 225 cm^2 standard concrete plates with the formed 2 mm thick render coatings, which were being cured for 14 days.

- *vapour-permeability of render coatings* was determined by using gypsum plaster plate samples according to LST EN ISO 7783-2:2002. The 2 mm thick coatings formed on the plates. After 14 days the samples were tightly installed on the glasses with water. The glasses with the samples were placed in the test chamber where temperature and humidity are controlled. During certain periods of time glasses with the samples were weighted and the density of the vapour flow through the paint coating was estimated according to LST EN ISO 7783-2.

- *resistance to weathering impacts* – 2 mm thick render coatings formed on the glass plates were artificially aged in the apparatus *QUV/ spray with UVA 340* lamps. The test cycle consisted of 5h of luminos discharging and 12 min. of overhead irrigation. The samples were inspected every 20 test cycles. The chalking level and other coating degradations were assessed according to the sample standard pictures and standard scales specified in parts 2-5 of the standard LST EN ISO 4628.

All samples of tests were cured for 14 days under the conditions of (21±2) ^oC temperature and (60±10) per cent of relative air humidity.

RESULTS AND DISCUSSIONS

In compliance with the established conditions for development of optimal render coating compositions a universal composition of a render was designed (Daunoravičius *et al.* 2011). The content of liquid glass in the composition (non-volatile substances) – 3.67 per cent, polymeric dispersion (non-volatile substances) – 3.0 per cent. Pigment and micro-filler mass ratio was 1: 4.4. The ratio of non-volatile substances of liquid glass and polymeric dispersion with the total mass of pigments and fillers equalled to 1:11.2. The quantities of additives were chosen on the basis of the manufacturers' recommendations. Render composition and mass percentage are provided in Table 4.

Table 4. Universal composition of a silicate render and its coating properties

Item No	Paint component	Content, masses %	Render coating property
1	Water	7	Vapour permeability 260 g/m^2. per day; S_d = 0.08 m; Resistance to abrasion 4.18 mg/rpm;
2	Liquid glass	10.5 (3.67)	
3	Polymeric dispersion A11	6 (3)	
4	Micro-filler 10 µm	12	
5	Micro-filler 5 µm	18	

6	Micro-filler Talc	5	Strength of cohesion with concrete 1.4 MPa;
7	Fibre micro-filler	0.5	Chalking 3 points;
8	Pigment TiO_2	8	Water permeability coefficient
9	Larger filler 2 mm	31	w_{24}= 0.37 kg/($m^2 \cdot h^{0,5}$);
10	Dispergator	0.1	Drying time 60 min;
11	Silicate stabilizer	0.3	Full drying time 72 h.
12	Thickener	1.3	
13	Antifoamer	0.2	
14	Emulgator	0.1	

A universal, sufficiently economic and characteristic of good qualities render composition was produced. However, it has its drawbacks. The most important one is a high level of water permeability attributed to coatings.

Silicon organic compounds were used to make the render hydrophobic. There are many types of silicon hydrophobic materials, depending on the length of alkyl groups adjoining the Si component. As shown by the data presented in Fig.1, the most effective paint additives are aminosilane and aminosiloxane emulsions as well as silicon resin emulsion. As the quantity of the hydrophobic additive increases its hydrophobic effect becomes relatively smaller and therefore the most effective content of such additive is 1 per cent of the total mass of the render.

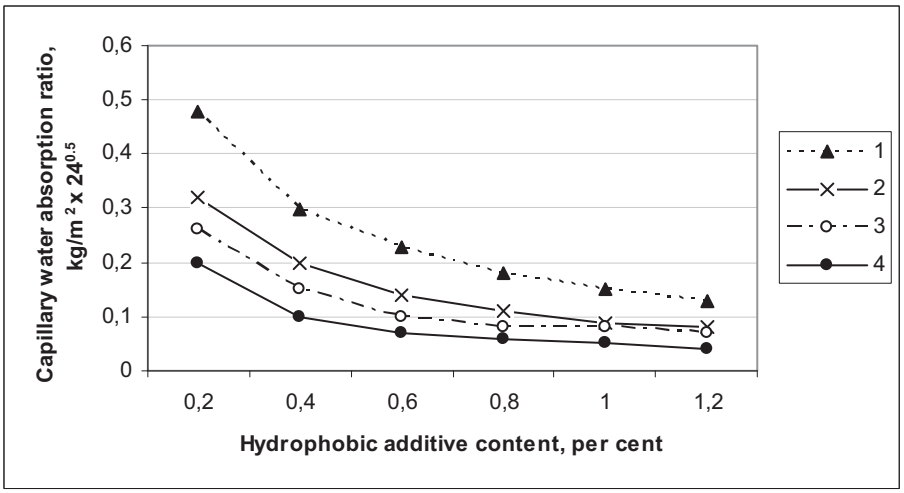

Figure 1. Dependence of the capillary water absorption indicator in test render coatings on the type of the hydrophobic agent: *1* – silicone resin emulsion 1; *2*– silicone resin emulsion 2; *3* – aminosilane emulsion; *4* – aminosiloxane emulsion

The strength of dry coatings was assessed through their resistance to abrasion. The results indicate that resistance to abrasion depends to some extent on the content of liquid glass (Fig. 2). By increasing the liquid glass content from 9.5 per cent to 13 per cent, the loss of the coating mass to abrasion can be brought down from 6.9 to 2.9 mg/100 rew.

The results of the strength of coating adhesion to concrete by tearing are shown in Fig. 2. Apparently, this indicator depends on the content of the binding agent used in the paint, i.e. liquid glass the most. If the content of liquid glass in paint is raised from 9.5 per cent to 13 per cent, the strength of paint-to-concrete cohesion goes up to 1.2 from 2.8 Mpa.

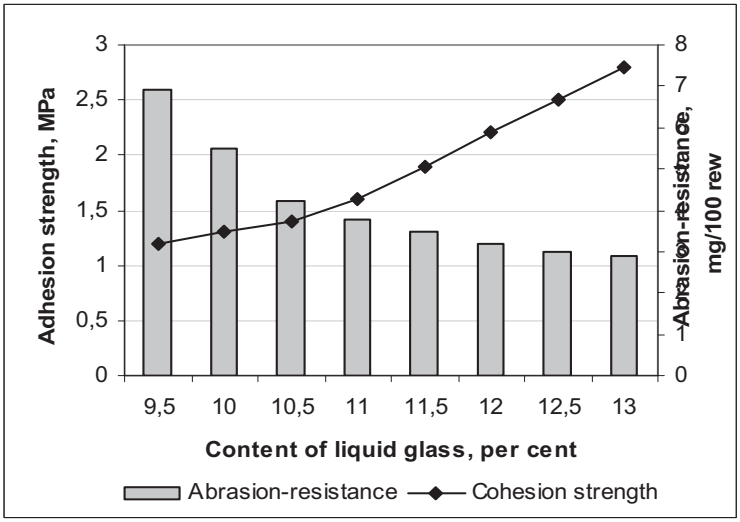

Figure 2. Dependence of the adhesion strength and abrasion-resistance of silicate render coatings on the content of liquid glass

Renders coating vapour permeability and water permeability slightly depends on the content of the liquid glass. As the content of liquid glass in the paint increases, vapour permeability and water permeability deteriorates slightly (Fig.3).

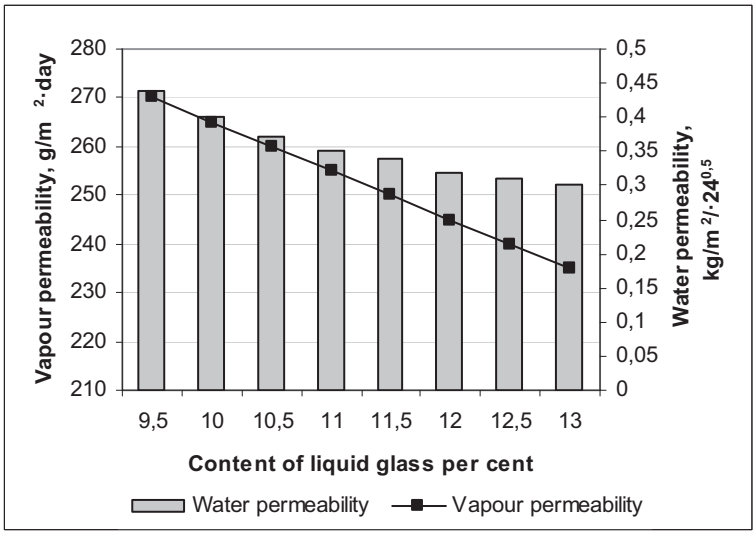

Figure 3. Dependence of water and water vapour permeability of render coatings on the content of liquid glass

However vapour permeability and water permeability of renders coatings can be reduced further through the addition of polymer dispersion, especially when its content in paint is increased to 8 per cent.The results of the tests of dependence of vapour and water permeability on the content of the polymer dispersion is shown in Fig. 4.

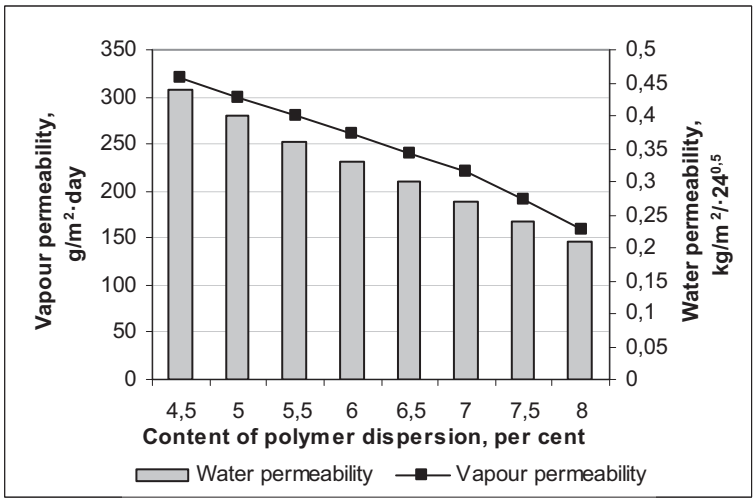

Figure 4. Dependence of water and water vapour permeability of render coatings on the content of polymer dispersion

Renders coating resistance to atmospheric impacts was identified through accelerated ageing using a QUV-spray machine. The chalking of the coatings and other visual changes were assessed after a certain amount of test cycles. The extent of coating chalking after 100 test cycles is shown in Fig. 5.

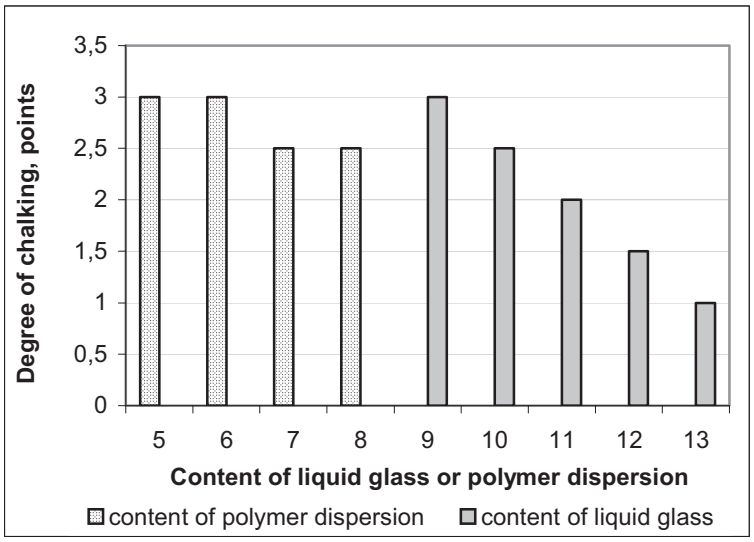

Figure 5. Dependence of chalking of render coatings after 100 test cycles on the content of polymer dispersion or content of liquid glass

It can be seen that after accelerated ageing trials, coatings with higher liquid glass content chalk less. A similar tendency is observed when the polymer dispersion content goes up to 8 per cent. No other visual defects were observed in paint coatings in the process of accelerated ageing.

The aforementioned trials determined dependencies between the content of core components or additives in renders and the properties of the coatings. Given the above dependencies, the formulations of silicate render could be adjusted accordingly to change the coating properties and come up renders with certain special properties.

In the previous work the conditions for development of special silicate dispersive paints were determined (Daunoravičius *et al.* 2010) Such paints were produced by correcting the quantities of the main components of silicate paints (modified binder, fillers, pigments) within the optimal limits and at the same time, significantly changing the main technological properties of paints and operational properties of their coatings, i.e. water and vapour permeability, mechanical strength of dry and wet coating. By analogous correction of the universal composition of the silicate renders and changing its properties, the renders possessing certain extremely high-

quality special properties - like hydrophobia, resistance to mechanical impacts or atmospheric effects, extremely high water vapour permeability - were produced. When generating compositions of such renders the following provision was followed that in order to produce renders with a set special property, it is necessary to maximize (minimize) the content of a component affecting this property without infringing its optimal quantitative relations with the other components of the composition.

Table 5 presents the render compositions characteristic of special properties produced by maintaining optimal quantitative relations of the components. Their properties are provided in Table 6.

Table 5. Special compositions of silicate renders

Component	Renders compositions, masses %					
	SRU	SRW	SRS	SRV	SRC	SRE
Water	7	6	6	7	7	7.5
Liquid glass	10.5	10	12.5	10.5	10.5	10
Polymeric dispersion	6	7	6	5	6	5
Micro-filler 10 µm	12	12	12	12	10	12
Micro-filler 15 µm	18	18	18	18	16	20
Micro-filler (talc)	5	5	5	6	5	5
Fibre micro-filler	0.5	0.5	0.5	0.5	0.5	0.5
Pigment TiO_2	8	8	7	8	4	6
Pigment (Fe, Cr oxides)	-	-	-	-	8	-
Larger filler 1-2 mm	31	30.5	31	31	31	32
Dispergator	0.1	0.1	0.1	0.1	0.1	0.1
Silicate stabilizer	0.3	0.3	0.3	0.3	0.3	0.3
Thickener	1.3	1.3	1.3	1.3	1.3	1.3
Antifoamer	0.2	0.2	0.2	0.2	0.2	0.2
Emulgator	0.1	0.1	0.1	0.1	0.1	0,1
Hydrophobizator	-	1	-	-	-	-

The notations of the render compositions mean the following:
SRU – universal composition
SRW – water-impermeable render
SRS – render of increased strength
SRV – render of increased vapour-permeability
SRC – colour render
SRE – cost efficient render

Table 6. Properties of special silicate renders

Property	Renders compositions, masses %					
	SRU	SRW	SRS	SRV	SRC	SRE
Vapour permeability, $g/m^2 \cdot$per day	260	210	220	410	330	330
Water permeability coefficient w_{24}, $kg/(m^2 \cdot h^{0,5})$;	0.37	0.21	0.25	0.40	0.42	0.44
Resistance to abrasion mg/rpm.	4.18	4.06	3.02	4.29	4.52	4.81
Strength of cohesion with concrete, MPa	1.4	1.5	2.5	1.5	1.4	1.2
Chalking, points	3	2	2	2	3	4
Colour	White	White	White	White	Various	White

CONCLUSIONS

1. By directional correction of the universal composition of the silicate render within the limits of the optimal quantitative relations of the components the special renders characteristic of one extremely high-quality property have been produced. Such renders are designated for the use in cases of complicated environmental and operational conditions.

2. Renders with one single exceptionally well-distinguished property of the coat, like hydrophobia, resistance to mechanical impacts, water vapour permeability can be produced by increasing (reducing) the content of the component that determines that property, or through the addition of additives. An addition of 1 per cent of hydrophobic agent and the polymer dispersion content was increased up 7 per cent produced highly waterproof render (w_{24} = 0.21 kg/($m^2 \cdot h^{0,5}$), when the liquid glass content was raised to 12.5 per cent, the paint became resistant to abrasion (4.18 mg/rpm.). Render with better water vapour permeability qualities (410 g/m^2·per day) was produced by dropping the liquid glass content to 10.5 per cent and the polymer dispersion content to 5 per cent. On top of that, 8 per cent of mineral pigment added resulted in coloured render, and by adding 20 per cent of cheaper filling produced the render became more cost-efficient.

REFERENCES

Ailer, R.1982. The Chemistry of Silica. Part 1. Mir, Moscow, 1982. 424 p. (in Russian).

Daunoravičius, M., Bieliūnienė, V., Ragauskienė, A., Smetonaitė, E. 2011. Optimization of external renders formulations based on liquid glass. In: Book of abstracts of the 20th International Conference Materials Engineering 2011, Kaunas, Lithuania, 2011.

Daunoravičius, M., Smetonaitė, E., Norvaišienė, R. 2011. Formulation of efficient silicate disperse paints. In: Proceedings of the Final Conference of the COST Action C25, Insbruck, 2011 / editors: L. Bragança, H. Koukkari, R. Blok, H. Gervásio, M. Veljkovic, R.P. Borg, R. Landolfo, V. Ungureanu, C. Schaur. Malta: University of Malta, 2011. 87-96.

Daunoravičius, M., Bieliūnienė, V., Ragauskienė, A., Smetonaitė, E. 2010. Analyses of Special Silicate Paints. Chemical Technology, 1 (54) 2010. 19-27 (in Lithuanian).

Daunoravičius, M., Bieliūnienė, V., Ragauskienė, A., Smetonaitė, E., Klovas, A. 2010. Special silicate disperse paints: formulation, production and properties. In: Proceedings of the 2nd International Conference Advanced Construction, Kaunas, Lithuania, 2010. 113-121.

Korneev, V.I., Danilov V.V. 1991. Production and Use of Liquid Glass. Stroiizdat, Leningrad, 1991. 177 p. (in Russian).

Lotov, V.A. 2007. Nanodisperse Systems in Construction Material and Product Technology. Izviestija Tomskogo politechniczieskogo instituta, 311 (3) 2007. 84-88 (in Russian).

Margraf, R., Könner, W. 1998. Dispersive Silicate Paints and Their Properties. Farbe + Lack, 104 (8) 1998. 64-75 (in German).

Wagner, O. 1993. Fillers for Dispersive Silicate Paints. Farbe + Lack , 9 1993. 773-777 (in German).

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Recycled Aggregate Concrete with Fluorescent Waste Glass and Coal/Wood Ash Concrete Wastes

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EXTENDED ABSTRACT

Concrete as a primary building construction material is the most consumed man-made material in the world and also is one of the most consuming landfills waste materials. Production of cement (hydraulic binder) is an energy-intensive and highly polluting process which contributes about 5-8% to global CO_2 emissions and accounts for 3% of total (5% of industrial) energy consumption worldwide. The aggregates constitute approximately 80% of concrete volume. The disposal of the construction and demolition (C&D) waste is becoming increasingly difficult and expensive and also environmental concerns are increasingly limiting the option of landfilling such waste. Recycled aggregate is a valuable resource; value-added consumption of recycled aggregate, as replacement for virgin aggregate in concrete, can yield significant energy and environmental benefits. Glass is also one of the most popular materials due to progressive growth of urbanization nowadays. Disposal of glass waste and especially of non-recycled waste glass is a complex problem for many countries in the world. Waste glass as powder milled to certain surface specific area in order to accelerate beneficial chemical reactions in concrete offers desired chemical composition and reactivity for use it as a supplementary cementitious material (SCM) for enhancing the chemical stability, pore system characteristics, moisture resistance and durability of concrete. The beneficial effects of milled waste glass can enhance the residual cement occurring on the surface of recycled aggregates, thus improving the performance characteristics of recycled aggregate concrete (Nassar and Soroushian, 2012).

In present study is investigated the approach of optimized utilization of concrete aggregate wastes (CAW) in concrete. An experimental study was carried out to investigate the effects on the mechanical properties of concrete with CAW obtained from crushed concrete specimens (from previous studies with cement substitution at level of 30% with waste borosilicate (DRL) glass chippings obtained from fluorescent lamps and ground into powder with specific surface area of 2310 cm^2/g, waste glass suspension and coal/wood ashes (Kara, 2012)) after they have been stored as concrete waste. A total of 15 different concrete mixes were prepared. Concrete cubes' strength tests were carried out after 7, 28, 56, 84 and 112 days. Three sets of experiments were hold (substitution of natural aggregates at level of 100%, 50% and 50% +plasticizer). Recycled aggregates from concrete specimens with known mix composition have performed good mechanical strength results in comparison to control ones. The best obtained result was for the mixes with wood ash 68 MPa and waste fluorescent glass suspension CAW of 74 MPa.

Keywords: fluorescent waste glass suspension, coal/wood ash, recycled concrete aggregate waste.

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REFERENCES

Kara, P., Korjakins, A. 2012. Concrete with fluorescent waste glass suspension. In: Proceedings of 8th International Conference: Concrete in the Low Carbon Era 2012, Dundee, UK. (in press)

Kara, P., Korjakins, A., Kovalenko, K. 2012. The Usage of Fluorescent Waste Glass Powder in Concrete. Scientific Journal of Riga Technical University, Construction Science, 13 vol., 26-32.

Nassar, Roz-Ud-Din, Soroushian, P. 2012. Srength and durability of recycled aggregate concrete containing milled glass aspartial replacement for cement. Construction and Building Materials. 29. 368-377.

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Investigation of Thermal Properties of Cement Paste with Fluorescent Waste Glass and Coal/Wood Ashes

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EXTENDED ABSTRACT

The world is facing an unprecedented challenge to reduce emissions of greenhouse gases, such as CO_2, to limit global warming and climate change. Cementitious materials have a big role to play in assuming a sustainable future. Cementitious materials, mainly concrete, are by far and away the most used materials on earth. Every year about 1.5m^3 (3 tonnes) is produced for every person on the planet. This success is due to the widespread availability of the raw materials, its low cost and flexibility (Scrivener, 2012). Recycling is an important environmental and economical alternative for each material class, mainly for those that don't decompose easily in nature, such as glasses – not decomposed by microbial nor by atmospheric precipitation for thousand years (Delben et al., 2007). Finely ground waste glass having a particle size finer than 38 μm have pozzolanic behaviour and concrete containing ground glass exhibits a higher strength at both the early and late ages compared to fly ash concrete (Shao et al., 2000). Sahayan and Xu (2004) mentioned that fine glass powder could replace up to 30% of Portland cement. Within last decade most of research was carried out on utilization of waste glass (mostly cullet) in concrete as fine and coarse aggregates, mostly on mechanical properties of concrete, but only little research was carried out on the thermal properties of such concrete (Poutos et al., 2008). The present research intends to evaluate the influence of local industrial wastes such as fluorescent waste glass powder/suspension, bottom/fly coal/wood ashes on the thermal properties of a hydrating cement paste specimens. Hydration heat of cement paste mixes was tested in the room with temperature (20 ± 2)°C, cement paste mixes were cast in demountable 100x100x100 mm formworks made of textolite, afterwards a glass tube with a T-type thermocouple was placed in the centre of each test specimen in order to take measurements of temperature (thermocouple was connected to a data transmitting device and computer), after formworks were placed into a metal box and insulated with 30 mm thick polystyrene foam. The temperature at the centre of each concrete specimen was continuously monitored at least up to 20 h after production in the ambient environment of 20±2°C. The results showed that cement paste substitution with wastes like borosilicate and leaden silicate waste glass, coal/wood bottom ashes at level of 30% have significant influence on peak temperatures with decrease from 68.3°C to 43.3°C that is quite reasonable for building massive concrete structures.

Keywords: fluorescent waste glass, fly ash, bottom ash, cement paste, thermal properties

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REFERENCES

Delben, A. A. S. T., Menezes, Delben, F. L., J. R., Coelho, M. B., Ribeiro, R. F. 2007. Effect of glass cullet on thermal properties of kaolinite. Journal of Thermal Analysis and Calorimetry, Vol. 87, 3, 879–882

Poutos K.H., Alani A.M., Walden P.J., Sangha C.M. 2008. Relative temperature changes within concrete made with recycled glass aggregate. Construction and Building Materials 22, 557–565

Sahayan A, Xu A. 2004. Value-added utilization of waste glass in concrete. Cem Concr Res 34:81–89. doi:10.1016/S0008-8846(03)00251-5

Shao Y, Lefort T, Moras S, Rodriguez D. 2000. Studies on concrete containing ground waste glass. Cem Concr Res 30:91–100. doi:10.1016/S0008-8846(99)00213-6

Skrivener, K. 2012. Nanoscience for sustainable cementitious materials. Proceedings of 40th ICT Convention/Symposium 22nd March 2012, 27-34.

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Octacalcium Dihydrogen Orthophosphate Pentahydrate: Formation, Stability and Influence on Standard Properties of Portland Cements

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Abstract. Acid phosphates are the main harmful impurity of phosphogypsum limiting it utilization on industry of building materials. The present work describes a study formation and stability of octacalcium dihydrogen orthophosphate pentahydrate {$Ca_8H_2(PO_4)_6 \cdot 5H_2O$ or $Ca_8(HPO_4)_2(PO_4)_4 \cdot 5H_2O$} from H_3PO_4 and $Ca(OH)_2$. It forms in acid medium (pH ≥ 5,3) and by then it is closer to the dicalcium hydrogen orthophosphate dihydrate ($CaHPO_4 \cdot 2H_2O$), formation pH ≤ 4,7 but according to state material (x-ray pattern) it is very similar to the calcium phosphates group of hydroxyapatite {$Ca_{10}(PO_4)_6(OH)_2 \cdot nH_2O$; $Ca_3PO_4 \cdot mH_2O$ and $Ca_{10-x}(HPO_4)_x(PO_4)_{6-x}(OH)_{2-(0<x<1)} \cdot 3\text{-}4{,}5\ H_2O$} (formation pH = 6,5-11) and this state is stability in alkalis medium. W/C, setting times and volume stability of Portland cements CEM I and CEM II pastes, as well as compressive and flexural strengths of cement mortars with $Ca_8H_2(PO_4)_6 \cdot 5H_2O$ (1.09 % and 2.18 % P_2O_5 counted to gypsum) were evaluated. Compressive strength was 3-5 % less and setting time was 20-30 min longer of cements with this additive.

Keywords: calcium phosphates, synthesis, $Ca_8H_2(PO_4)_6 \cdot 5H_2O$, Portland cements

INTRODUCTION

Phosphogypsum is a by-product of the phosphoric acid industry and consists of 65-70 % gypsum, 25-30 % water and 5-10 % impurities, i.e. phosphoric acid and its salts, hydrofluoric acid and its compounds, R_2O_3 (Al_2O_3 + Fe_2O_3), quartz, apatite, alkali, organic matter, and others. The P_2O_5 and F impurities are found in three different forms: on the surface of gypsum crystals as water soluble compounds (H_3PO_4, $Ca(H_2PO_4)_2 \cdot H_2O$, H_2SiF_6), substituted in the lattice of gypsum crystals (effectively solid solutions of $CaHPO_4 \cdot 2H_2O$, $SrSO_4$ or Na_2SiF_6) and as insoluble compounds, i.e. apatite and quartz. These impurities, particularly hydrofluoric acid and its salts, contaminate an environment. Soluble phosphates {H_3PO_4 and $Ca(H_2PO_4)_2 \cdot H_2O$} and soluble fluorides had maximum influence on the fall of compressive strength of Portland cement and plaster [Tabikh and Miller, 1971; Ivanickij *et al.* 1990; Metha and Brady, 1977; Lutz, 1994; Wirsching, 1981]. $CaHPO_4 \cdot 2H_2O$ had small influence, but with the present of $Ca(OH)_2$ it had great influence on the plaster properties [Wirsching, 1981; Singh, 1993; Berry, 1972; KNAUF, 1978; Stonis *et al.* 1984; Wirsching, 1978; Beretka *et al.* 1981; Beretka *et al.* 1982]. The most impurities in phosphogypsum can be found in the particle size fractions above 160 and below 25 µm. There are more than few plants (those of "Onoda" in Japan, "Giulini chemic GmbH", "Knauf" in Germany, etc.) where the impurities are eliminated by washing phosphogypsum with water or separating of coarse and very fine particles. Up to 4 m^3 of water is necessary for 1 ton of phosphogypsum. The phosphogypsum admixtures are also eliminated by using a combined method when phosphogypsum is washed with a smaller amount of water, and the rest of the acid admixtures are neutralized by adding the following additives: $Ca(OH)_2$, $CaCO_3$, K_2CO_3, KOH, Portland cement, NH_4OH, etc. [Wirsching, 1981; Singh, 1993; Berry, 1972; KNAUF, 1978; Stonis *et al.* 1984]. The acid impurities are not fully eliminated from the phosphogypsum crystals [Ivanickij *et al.* 1990]. Actually, in all technologies applied for the processing of phosphogypsum into the gypsum, binder wet processing are used for the elimination or neutralization of impurities [Van Wezer, 1962; Beretka, 1982; Kaziliunas, 1983; Olmez and Erdem, 1988; Singh, 2000; Singh, 2003; Singh, 2005; Singh, 2002; Potgieter *et al.*2003; Kaziliunas *et al.* 2006; Singh *et al.* 1996; Degirmenci, 2008; Erdogan *et al.* 1994; Altun and Sert, 2004]. In such cases the great amount of water must be eliminated by evaporation. All these operations for prepare of phosphogypsum considerably increases the energetic expenditure, and the obtained product turns to be incompetitive to natural gypsum stone. On the other hand, as new bioceramics for bone regeneration calcium silicate (b-$CaSiO_3$, b-CS) ceramics has received a great deal of attention. The remarkable biocompatibility and osteoconductivity of calcium phosphate bioceramics has made them attractive materials with great potential for the repair of bone defects resulting from congenital deformity correction, injury, trauma, etc. As an important representative, b-tricalcium phosphate (b-$Ca_3(PO_4)_2$, b- TCP), with a similar chemical composition to the mineral component of bone, has been used as a scaffold for bone regeneration. However, although pure b-TCP bioceramics are

osteoconductive, they lack the ability to stimulate cell differentiation and bone regeneration, which impede their wider clinical application [Viswanath *et al.* 2010; Tamimi *et al.* 2012; Combes and Rey, 2010; El Briak *et al.* 2008; Ginebra *et al.* 2010; Suzuki, 2010; Tandier *et al.* 2011; Carrodeguas and Aza, 2011; Dorozhkin, 2010]. In medicine octacalcium dihydrogen orthophosphate pentahydrate {$Ca_8H_2(PO_4)_6{\cdot}5H_2O$ or $Ca_8(HPO_4)_2(PO_4)_4{\cdot}5H_2O$} has been prepared from $Ca(NO_3)_2$ and $(NH_4)_2HPO_4$ solutions [Combes and Rey, 2010; Dorozhkin, 2010].

The aim is the determining of the principal possibilities preparation of phosphogypsum for cement industry escaping wet processing. In chemical factory of Kedainiai F ion tied to aluminum fluoride, and the main harmful impurities phosphogypsum becomes acidic phophates. The maximum amount of their - 1.09 % P_2O_5. For precaution of research, the amount is doubled (2.18 %). The present work describes a study formation and stability of octacalcium dihydrogen orthophosphate pentahydrate {$Ca_8H_2(PO_4)_6{\cdot}5H_2O$ or $Ca_8(HPO_4)_2(PO_4)_4{\cdot}5H_2O$} from H_3PO_4 and $Ca(OH)_2$. W/C, setting times and volume stability of Portland cements CEM I and CEM II pastes, as well as compressive and flexural strengths of cement mortars with $Ca_8H_2(PO_4)_6{\cdot}5H_2O$ (1.09 % and 2.18 % P_2O_5 calculated to gypsum) were evaluated.

METHODS

MATERIALS. Orthophosphoric acid and $CaCO_3$ have been used quality "analytical grade". CaO has been produced while burning the "C" (clean) mark $Ca(OH)_2$ at the temperature of 900 ^oC for 2 h.

Cement testing materials - according EN 196-1 and EN 196-2.

Portland cements - of JSC "Akmenes cementas", Lithuania

Table 1. Composition of Portland cements, %

Portland cement	C_3S	C_2S	C_3A	C_4AF	Lime	MgO	Alkalis	Quartz	Calcite	SO_3
CEM I 42.5 N	63.6	5.8	3.9	12.6	1.1	3.6	0.78	0.9	3.4	2.6
CEM I 42.5 R	63.3	8.2	4.2	12.7	0.8	3.8	0.8	0.6	2.2	2.9
CEM II/A-L 42.5 N	54.6	6.7	3.7	12.3	0.62	3.4	0.64	0.6	12,2	2.8
CEM II/A-LL 42.5 R	53.2	8.3	4.0	10.5	0.95	3.4	0.6	1.0	14.2	2.7

Table 2. Standart properties of Portland cements

Portlandcement	W/C	Setting time, min		Compressive strength, N/mm^2 after		Soundness, mm
		initial	finish	2 (7) days	28 days	
CEM I 42.5 N	0.27	180	250	(19)	47	2
CEM I 42.5 R	0.28	170	230	23	51	4
CEM II/A-L 42.5 N	0.26	210	270	(17)	45	2
CEM II/A-LL 42.5 R	0,282	180	260	22	48	3

EQUIPMENT. The following equipment has been used in the testing: a magnetic mixer MM, an universal-purpose ionometer EV-74, X-ray powder diffraction (XRD) data were collected with a DRON-6 X-ray diffractometer with Bragg–Brentano geometry using Cu Kα radiation, operating with thevoltage of 30 kV and emission current of 20 mA and testing equipment - according EN 196-1 and EN 196-2.

METHODS. Synthesis of $Ca_8H_2(PO_4)_6{\cdot}5H_2O$ or $Ca_8(HPO_4)_2(PO_4)_4{\cdot}5H_2O$: stoichiometry CaO was hydrated 30 min. in distillated water with mixing suspension and pouring of H_3PO_4 solution 25-30 min. After mixing 40 min. the suspension was filtered and drayed at 40 ^oC. Quantity of $Ca_8H_2(PO_4)_6{\cdot}5H_2O$ added to Portland cements had been calculated by SO_3 stock in cement and 1.09 % or 2.18 % P_2O_5 in gypsum.

RESULTS AND DISCUSION

Formation of octacalcium dihydrogen orthophosphate pentahydrate {$Ca_8H_2(PO_4)_6{\cdot}5H_2O$ or $Ca_8(HPO_4)_2(PO_4)_4{\cdot}5H_2O$} from H_3PO_4 solution and $Ca(OH)_2$ suspension is alike to formation of calcium orthophosphates of the hydroxiapatite group {$Ca_3(PO_4)_2{\cdot}nH_2O$, $Ca_5OH(PO_4)_3{\cdot}mH_2O$, etc.} [Stonis *et al.* 1984; Kaziliunas, 1983; Kaziliunas *et al.* 2006]. The first phase of the reaction is x-ray amorphous colloidal material [Kaziliunas, 1983; Dorozhkin, 2010]. Location of this material determines speed and direction of the reaction [Kaziliunas, 1983]. When a flow of CaO is more what a flow of P_2O_5 (pH alkaline) the colloidal material is formed in the solution far from the lime surface. It crystallizes into octacalcium dihydrogen orthophosphate pentahydrate $Ca_8H_2(PO_4)_6{\cdot}5H_2O$ (curve 3 Fig. 1 and Fig. 2) without interrupting the process of lime dissolving:

$$6H_3PO_4 + 8Ca(OH)_2 + mH_2O \rightarrow Ca_8H_2(PO_4)_6{\cdot}5H_2O + nH_2O \quad (1)$$

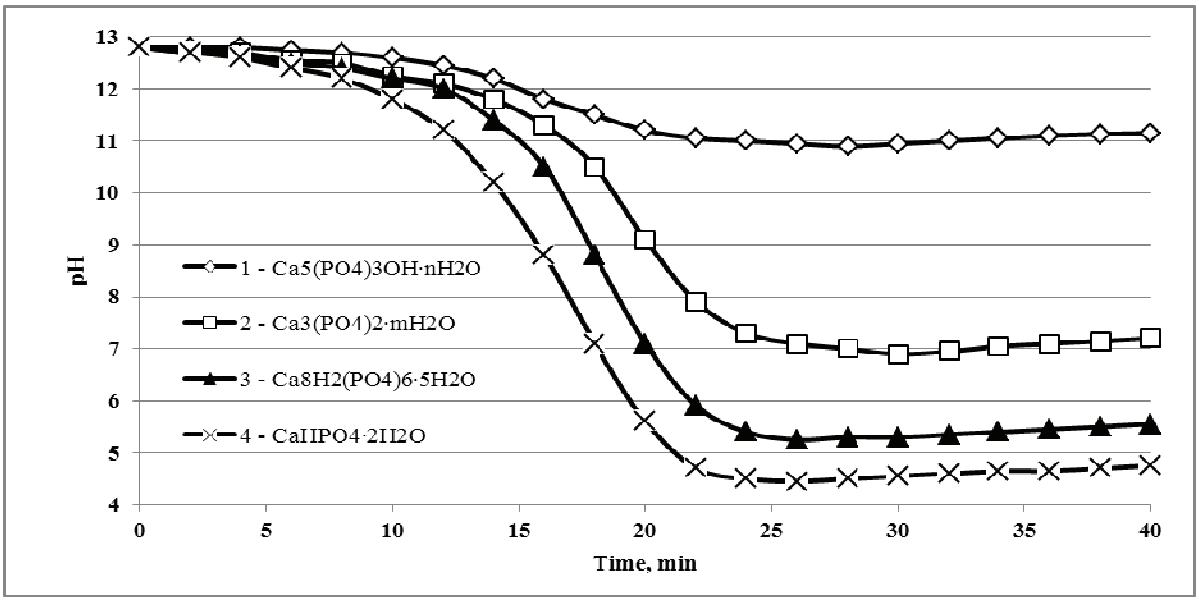

Figure 1. The kinetic of the alteration pH suspensions of stoichiometry components by pouring of 18 % H_3PO_4 solution into 5-10 % lime suspension for 25-30 min. and x-ray pattern of hard phase after 40 min (Fig. 2): 1 - $Ca_5OH(PO_4)_3 \cdot mH_2O$, 2 - $Ca_3(PO_4)_2{\cdot}nH_2O$, 3 - $Ca_8H_2(PO_4)_6{\cdot}5H_2O$, 4 - $CaHPO_4{\cdot}2H_2O$

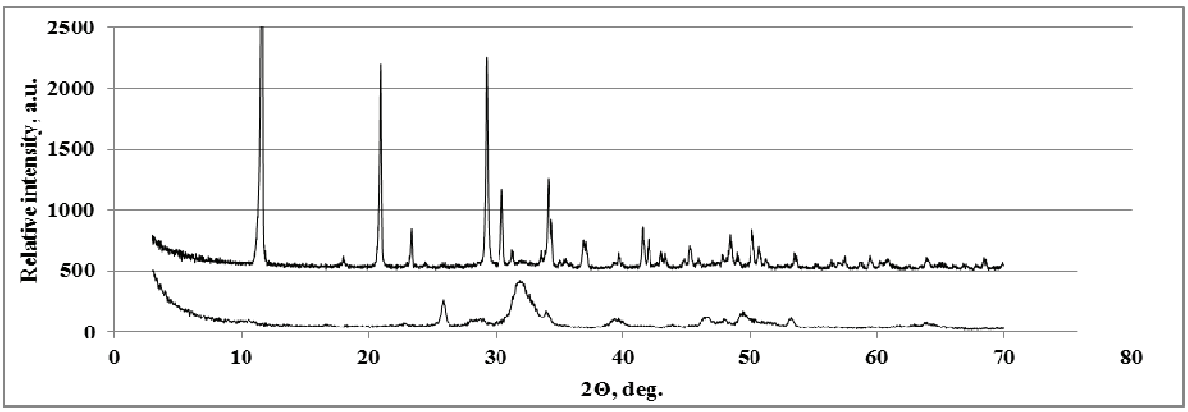

Figure 2. X-ray diffraction patterns of octacalcium dihydrogen orthophosphate pentahydrate $Ca_8H_2(PO_4)_6{\cdot}5H_2O$ – curve 1 and calcium hydrogen phosphate $CaHPO_4{\cdot}2H_2O$ – curve 2

X-ray paterns of octacalcium dihydrogen orthophosphate pentahydrate {$Ca_8H_2(PO_4)_6{\cdot}5H_2O$ or $Ca_8(HPO_4)_2(PO_4)_4{\cdot}5H_2O$} and calcium orthophosphates of hydroxyapatite group {$Ca_3(PO_4)_2{\cdot}nH_2O$, $Ca_5OH(PO_4)_3 \cdot mH_2O$} are identical.

And, on the contrary, if the concentration of dissolved CaO is smaller than the concentration of P_2O_5, the place of the formation of x-ray amorphous calcium orthophosphate comes closer to the lime surface. The colloidal new combinations clothe the lime particles with the layer, which is stable in the alkaline medium thus not allowing their free dissolving. The suspension pH moves to the acid side. Under such conditions, x-ray amorphous calcium orthophosphate crystallizes into calcium hydrogen phosphate ($CaHPO_4{\cdot}2H_2O$) (curves 1, 2, 4 of Fig. 3 and Fig. 4) thus releasing the lime particles from the colloidal cloth. The lime starts dissolving freely, and the suspension pH suddenly increases. The decrystallized calcium hydrogen phosphate crystals in the alkaline lime medium pass into octacalcium dihydrogen orthophosphate pentahydrate. However, this process is about 50 times slower than the direct one:

$$H_3PO_4 + Ca(OH)_2 + mH_2O \rightarrow CaHPO_4{\cdot}2H_2O + nH_2O \quad (2)$$

$$6CaHPO_4{\cdot}2H_2O + 2Ca(OH)_2 + mH_2O \rightarrow Ca_8H_2(PO_4)_6{\cdot}5H_2O + nH_2O \quad (3)$$

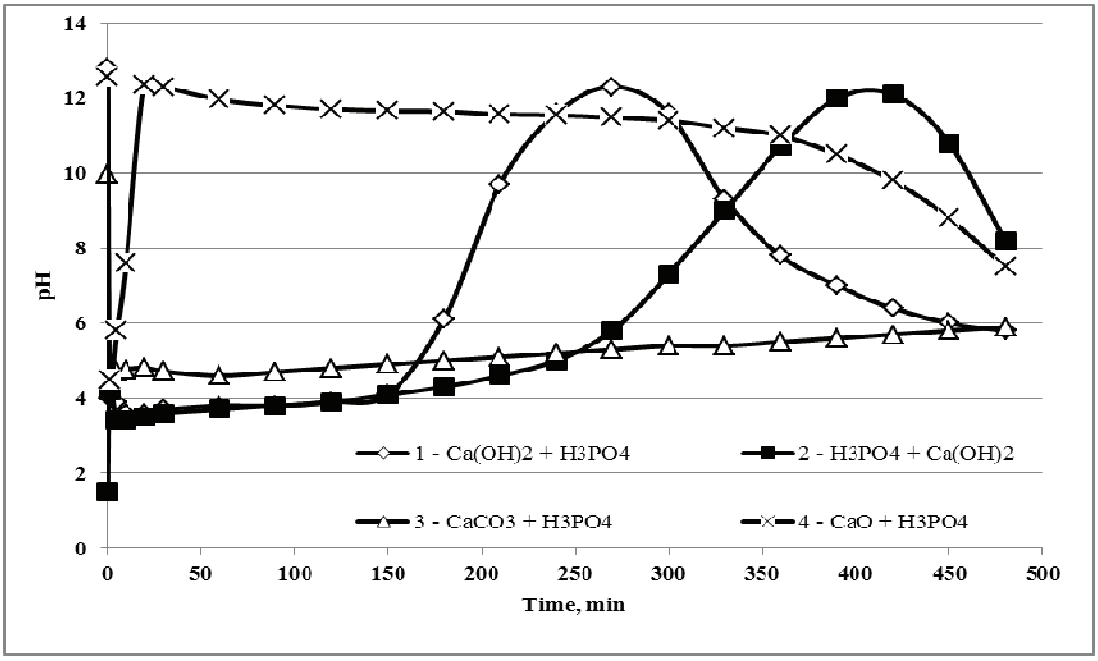

Figure 3. The kinetic of the alteration pH suspensions of stoichiometry components to prepare $Ca_8H_2(PO_4)_6{\cdot}5H_2O$ after swift pouring of 18 % H_3PO_4 solution into 8 % lime suspension (1 and 4 curves) or conversely (2 curve). 3 - 18 % H_3PO_4 solution into 8 % $CaCO_3$ suspension (quantity of $CaCO_3$ was 1.5 time more stoichiometry $Ca_8H_2(PO_4)_6{\cdot}5H_2O$)

X-ray diffraction pattern of reaction products after mixing 450 min. H_3PO_4 with lime and with $CaCO_3$ are presented in Fig. 4.

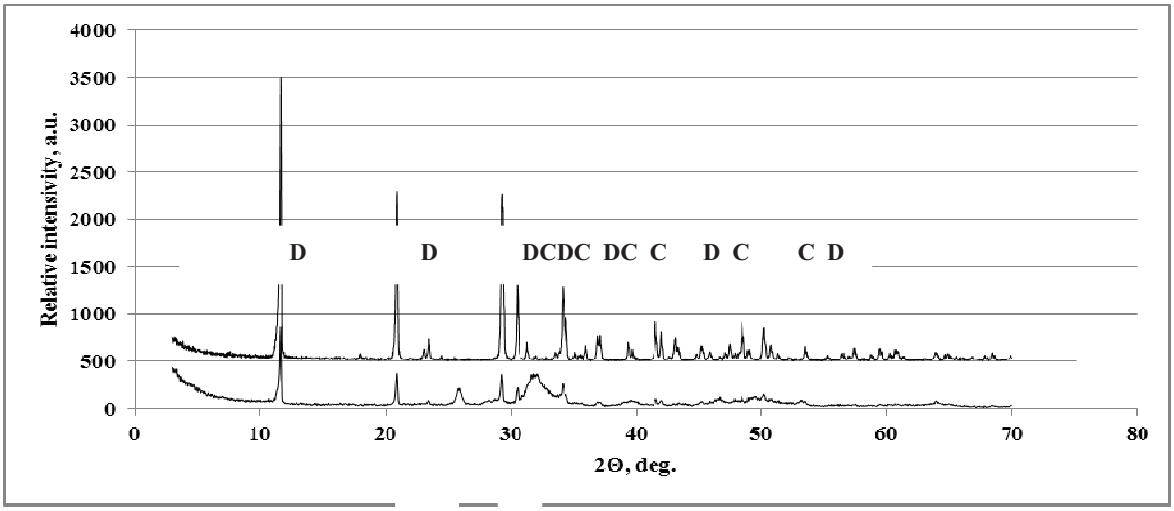

Figure 4. X-ray diffraction pattern of reaction products H_3PO_4 with lime after mixing 450 min. – 1 and with $CaCO_3$ – 2: D - $CaHPO_4{\cdot}2H_2O$, C - $CaCO_3$, O - $Ca_8H_2(PO_4)_6{\cdot}5H_2O$ (curve 1)

In reaction of $CaCO_3$ with H_3PO_4 (curve 3 of Fig. 3) was formed only $CaHPO_4{\cdot}2H_2O$ (curve 2 of Fig. 4). Reaction of $CaHPO_4{\cdot}2H_2O$ with CaO or $Ca(OH)_2$ without mixing continued yet longer (Fig. 5).

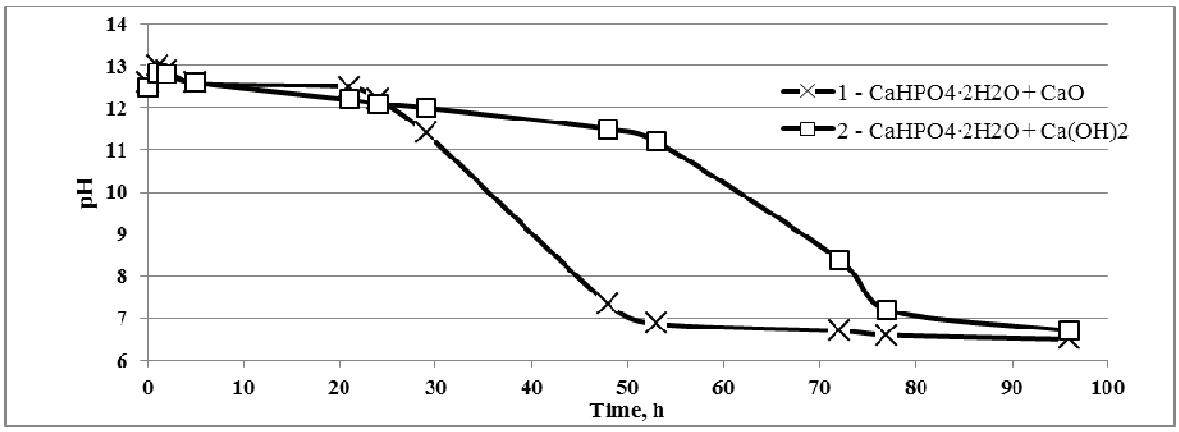

Figure 5. The kinetic of the alteration pH suspensions of stoichiometry components to prepare $Ca_8H_2(PO_4)_6 \cdot 5H_2O$ from $CaHPO_4 \cdot 2H_2O$ suspension and CaO or $Ca(OH)_2$ suspension without mixing

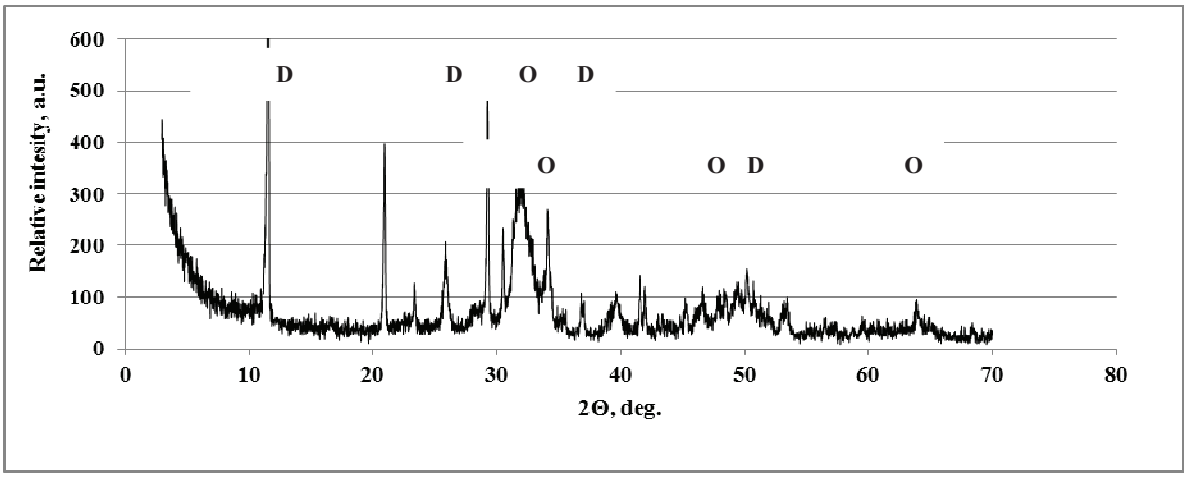

Figure 6. X-ray diffraction pattern solid phase of reaction $CaHPO_4 \cdot 2H_2O$ with CaO after 90 h without mixing: D - $CaHPO_4 \cdot 2H_2O$, O - $Ca_8H_2(PO_4)_6 \cdot 5H_2O$

Influence of $Ca_8H_2(PO_4)_6 \cdot 5H_2O$ on W/C and soundness of Portland cements are presented in Table 3.

Table 3. Influence of $Ca_8H_2(PO_4)_6 \cdot 5H_2O$ on W/C and soundness of Portland cements

P_2O_5, % calculated to gypsum	CEM I 42,5 R		CEM I 42,5 N		CEM II/A-LL 42,5 R		CEM II/A-L 42,5 N	
	W/C	soundness, mm	W/C	soundness, mm	W/C	soundness, mm	W/C	soundness, mm
Without phosphates	0,28	4	0,27	2	0,282	3	0,26	2
1.09	0,28	3	0,267	2	0,28	1	0,265	1
2.18	0,281	2	0,265	1	0,284	1	0,27	1

Additive of $Ca_8H_2(PO_4)_6 \cdot 5H_2O$ have not sensible influence on W/C and soundness of Portland cements.
Influence of $Ca_8H_2(PO_4)_6 \cdot 5H_2O$ on standard strength of Portland cements is presented in Fig. 7.
Influence of $Ca_8H_2(PO_4)_6 \cdot 5H_2O$ on setting time of Portland cements is presented in Fig. 8.

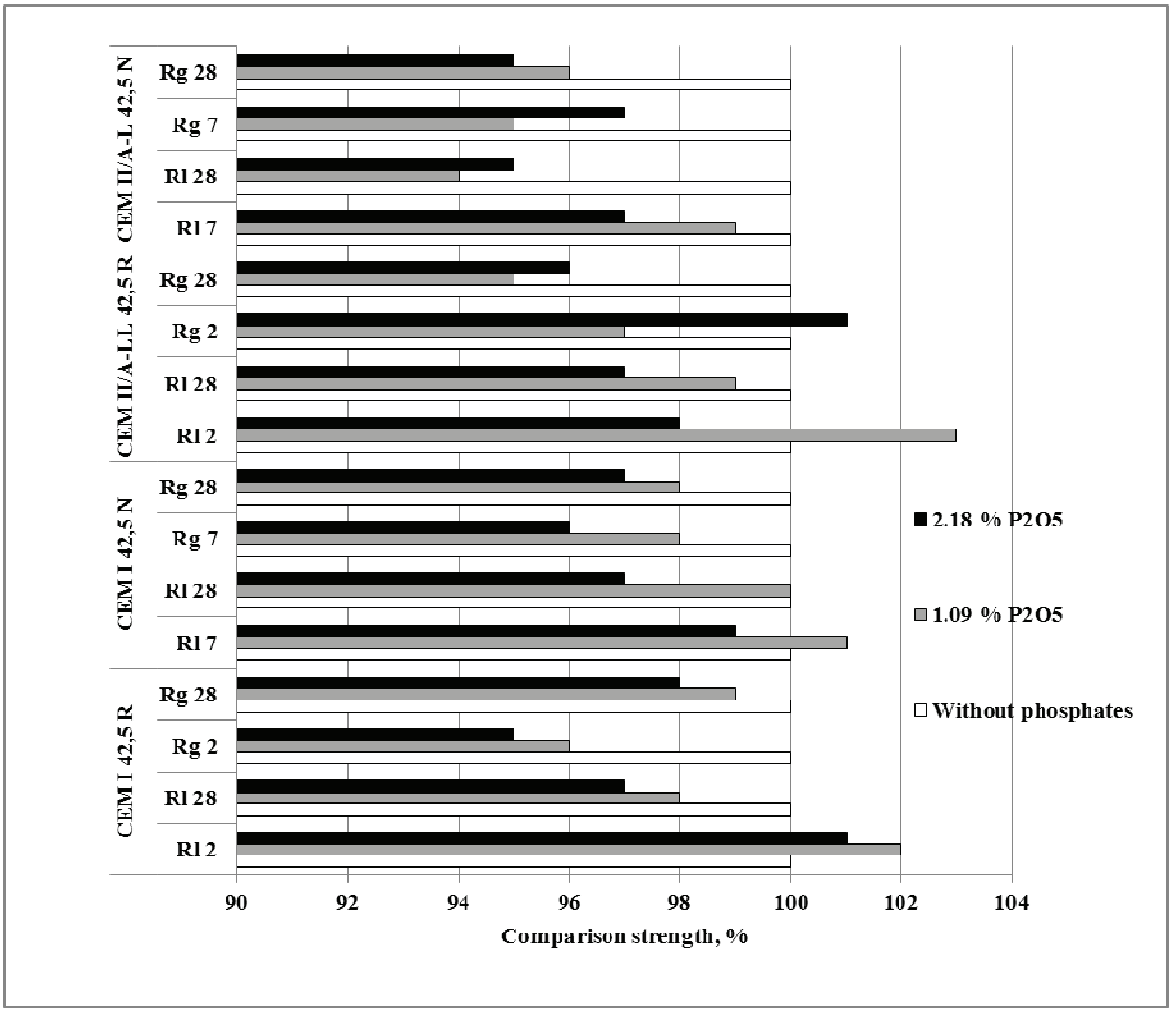

Figure 7. Influence of $Ca_8H_2(PO_4)_6{\cdot}5H_2O$ on standard strength of Portland cements. Rl 2, Rl 7 and Rl 28 – flexural strength after 2, 7 and 28 days; Rg 2, Rg 7 and Rg 28 – compressive strength after 2, 7 and 28 days. Quantity of $Ca_8H_2(PO_4)_6{\cdot}5H_2O$ was calculated to gypsum (SO_3) in Portland cements and P_2O_5 % in gypsum

Compressive strength of Portland cements with additive of $Ca_8H_2(PO_4)_6{\cdot}5H_2O$ (1.09 and 2.18 % P_2O_5) are 3-5 % less of cements without admixture.

Setting time of Portland cements with additive of $Ca_8H_2(PO_4)_6{\cdot}5H_2O$ (1.09 % and 2.18 % P_2O_5 in gypsum) are 20-30 min. longer of cements without admixture.

Portland cements with calcite additive are more sensitive to this admixture.

The obtained data do not fully explain the results and calls for future studies of phosphate and other impurities affect.

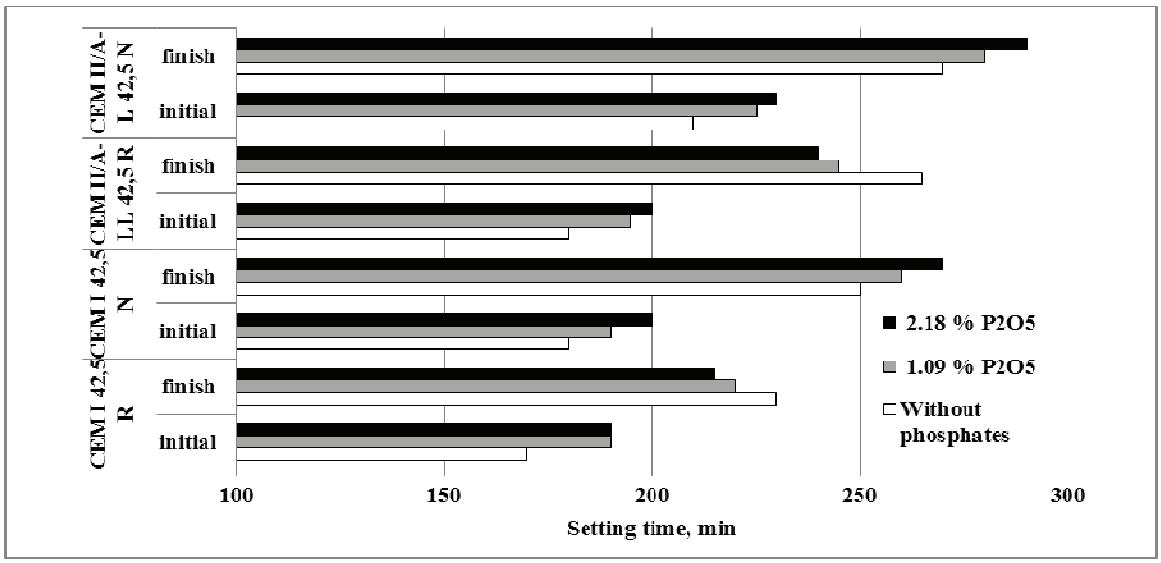

Figure 8. Influence of $Ca_8H_2(PO_4)_6{\cdot}5H_2O$ on setting time of Portland cements. Quantity of $Ca_8H_2(PO_4)_6{\cdot}5H_2O$ was calculated to SO_3 in Portland cements and P_2O_5 % in gypsum

CONCLUSIONS

1. $Ca_8H_2(PO_4)_6{\cdot}5H_2O$ forms in acid medium (pH ≥ 5,3) and by then it is closer to the dicalcium hydrogen orthophosphate dihydrate ($CaHPO_4{\cdot}2H_2O$), formation pH ≤ 4,7 but according to state material (x-ray pattern) it is very similar to the calcium phosphates of hydroxyapatite group {$Ca_{10}(PO_4)_6(OH)_2{\cdot}nH_2O$; $Ca_3PO_4{\cdot}mH_2O$ and $Ca_{10-x}(HPO_4)_x(PO_4)_{6-x}(OH)_{2-(0<x<1)}{\cdot}3\text{-}4{,}5\ H_2O$} (formation pH = 6,5-11) and this state is stability in alkalis medium.

2. Additive of $Ca_8H_2(PO_4)_6{\cdot}5H_2O$ have not sensible influence on W/C and soundness of Portland cements.

3. Compressive strength are 3-5 % less and setting time are 20-30 min. longer of Portland cements with additive of $Ca_8H_2(PO_4)_6{\cdot}5H_2O$ (1.09 % and 2.18 % P_2O_5 in gypsum). Portland cements with calcite additive are more sensitive to this admixture.

REFERENCES

Altun, A.I., Sert, Y. Utilization of wethered phosphogypsum as set retarder in Portland cement. // Cement and Concrete Research 34 2004: pp. 667-680.

Beretka, J., Crook, D. N., King, G. A. Phisico-chemical Properties of By-product Gypsum. // Journal Chem. Tech. Biotechnol. 1981, 31, 151-162.

Beretka, J., Crook, D. N., King, G. A. Effect Calcium Oxide on the Hydration of Calcined By-Product Gypsum. // Journal Chem. Tech. Biotechnol. 1982, 32, 600-606.

Beretka, J., Hydration of Calcium Sulphate Heminydrate in the Presence of Phosphoric Acid and Calcium Oxide: I. The Kinetics of Hydration. J. Chem. Tech. Biotechn. 32 1982: pp. 607-613.

Berry, E.E. Some Observations on the Setting of Calcium Sulphate Hemihydrate Plaster in the Presence of Phosphoric Acid and Hydrated Lime. // Journal appl. Chem. Biotechnol. 1972, 22, 667-671.

Carrodeguas, R.G., De Aza, S. α-Tricalcium phosphate: Synthesis, properties and biomedical applications // Acta Biomaterialia, 7, 2011: pp. 3536-3546.

Combes, C., Rey, C. Amorphous calcium phosphates: Synthesis, properties and uses in biomaterials // Acta Biomaterialia, 6, 2010: pp. 3362–3378.

Degirmenci, N. Utilization of phosphogypsum as raw and calcened material in manufacturing of building products. // Construction and Building Materials: 22, 2008: pp. 1875-1862.

Dorozhkin, S.V. Amorphous calcium (ortho) phosphates // Acta Biomaterialia, 4, 2010: pp. 4457-4475.

El Briak-BenAbdeslam, H., Ginebra, M.P., Vert, M., Boudeville, P. Wet or dry mechanochemical synthesis of calcium phosphates? Influence of the water content on DCPD–CaO reaction kinetics // Acta Biomaterialia, 4, 2008: pp. 378–386.

Erdogan, Y., Demirbas, A., Genc, H. Party-refined chemical by-product gypsum as cement additives. // Cement and Concrete Research 24, 1994: pp. 601-604.

Ginebra, M.P., Espanol, M., Montufar, E.B., Perez, R.A., Mestres, G. New processing approaches in calcium phosphate cements and their applications in regenerative medicine. // Acta Biomaterialia, 6, 2010: pp. 2863–2873.

Ivanickij, V.V., Klassen, P.V., Novikov A.A. and other. 1990. Фосфогипс и его использование [Phosphogypsum and it utilization]. Moskva, Chimija, 1990: 222 p. (in Russian).

Kaziliunas A., Разработка технологии нейтрализасции фосфогипса и изготовления быстро твердеющих гипсоцементнопуццолановых вяжущих [Preparation of Technology for Phosphogypsum Neutralization and Reseption of Quicly Hardening Gypsum-Cement- Pucolanic Binders. Doctor tesis. Kaunas, 1983. 23 p. (in Russian).
Kaziliunas, A., Leskeviciene, V., Vektaris, B., Valancius, Z. The Study of Neutralization of the Dihydrate Phosphogypsum Impurities. Ceramics–Silikaty 50 (3) 2006: pp. 178-184.
Getting Rid of Phosphogypsum – III. Conversion to Plaster and Plaster Products // Phosphorus and Potassium, 1978, Nr. 94, pp. 24-39.
Lutz, R. Preparation of Phosphoric Acid Waste Gypsum for Further Processing to Make Building Materials. Zement, Kalk, Gips 12 1994: pp. 98-102.
Mehta, P.K., Brady, J.R. 1977. Utilization of phosphogypsum in portland cement industry. // Cement and Concrete Research 5, 1977: pp.537-544.
Olmez, H., Erdem, E. The effects of phosphogypsum on the setting and mechanical properties of Portland cement and trass cement. // Cement and Concrete Research 19, 1989: pp. 377-384.
Olmez, H., Yilmaz, V.T. Infrared study on the refinement of phosphogypsum for cement. // Cement and Concrete Research 18, 1988: pp.449-454.
Potgieter J.H., Potgieter S.S., McCrindle R.I., Strydom C.A. An investigation into the affect of varous chemical and physical treatment of South African phosphogypsum to render it suitable as a set retatder for cement. Cement and Concrete Research 33 2003: pp. 1223-1227.
Singh, M. Purifying phosphogypsum for building manufacture. // Construction and Building Materials: 7, 1993:pp. 3-7.
Singh, M. Influence of blended gypsum on the properties of Portland cement and Portland slag cement. // Cement and Concrete Research 30, 2000: pp.1185-1188.
Singh, M. Treating Waste Phosphogypsum for Cement and Plaster Manufacture. Cement and Concrete Research 32 2002: pp. 1033-1038.
Singh, M. Effect of Phosphatic and Fluoride Impurities of Phosphogypsum on the Properties of Selenite Plaster. Cement and Concrete Research 33 2003: pp. 1363-1369.
Singh, M. Role of Phosphogypsum Impurities on strength and microstructure of Selenite Plaster. Construction and Building Materials, 19, 2005: pp.480-486.
Singh, M., Garg, M., Verma, C.L., Handa, S.K., Kumar, R. An improved process the purification of phosphogypsum. // Construction and Building Materials, 10, 1996: pp. 597-600.
Stonis, S., Kaziliunas, A., Bacauskiene, M. Строительный гипс из фосфогипса. Технология изготовления и перспективы развития [Plaster of Paris from Phosphogypsum: Its Obtaining Technology and the Perspective for the Development of Production]. Building Materials 3 1984: pp. 9-11 (in Russian).
Suzuki, O. Octacalcium phosphate: Osteoconductivity and crystal chemistry // Acta Biomaterialia, 6, 2010: pp. 3379–3387.
Tabikh, A.A., Miller, F.M. 1971. The nature of phosphogypsum impurities and their influence on cement hydration. // Cement and Concrete Research 6, 1971: pp. 663-678.
Tadier, S., Le Bolay, N., Rey, C., Combes, C. Co-grinding significance for calcium carbonate–calcium phosphate mixed cement. Part I: Effect of particle size and mixing on solid phase reactivity // Acta Biomaterialia, 7, 2011: pp. 1817-1826.
Tamimi, F., Sheikh, Z., Barralet, J. Dicalcium phosphate cements: Brushite and monetite // Acta Biomaterialia, 8, 2012: pp. 474-487.
Van Wazer J. R., Фосфор и его соединения. [Phosphorus and its compounds]. Volume I: Chemistry. (in Russian), Moskva, 1962: pp. 374-461.
Viswanath, B., Shastry, V.V., Ramamurty, U., Ravishankar, N. Effect of calcium deficiency on the mechanical properties of hydroxyapatite crystals // Acta Materialia, 58, 2010: pp. 4841–4848.
Wirsching, F. The Knauf Phosphogypsum Processes. TIZ - Fachberichte Rohstoff-Engineering 105 1981: pp. 382-389.
Wirsching, F. Lime Sensitivity - a Characteristic of the Phosphoric Acid - By-product Gypsum. Mater. Constr. 11 1978: pp. 62-64.

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High Efficiency Porous Ceramics for the Production of Insulation Buildings Materials

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Abstract. Marketable building materials such as heat insulation materials have significant impact on the environment both at stage of exploitation and at stage of utilisation after exploitation. Nowadays the improvement of energy and environmental performances are relevant targets as the building sector is strategically important for achieving sustainability. Development of new ecological insulation materials manufactured from domestic raw materials is a topical problem in Latvia. In the present work such natural materials as clay and wood, waste of metallurgy and agriculture industries were used to produce the insulation materials. During the theoretical and experimental survey the several types of ceramic insulation material have been obtained. Due to the outstanding properties of this resulting material, like air penetrability and other, the insulation and bearing materials will be able to regulate the level of moistures in the room and to ensure the favourable microclimate in the dwelling. The mechanical properties, such as compressive and bending strength and others, as well as the physical properties have been tested for the obtained materials. The heat insulation property of the resulting material can ensure comfortable atmosphere in the dwelling both during cool winter time and hot summer season.

Keywords: porous ceramics, ecological materials, insulation materials, production waste.

INTRODUCTION

Along with a steady increase of energy prices and concerns regarding energy supply in future as well as the need to reduce greenhouse facilitating emission gases, it is crucial to make steps towards providing an adequate energy efficiency label in order to encourage a reduce of energy resource consumption. (The Ministry of Transport of the Republic of Latvia, 2008).

Latvia must accept the challenge of the leading European Union countries in the efforts to maintain the growth of green energy strategy thus creating an organized, environment and climate friendly economy (RTU IESE, 2011) however, in order to achieve the goal a varied set of energy efficiency improvement set must be implemented by reducing the loss of heat and the subsequent CO_2 emissions – such goal may be achieved by using efficient and long-lasting heat insulation supplies.

Modern knowledge and technology opens a broad range of opportunities to use local resources for the production of heat insulation materials, therefore, regardless of the fact that the research and development of each material is a time consuming process and the consumer shall most often choose well known and cheap supplies, porous ceramic heat insulation materials may serve as alternative to the existing heat insulation materials in the market, such alternative being produced from local raw materials using clay as binding agents, but wood-processing by-products, hay or hemp/flax sheaves being used as the scorching filler agent, thus elaborating a material with required heat and acoustic isolation qualities as well as fire resistance and chemical stability in aggressive environment and in the meantime ensuring industry development in Latvia.

Clay is the principal raw materials of ceramic materials and their products (Popovs, 1978), as well as it is the most common sediment and the primary make-up material of the top layers of earth's crust (Kurhs V. and Stinkule A., 1997), clay is also one of the predominant sediment with a very diverse content in the territory of Latvia.

Notwithstanding the conventional use of clay to produce ceramics, summarized data from more than 100 once studied clay mines confirm that here one may find a sufficient amount of high quality raw materials suitable for industrial applications – currently the legal clay mining in Latvia is only available in five mines. The currently mined amount of clay a year in Latvia for industrial purposes constitutes around 10% from the annual amount of clay that was extracted during the 70s and 80s of the last century. The current rate of clay use corresponds the rate observed during the latter half of 50s of the last century, thus clay may be successfully

mined and used for production of locally procured ceramic materials, facilitating both the economic and industrial development of the country. (LEGMC, 2012).

The properties of ceramic materials depend on various factors, the varying and obtained results' analysis of which allows developing the optimum technological conditions and processes to obtain a material with the required qualities. In order to improve the qualities of ceramic materials, not only their chemical structure is of importance, but also its improvement potential upon necessity, using the existing waste products, industrial and processing by-products, which have traditionally been used e.g. wood-processing by-products or straw, thus regulating mainly the porosity and density of the material; however, e.g. in Russia, where multiple regions suffer a lack of quality clay, in order to obtain high quality ceramic products, a research was conducted in which for the purposes of clay improvement and consumption reduction waste products were also applied by consuming the accumulated mining industry waste – dunite, which needs to be processed, obtaining samples that were burnt at 950 °C, reaching a compressive strength of 15.5 to 21.4 MPa. (Hudjakova L. and Voiloshnikov O, 2011).

Simultaneously to the research of ceramic materials, porous ceramic has also been a subject to broad study gaining ever increasing attention in the world of materials, thanks to its wide opportunities of use in various technology and technical industries – from construction to mechanical engineering and even in space flight technologies. Porous ceramic is mainly used for two principal purposes. The first purpose is linked to the heat and acoustic insulation features of ceramics, but the second purpose relates to the industries where the focal features of ceramic lie in its porous structure and other associated characteristics – size of pores, specific surface area, permeability etc.

The porous characteristics of a ceramic material are determined by the chemical –mineral content of the raw material, means of formation, thermal processing conditions etc. (Moroz I., 2011) In order to reduce the heat conductivity of ceramic materials, one must increase its porosity, which may be implemented by using gas generating additives such as calcite or magnetite (Vorobjev V. and Komar A., 1971), however, the second option involves burnable additives, thus obtaining porous ceramic. In the framework of the research for the acquisition of porous ceramic woodchips and flax, as well as hemp sheaves were used as burnable filling agents thus not only obtaining a porous structure of the material, but also ensuring an additional release of heat during the burning process, which distributes throughout the volume of the sample in a uniform manner, which not only enables a more uniform burning of the samples, but also allows to save on necessary energy resources and reduce the period of time required to complete the burning process. Notwithstanding that, gases are released during the burning process that facilitates the hardening of pore walls, thus improving the overall strength of the material. (Rogovoi M et al. 1975) The production of porous ceramic with the use of woodchip as the burnable matrix is widely researched both in Latvia by obtaining samples with a strength of 10 to 12 MPa in a density up to 1.5 g/cm^3, by using 25% woodchip and burning the clay in a 950 – 960 °C temperature, (Sedmale et al. 2009) as well as elsewhere across the globe, for instance, in the Federal University of Kazan along with the employees of leading Russian scientific centers studies were conducted to assess the impact of the material porosity and multiple samples were produced in which for the purpose of pore formation such scorching additives as woodchips and rottenstone were used in series, obtaining samples that were up to 17 MPa strong upon compression. (Salahov A. et al. 2011) Also Research in Russia was also conducted to develop a new ceramic based, high efficiency heat insulation material with low volume mass of 200-500 kg/m^3 at a processing temperature of 840-960 °C, however, this material exhibited insufficient strength for it to be used in load-bearing walls. (Amamchan M., 2009) In order to solve the ceramic material strength increase issue it is being offered to use .e.g. nanotechnologies thus forming ceramic solid matter nano-crystals. (Salahov A. et al. 2008)

A porous ceramic was produced in the course of the research not only by using the traditionally used burnable filler agents but also using a polymer material saturated with clay slip. Similar research was also conducted for instance in the Electro-Chemistry Institute of Belgrade University in order to identify the factors that affect the microstructure of porous ceramic, using a clay slip saturated polymer material, drawing a conclusion that by producing porous ceramic and using polymer sponge saturation method, the viscosity of the mixture plays a crucial role. (Tripkovic D., et al. 2006) The acquisition of porous ceramic by using foam polyurethane sponge as the burnable matrix is facilitated by the fact that the existing technology which is being used for the production of foam polyurethane, allows a wide formation of desirable porous structures with sizes of pores from a few micrometers to 2-3 millimeters. (Efimova V. and Belomerja N., 2003)

The goal of the given research is to obtain a porous ceramic material with specific features of strength and density thus achieving a material that could be used to insulate buildings.

METHODS

Jelgava carbonized clay with sintering temperature – 950 °C and melting temperature – 1010 °C, with volume mass – 1600 kg/m³ and humidity level of 24 % as well as milled glass were used for preparation the samples, where the organic filler – chippings and hemp/ flaxen shoves or matrix of polymer material are used as

burnable matrix. The chemical structure of glass is given in Table 1, but the chemical structure of clay – in Table 2.

Table 1. Chemical composition of ground glass

Component	SiO_2	PbO	B_2O_3	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O
Amount, %	74.20	0	16.63	1.65	0.16	2.09	0	3.82	0.93

Table 2. Chemical composition of clay

Component	SiO_2	Al_2O_3	Fe_2O_3	MgO	TiO_2	CaO	MgO	Na_2O	K_2O	P_2O_5	Cr_2O_3	SO_3
Amount, %	49.5	13.04	5.14	0.071	0.757	8.69	3.68	0.63	3.64	0.138	0.008	0.050

By preparing samples using plant fillers, such as the burnable fillers, there were used wood chips and hemp/ flaxen shoves from Kraslava region Piedruja parish, which were sieved in beforehand in order to deselect admixtures of large scale, like, flinders, shingles, chunk wood, as well as admixtures of organic and mineral origin, like soil and sand. The size of shoves used in the survey does not exceed 5 mm. Characteristics of shoves:

- Greyish green (hem shoves), greyish yellow (flaxen shoves) colour;
- With poured volume mass range from 50 kg/m^3 up to 75 kg/m^3;
- With humidity level not exceeding 12 % of mass;
- Admixture of long grain in shove mass does not exceed 8 % of the volume unit;
- There are no signs of mould on the shove surface or the signs of biological degradation of shove mass.

Clay was dried in the drying oven and ground in RETSCH PM 400 mill for 10 minutes in dry condition.

When the required components – clay, glass and shoves are prepared, they are dosed in the required amount and mixed in dry condition, gradually adding water till the sufficiently homogenous mixture for sample making is obtained.

Proportion of dry clay, glass, burnable matrix and water used in the investigations varied depending on the size and type of the used burnable matrix. Components of dry mixture are dosed according mass, where dry, milled clay is 40 – 70 %, glass 5 – 40 %, but the burnable matrix 4 – 20 %. The volume of added water shall be chosen so that it would provide both the viscosity of the required mixture and strength of the obtained samples as well as likely lesser shrinkage and energy consumption for sample drying.

There were made cylindrical samples of up to 25 mm in diameter and up to 32 mm in height and were dried without additional loading under pressure for 8 hours in temperature of 50 °C.

Samples were burned gradually one or two times in temperature up to 1000 °C, for 14 – 22.0 hours in total. The regime of sample burning one time is presented in Figure 1a. The regime of sample burning two times is presented in Figure 1b.

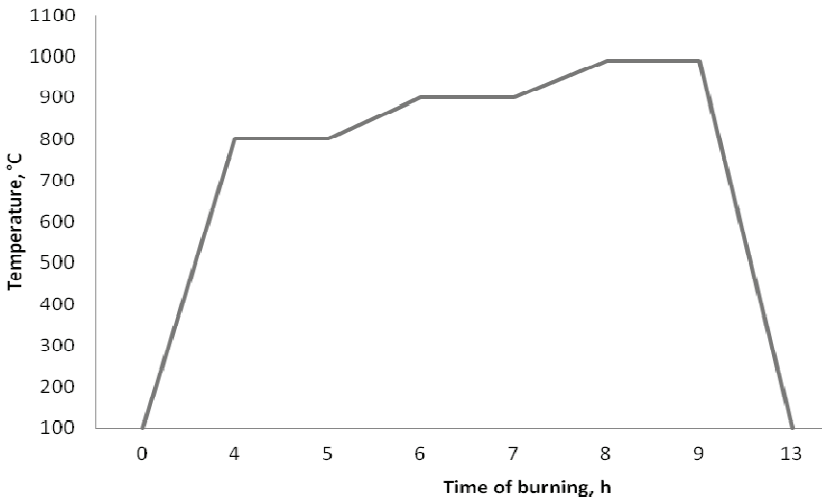

Figure 1a. Regime of sample burning one time, using plant matrixes as the burnable matrix

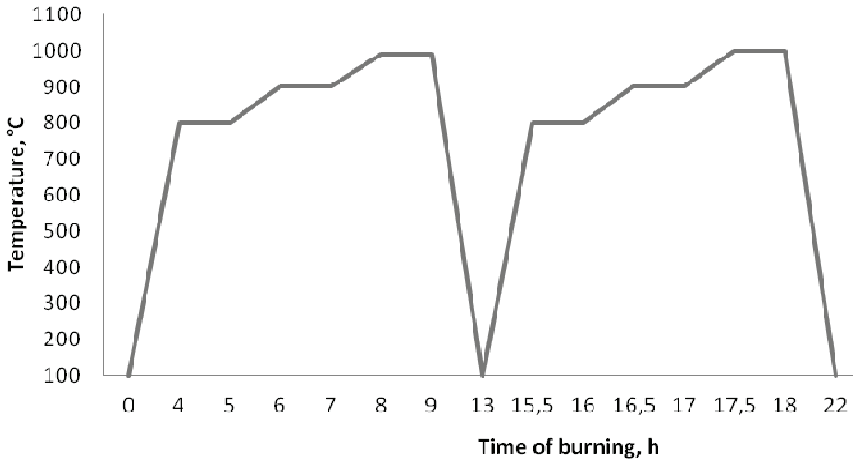

Figure 1b. Regime of sample burning two times, using plant matrixes as the burnable matrix

When making porous ceramics, using polymer material as burnable matrix, there were used clay, chamotte, ground glass and matrix of polymer material.

The clay for the survey was used in dry condition and was ground in the globe mill. The same procedures have been done by chamotte – it was ground in RETSCH PM 400 mill for 2 minutes. When the required components are prepared (grinding), they are dosed in the required amount and mixed in dry condition, gradually adding water till the sufficiently homogenous mixture is obtained.

Proportion of dry clay, chamotte, burnable fillers and water used in the investigations varied depending on the pore size and pore type from the used burnable fillers. Components of dry mixture are dosed according mass, where dry, milled clay is 66 – 75 %, chamotte 11 – 15 %, but the burnable matrix 11 – 22 %. By water addition there were made liquid clay slip, mixing clay, chamotte and previously ground glass in mill (5-10 %).

In the beginning polymer sponge with pore size of 1 – 3 mm were impregnated with the obtained mixture and then compressed so that air is squeezed out of it, immersed in the mixture and then released, allowing it to dilate and obtain the initial form. Such step of compressing – dilating was repeated in order to reach the desirable density. In the next step the residual clay slip part was removed (25 % – 75 %), so providing sufficiently high porosity.

Sizes of sample: square samples with thickness of 6 – 8 mm and edge sized of 100 x 100 mm.

Conditions of material development: drying in the drying oven for 12 hours in temperature of 50°C, favourably influenced by the large area of sample surface and the type of penetrating pores. Afterwards the samples were burnt for 14 hours, keeping the maximal temperature (1080 °C) for one hour. The regime of sample burning is presented in Figure 2.

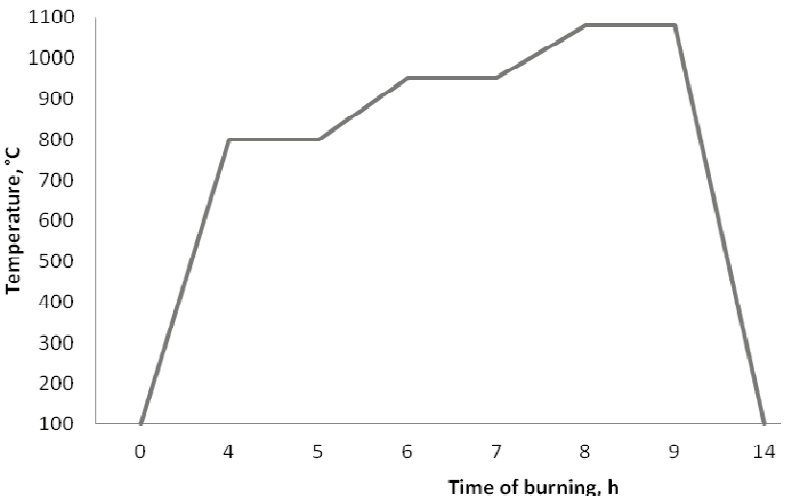

Figure 2. Regime of sample burning, using polymer material sponge as the burnable matrix

The regime of sample drying as well as burning was chosen so that the time and energy resources required for material development are minimal, but sufficient in order to provide the obtaining of material with certain properties in the result of it.

Verification of samples developed by both of the methods was realized by ZWICK Z100 perpendicular to the formation direction of the samples, thus providing the establishment of mean strength in cross section, reducing the influence of certain weakening, which could have formed while samples were removed from mounds and a non-homogenous structural density in the direction of cross-section formation.

RESULTS

Porous ceramic materials were obtained during research. Pressure strength tests were performed, as well as their density was determined by varying filler and amount of water. Usage of polymeric sponge saturation method, by varying quantity of grinded glass in them, leads to development of several types of samples. Table No 1 summarizes two basic contents which are used in further material production and tests.

Table 3. Physical and mechanical properties of samples depending on the amount of glass

Amount of glass, %	Absorption of Water, %	Compressive strength, MPa	Contraction % (per edge)
10	180 - 210	0.5 – 1.5	3.8
5	230 - 250	0.5	4

Density of obtained samples was ranging from 140 to 320 kg/m^3. Used raw materials provide acquisition of necessary properties of ceramics where clay serves as cohesive substance, but chamotte provides necessary stiffness, by making stable frame during the burn of polymeric sponge, whereas the glass provides higher strength and better cohesion between mixture and sponge within sample formation process.

Usage of hemp and flax shoves as burnable filler, resulted in acquisition of samples with variable amount of grinded glass, which is compared with the resistance of obtained samples and described in table No 4.

Table 4. Compressive strength of samples depending on the amount of glass

Amount of glass, %	5	7.5	15
Compressive strength, MPa	0.27	0.30	0.97

By using 40% of grinded glass for making of the sample, obtained compressive strength was 3.95 MPa, but density of that sample was 740 – 820 kg/m^3.

Comparison of measures was performed for samples with variable amount of water from 10 - 20% due to their drying and burning, which is 5.8 – 11.8% for samples, respectively extending if amount of water is increased in the mixture.

Density of samples depending on the amount of used shoves is summarized in table No 5.

Table 5. Density of samples depending on the amount of used hempseed/ flax shoves

Amount of shoves, %	4 - 6	8 - 10	13 - 15	18 - 20
Bulk density, kg/m^3	880 - 950	750 - 820	610 - 720	320 - 460

Density of samples can be easily regulated, by changing amount of used fillers. But increasing the quantity of shoves, amount of the water needed for mixture, in order to get plastic mass, also increases, and in the result the time and contraction necessary for drying increases, reducing resistance.

Samples, in which quantity of shoves reaches 20% and more, have low resistance, and respective amount of grinded glass must be chosen in further researches in order to increase the resistance. Resistance also can be enlarged by double burning of samples, choosing higher temperature and shorter period in the second time. This topic will be studied more widely in further researches.

Macropores and micropores, showed in the figure 3, can be seen within the structure of porous ceramics, where measure of pores in obtained plant matrix samples is 0.033 – 1.7 mm and polymer matrix – 0.5 - 2.0 mm.

Using shoves as burnable filler, macropores and micropores, shown in the figure 3, can be seen within the structure of porous ceramics, where macropores have elongate form and a measure of pores in obtained plant matrix samples is 0.033 – 1.7 mm, but macropores got by burning of polymer material sponge, have regular form what copies the structure of sponge itself and measure of pores – 0.5 – 2.0 mm and they are shown in figure 4.

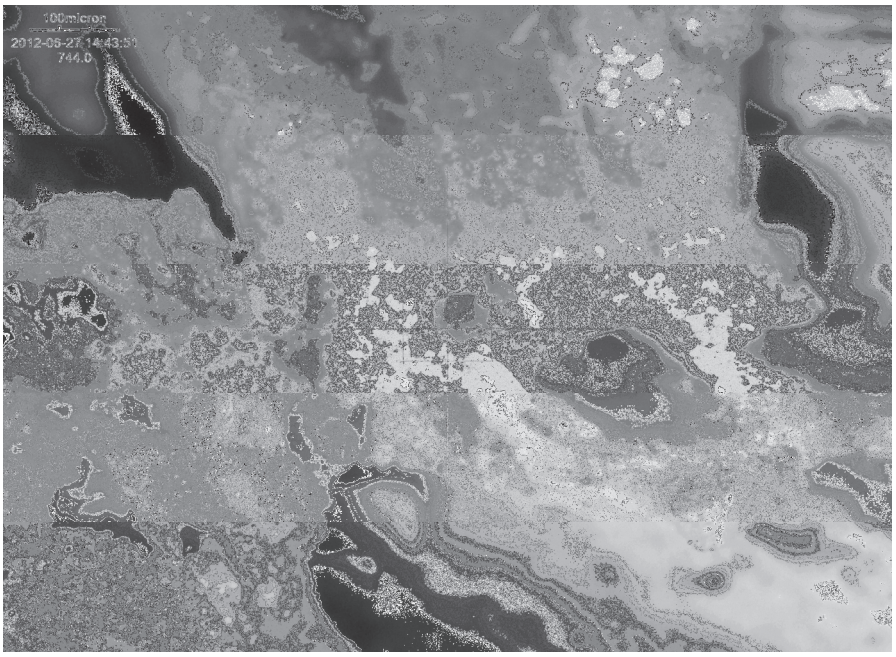

Figure 3. Micrograph of pores for samples which are made by plant matrix burning method

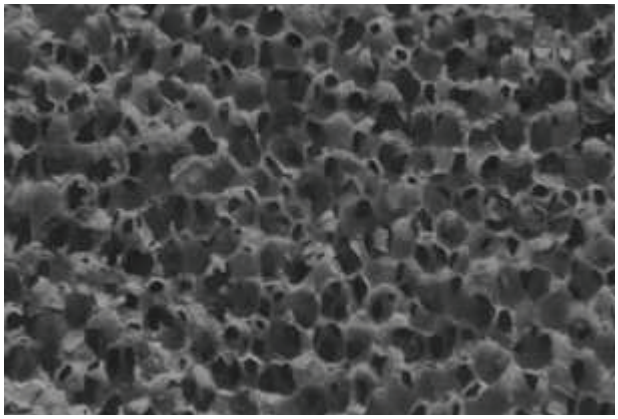

Figure 4. Structure of pores for samples which are made by polymer material matrix burning method

Currently thermal conductivity coefficient of porous ceramics, obtained during the experiment, is not determined, but if we compare information available in the literature sources and internet where, for example, thermal conductivity coefficient for Keraterm 44 ceramic block is 0.129 W/m·K (www.lode.lv), or for Wienerberger Porotherm ceramic block is 0.145 W/m·K (www.wienerberger.com), thermal conductivity for porous ceramics, obtained during experiment, could be reached similarly to aerated concrete within 0.08 – 0.10 W/m·K.

DISCUSSION

The results yielded by the research reflect on the existing and common raw material in Latvia – clay and its broad application opportunities in terms of construction material production by regulating its physical and mechanical properties with the addition of burnable fillers and ground glass.

In the course of the research woodchip, hemp and flax sheaves as well as other organic substances were used as the burnable fillers to obtain the porous ceramic, the focal drawback of the obtainable material was the heterogeneous porous structure, which is linked to the complex additive orientation and distribution in the volume of the sample which may be mitigated by using foam polyurethane sponge as the burnable fillers, however, with the application of this method, additional attention must be given to the foam polyurethane

sponge and the size of its pores in order to the ensure a complete filling of the sponge with the mixture content, as well as its content and consistency – in the event that it is not sufficiently plastic, polyurethane sponge components that are not being filled with the mixture content form empty areas after the scorching process that have a negative impact on the physical and mechanical parameters of the material by reducing its strength.

Due to the said reason, samples were produced in laboratory environment with thickness not exceeding 3 cm and thus ensuring the saturation of the sponge with the clay slip throughout the whole cross-section of the material. In order to obtain ticker porous ceramic samples, individual layers may be glued together by using clay before curing and after scorching processes. With the application of this method, additional attention must be given to the foam polyurethane sponge and the size of its pores in order to ensure a complete saturation of the sponge with the mixture content.

The advantage of the given method lies not only in the simplicity of the technology but also in the time and cost consumption efficiency, whereas its drawback is linked to the material's functional dependence on the sponge saturation quality during the formation of the material, as well as the limited dimensions of the producible samples, which is effectively solved by gluing multiple samples together.

The research provides a practical reflection of the acquisition of porous ceramics by varying the means of such acquisition, shifting between various burn-out fillers, thus obtaining a material with various pore sizes, amount as well as physically mechanical parameters. Such organic waste as hemp/flax sheaves or woodchip enables to obtain a material with porous structure where pore sizes are not specifically regulated; however, this process is very efficient in terms of time and financial consumption. In terms of feature control, a more successful method is the one that uses foam polyurethane sponge as the burnable matrix thus the obtained sample obtains its porous structure after the completion of burning process.

With the use of the mentioned methods, heat insulation elements of various forms and sizes may be obtained, whereas the use of polymer sponge for the production purposes of porous ceramic allows replicating any form of the burnable matrix.

In line with the conducted research, the addition of ground glass improves the strength of the obtained samples, however, it reduces the temperature necessary for burning as well as the amount of clay required, thus enabling to save on natural resources through an effective recycle of the glass waste. By increasing the amount of ground glass up to 40 % at a specific burning temperature, an essential increase is not only observed in terms of density of the material by reduction the amount of pores, but also its strength, thus allowing to obtain a high strength ceramic.

The data obtained in course of the research on the broad use opportunities of the material by improving its strength, so such materials could be used as load-bearing low story structures.

In the following research it would be useful to identify the optimum burning conditions of the material as well as the most beneficial relation between the porosity and strength of the material, facilitating its use for energy efficiency increase and domestic construction materials' production.

CONCLUSIONS

Porous ceramic materials are obtained during the research. Those materials are developed due to burnable fillers method, choosing plant matrixes and polymeric material what allows to get materials with definite and adjustable quantity and measures of pores.

Natural resources are validly used in material production, using wood-processing and fiber processing waste and grinded glass waste, thus minifying consumption of raw materials and energy, wherewith also pollutant emissions.

Reached physically chemical properties of porous ceramic materials can be improved by allowing them to compete with aerated concrete and concrete blocks with expanded clay granules.

Porous ceramic materials, obtained within the research, are breathable, do not rot and they are resistant against heat and thermal impact, corrosion, deterioration, aggressive environment.

Obtained materials can be used not only as ecological heat insulation or high-resistant ceramic materials, but also in other spheres, e.g., as materials for the immobilization of bacteria.

Usage of such materials will allow increasing energy efficiency of buildings, by using current and widely distributed resources of the country and thus promoting its economic development.

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REFERENCES

Amamchan M., 2009, Технология получения теплоизоляционного материала на основе легкоплавких глин [Technology of heat insulation material acquisition, using lightly melting clay], Строительные материалы, August, 68-69.

Efimova V., Belomerja N., 2003, Фильтрующая керамика с заданной структурой, [Percolation ceramics with definite structure], In: Proceedings of the 2th International Conference on Environmental Protection and usage of natural resources, Doneck, 138-139.

Hudjakova L., Voiloshnikov O., 2001, Практическое использование вмещающих пород медно-никелевых месторождений, [Practical usage of sediments which contain cooper-nickel], Горный информационно-аналитический бюллетень. Nr. 3, 143-145.

Kurshs V., 1992, Девонское терригенное осадконакопление на Главном девонском поле, [Devonian terrigenous deposition on the Main Devonian field], Riga : Зинатне, 208.

Kurshs V., Stinkule A., 1997, Latvijas derīgie izrakteņi, [Mineral deposits of Latvia], Riga: the University of Latvia, 67.

Latvian Environment, Geology and Meteorology Centre, 2012, Balance of mineral deposits (Raw materials for building materials manufacturing, peat and vulnerary mud) store per 2011, Riga.

Moroz I., 2011, Технология строительной керамики, [Technology of construction ceramics], Moscow: ЭКОЛИТ, 384.

Popovs L., 1978, Būvmateriāli un būvizstrādājumi, [Building materials and building-products], Riga: Zvaigzne, 364.

Rogovoi M., Kondakova M., Saganovski M., 1975, Расчеты и задачи по теплотехническому оборудованию предприятий промышленности строительных материалов, [Calculations and tasks about thermal and technical equipment in building material production companies], Moscow.:, Стройиздат, 320.

Salahov A., Tagirov L., Salahova R., Parfenov V., Ljadov N., 2011, Поры и прочностные характеристики строительных материалов, [Characterization of building material pore and strength], Строительные материалы Nr. 12, December, 25 -27.

Salahov A., Livada A., Salahova R., 2008, Нанотехнология – гарантия заданных свойств керамических материалов, [Nanotechnology – guaranty of defined properties for ceramic materials] ,Строительные материалы, April, 27-29.

Sedmale G., Cimmers A., Sedmalis U., 2009, Charasteristics of illite clay and compositions for porous building ceramics production, Institue of Silicate Materials, Riga Technical Univesity, ISSN 1392 -1231, Chemine Technologija, Nr. 2 (51).

Sedmale G., Korovkins A., Vircava I., Lindina I., 2012, Ķīmiski modificētu mālu ietekme uz keramikas materiāla īpašībām, [Impact of chemically modified clay on the ceramic material properties], In: Proceedings of the 70th Scientific conference of the University of Latvia on Geograpfy and Environmental Science, Riga, Latvia, 414.

The Ministry of Transport of the Republic of Latvia, 2008, Information message „On the informal council of Transport, telecommunication and power industry ministers of European Union".

The Riga Technical University Institute of Energy Systems and Environment, 2011, Green Energy Strategy of Latvia 2050, 28.

Tripkovic D., Radojevic V., Aleksic R., 2006, Factors affecting the microstructure of porous ceramics, Institute of Electrochemistry, University of Belgrade, J. Serb. Chem. Soc. 71 (3) 277–284.

Vorobjev V., Komar A., 1971, Строительные материалы, [Building materials], Moscow: Стройиздат.

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Application of Peat, Wood Processing and Agricultural Industry by-Products in Producing the Insulating Building Materials

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EXTENDED ABSTRACT

In order to improve total energy efficiency the use of effective heat insulation materials produced with local raw materials may positively affect domestic economic development. While reviewing such raw materials and resources in Latvia which could be potentially used for heat insulation materials production, there should be focus on peat as well as on the wood-processing and agriculture by-products. The chemical variety of peat indicates the potential of the resource, but in the meantime it restricts one to develop a homogenous technology for production of peat base heat insulation materials. In spite of various peats' advantages - it is mostly uses in two ways – in farming and as a combustible. New types of peat usage may be found by peat activation which improves the existing features of the materials and reveals new ones. It is possible to influence on the specific properties of raw materials by using various types and modes of activation. The activation of raw materials not only opens new possibilities in terms of use of such materials, but also allows using them more efficiently. Mechanically-thermal activation of peat in the planetary ball mill in the water environment was used to obtain peat binder. Such binding agent is ecologically clean and environmentally friendly which is especially important considering the current binding agents available in the heat insulation materials in the market. Within the research were obtained various insulation building materials: peat glue was used as a binder and agricultural waste - various fraction wood chips, hemp sheaves and peat – as filler, which is not only technically, but also economically more beneficial solution thus the high likeliness of natural raw materials and the low density allows one to produce efficient heat insulation materials. As a result of the research by Scientific construction materials institute of Russia it was found that chemically mechanic activation facilitates an intensive reaction between urea and the hydroxide in peat, as well as between the functional carbonyl groups and polysaccharide (Копаница *et al.* 2009) . It must be noted that the biggest effect was achieved only with high grade peat because it is more saturated with organic compounds any may form various chemical bonds with introduced modifiers. According to the conducted research, the increase of peat activation duration improves the compression strength of composite material. The observed increasing of compression strength was in the accordance with the results, obtained by other researchers. Produced peat-woodchip/hemp composite material is 100% recyclable in a form of a filling agent for production of similar materials. A wide use of the obtained material produced fully with locally extracted raw materials, allows solving building and structure energy efficiency issues with the use of Latvia's internal resources which would generate additional employment and facilitate economic growth. The use of such material shall enable to solve building energy efficiency problems by using only domestic resources.

Keywords: peat, composites, ecological materials, insulation materials.

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REFERENCES

Н.О. Копаница, А.И. Кудяков, М.А. Ковалева. 2009. Эффективные строительные материалы на основе торфа [Efficient on peat based building materials]/ Материалы Международной заочной научно-практической конференции «Проблемы изучения и использования торфяных ресурсов Сибири», 24 – 27.08.2009.

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Effects of Interaction of Static Load and Frost on Damage Mechanism of Concrete Elements

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EXTENDED ABSTRACT

Frost damage is typical material deterioration in concrete structures subjected to external environmental conditions. However, the weather conditions do not make the sufficient factor causing the worsening of the concrete properties (Fagerlund, 2002). There is the lack of information concerning the influence of the tensile stress on the typical process of surface scaling due to freezing liquid contact with selected surface of element tested, which is the frequent situation in service life of concrete and reinforced concrete structures. Two different approaches to the estimation of cyclic freezing and thawing influence on concrete properties were presented in the paper. The analysis of interaction of static load and freeze-thaw cycles with chloride exposure regime on surface scaling process of concrete was performed. The fracture parameters were used to assess the internal cracking progress in concrete. Fracture mechanics can help analyze the response of microstructure to external load (Jenq, Shah, 1985).

The tests were carried on for non-air-entrained concrete as well as for air-entrained concrete. In order to realize the interaction of freeze-thaw cycles and load the beam specimens were tested in third-point loading condition. The scaled material was collected from the top surface of specimen, which was subjected to tensile stress. The specimens for fracture parameters evaluation were subjected to cyclic freezing in air and thawing in water. The critical stress intensity factor K_{Ic}^{s} and the critical crack tip opening displacement $CTOD_c$ were determined using procedure recommended by RILEM, based on the fracture model by Jenq and Shah (1985).

The analysis of test results showed the significant influence of stress on the increase in mass of material scaled from the specimen surface subjected to cyclic freezing and thawing, for both concretes, with and without air-entraining admixture. The differences in mass of material, scaled from specimens subjected to various stress levels, increased together with the number of cycles. In case of the unloaded concrete specimens, after the initial rapid growth in mass of scaling, the slowdown of the process was observed and then the mass of scaling accumulated gradually. For loaded concrete specimens, the mass of the scaling increase was almost linear together with the number of cycles, for different stress levels.

The fracture parameters were determined on the basis of *P–CMOD* curves obtained for concrete specimens. For extremely damaged concrete, the linear portion of *P–CMOD* curve was very short, the maximum load was achieved quickly, and the strain softening was observed. In the process of degradation the concrete behavior was more ductile in comparison to reference concrete but the maximum load (P_{max}) is strongly limited. For frozen specimens the value of K_{Ic}^{s} decreased and the $CTOD_c$ increased, which means that the fracture process (stable crack propagation) appeared for greater crack opening displacement.

Keywords: concrete, cyclic freezing and thawing, interaction, scaling, fracture parameters.

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REFERENCES

Fagerlund, G. 2002. Mechanical damage and fatigue effects associated with freeze-thaw of materials. In Proc of 2nd International RILEM Workshop on Frost Resistance of Concrete, Essen, 18-19 April 2002, 117-132.

Jenq, Y. S., Shah, S.P. 1985. A two parameter fracture model for concrete. Journal of Engineering Mechanics, 111, 1227-1241.

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Effect of Natural Zeolite Clinoptilolite on the Strength Properties of Portlandcement

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Abstract. Effects of using natural zeolite clinoptilolite (Na, K, Ca)2-3 Al3 (Al, Si)2 Si13 O36 ·12H2O as the cementing material on the strength properties of Portland cement paste were investigated. Incorporation of 5 %, 7 %, 10 % (by weight) of the fine natural zeolite clinoptilolite in to ordinary portlandcement matrix with water, using ratio (W/C) of 0,38. The Portland cement paste samples with addition of clinoptilolite were cured at room temperature for 3, 7, 14, 28 days. Mechanical performance of the Portland cement paste samples with clinoptilolite was determined by measuring bending and compressive strength of the hardened cement paste specimens. Increasing amount of fine natural zeolite clinoptilolite in the Portland cement paste promouted the formation of sulfoaluminate compaunds wich caused the possibility decrease of compressive strength of the hardened cement paste, but in this study was determined, that adittion of natural zeolite clinoptilolite to Portland cement slightly improved the strenght of hardened cement paste. Pozzolanic reactions takes place when oxides SiO_2 and Al_2O_3 reacts with alkaline compounds of Portland cement hydration reactions and different calcium hydrosilicates C-S-H minerals are formed.

Keywords: natural zeolite, clinoptilolite, Portland cement, puzzolanic materials.

INTRODUCTION

Natural zeolites (i.e., those found in volcanogenic sedimentary rocks) have been and are being used as building stone, as lightweight aggregate and pozzolans in Portland cements and concretes (Mumpton, 1999). Natural zeolite, a type of frame structured hydrated aluminosilicate mineral is used as a type of natural pozzolanic material. This mineralogical material containing large quantities of reactive SiO_2 and Al_2O_3 and it is widely used in the cement industry in as a cement blending material. Like other pozzolanic materials such as silica fume and fly ash, zeolite contributes to concrete strength mainly through the pozzolanic reaction with $Ca(OH)_2$ and the pozzolanic reactivity of this type of material in comparison with other pozzolans is interest. Natural zeolite clinoptilolite has a high proportion of pore space in a chemically neutral structure and is resistant to high temperatures and is well suited for applications such as chemical sieves and puzzolans. Investgation of the natural zeolite used in research work as a pozzolanic material, with the reactivity between that of silica fume and fly ash (Poon *et al.*1999). The study and to examine physical, chemical, mechanical and microstructural properties of mortars produced by blending clinoptilolite in to Portland cement with increasing ratios (Yilmaz *et al.* 2007). It was observed that plasticity times extend depending on the blend ratios of clinoptilolite blended cements and that early strengths change according to Blaine values. It was also determined that the final strengths develop in proportion to reactive SiO2 and ion exchange capacity of clinoptilolite.

The effects of zeolite, coal bottom ash and fly ash as Portland cement replacement materials on the properties of cement was investigated in different combinations of tests (Campolat *et al.* 2004). These materials are substituted for Portland cement in different proportions and physical properties such as setting time, volume expansion, compressive strength and water consistency of the mortar are determined. These physical properties are compared with those of Portland cement. The results showed that replacement materials have some effects on the mechanical properties of the cement. The inclusion of zeolite up to the level of 15% resulted in an increase in compressive strengthat early ages, but resulted in a decrease in compressive strength when used in combination with fly ash and setting time was decreased when zeolite was substituted.

Investigations of the pozzolanic activity of zeolites, experimental blended cements prepared by mixing together ordinary Portland clinker, natural zeolites type A or X , and gypsum, were subjected to the Fratini's test (Colella *et al.* 2008). The same mixtures without gypsum were used to prepare cement pastes with water, which, after curing for 3–28 days, were subjected to mechanical strength measurements. Both zeolites proved to be

effective as pozzolanic materials, including cation exchange, dissolution of the zeolitic structure, possible formation of transient gel phases, and precipitation of hydrated calciumsilicates and aluminates. Pozzolanic activity was demonstrated to depend on zeolite structure. Zeolite A reacted more readily than zeolite X. Zeolite X being slightly more siliceous than zeolite A, contributed to a greater extent to the development of the mechanical resistances of the Portland cement pastes at short curing times.

The properties and the hydration of Portland cements containing natural zeolite,was studied (Perraki *et al.* 2010) and mineralogical characterization of the natural zeolite was performed. In addition, the pozzolanic reactivity of the natural zeolite was evaluated on the basis of the Chapelle test. The mechanical and physical properties of blended cements, incorporating 0%, 10% and 20% (per weight) of fine zeolite were determined. The hydration rate and products were studied by means of X-ray diffraction and FT-IR spectroscopy, in combination with thermoanalytical methods. The examined natural zeolite consists of heulandite type-II and is a pozzolanic material that contributes to the strength development of zeolite-cement mixtures, the consumption of $Ca(OH)_2$ formed during the hydration of Portland cement and the formation of cement-like hydrated products. The addition of natural zeolite up to 20% w/w does not significantly affect the physical and mechanical properties of the blended Portland cements.

In the study presented the effectiveness of a natural zeolite in enhancing mechanical and durability properties of concrete is evaluated and is also compared with other pozzolanic admixtures (Ahmadi *et al.* 2009). The pozzolanic reactivity of natural zeolite and silica fume were examined by a thermogravimetric method. The results indicated that natural zeolite was not as reactive as silica fume but it showed a pozzolanic reactivity. In the second part, zeolite and silica fume were substituted for cement in different proportions in concrete mixtures, and several physical and durability tests of concrete were performed. These experimental tests included slump, compressive strength, water absorption, oxygen permeability, chloride diffusion, and electrical resistivity of concrete. Based on these results, the performance of concretes containing different contents of natural zeolite improved and even were comparable to or better than that of concretes prepared with silica fume replacements in some cases. Expansion tests on mortar prisms showed that natural zeolite is as effective as fly ash.

The pozzolanic reaction between portlandite and different types of natural zeolites was studied (Mertens *et al.* 2009). Analcime, phillipsite, chabazite, erionite, mordenite and clinoptilolite-rich tuffs were mixed with portlandite and water (1:1:2 by weight), and the progress of the pozzolanic reaction was quantitatively determined by thermogravimetrical analyses from 3 to 180 days.The difference in reactivity of the samples containing natural zeolites with varying Si/Al ratios, as well as between clinoptilolite samples exchanged with different cations or ground to different grain sizes was assessed.The results indicate that the external surface area only influences the short term reactivity, whereas the cation content has an effect on both the long and short term reactivity. The early reactivity of the unexchanged samples can be explained by these two parameters, but their long term reactivity is mainly related to the Si/Al ratio of the zeolites. Samples with zeolites rich in Si react faster then their Al rich counterparts.

Pozzolanic activity of clinoptilolite was studied in comparison to silica fume, fly ash and a zeolitic natural pozzolan (Uzal *et al.* 2009). Chemical, mineralogical and physical characterizations of the materials were considered in comparative evaluations. Pozzolanic activity of the natural zeolite was evaluated with various test methods including electrical conductivity of lime pozzolan suspensions; and free lime content, compressive strength and pore size distribution of hardened lime pozzolan pastes. The results showed that the clinoptilolite possessed a high lime–pozzolan reactivity that was comparable to silica fume and was higher than fly ash and a non-zeolitic natural pozzolan. The high reactivity of the clinoptilolite is attributable to its specific surface area and reactive SiO_2 content. Relatively poor strength contribution of clinoptilolite in spite of high pozzolanic activity can be attributable to larger pore size distribution of the hardened zeolite–lime product compared to the lime–fly ash system.

Volcanic pozzolans are vitreous or poorly crystallized materials rich in SiO_2 and Al_2O_3 that react with the portlandite generated during cement hydration to yield hydrated calcium silicates and aluminates with low solubility and good cementitious properties.The purpose of the study was to analyze the reaction between calcium hydroxide and two natural pozzolans, characterize the C–S–H gel produced and determine the relationship between pozzolan composition and structure and its capacity to fix calcium (Martinez-Ramirez *et al.* 2006). The findings of the XRD and FTIR analyses conducted with this aim included a gradual decline of the natural zeolite heulandite and faujasite peaks on the diffractograms with reaction time, and changes in the IR absorption bands attributed to the natural zeolites, along with the appearance of new bands indicative of the formation of the C-S-H gel.

The objective of study was to document the potential effect of the secondary minerals on the strength development of pozzolanic mortars and investigated this effect by thermally destabilising these minerals in three different pozzolanic deposits (Habert *et al.* 2008). First did a detailed mineralogical study, to identify the occurrence and the nature of the different secondary minerals. Kaolinite is abundant in poz-1 and different types of natural zeolites were identified in poz-2 and poz-3. The effect on the pozzolanic activity has been tested by strength measurements mortars at 1, 7 and 28 days. Strength of all blended Portland cements is enhanced while destabilising secondary alteration minerals. For kaolinite, showed that a strength improvement occurs as soon as it is destructured, even if it is not transformed in metakaolin. For natural zeolites, destabilisation takes place at low temperature (350 °C), but as recrystallisation products are easily formed.

In study of the effect of natural zeolite on the hydration of Portland cement was examined (Kakali *et al.* 2003). Complete mineralogical characterization of the natural zeolite was performed. In addition, the pozzolanic reactivity of the zeolite was evaluated on the basis of Chapelle test. Pastes of Portland cement, incorporating 0 %, 10 %, 20 % and 30 % per weight of natural zeolite were prepared and the pastes were water cured at 20 °C, for 1, 2, 7 and 28 days. The hydration rate and products were studied by means of X-ray diffraction and Fourier transform infrared spectroscopy, in combination with thermoanalytical methods. The examined natural zeolite consists heulandite type II and shows a good pozzolanic reactivity (0.555 g of $Ca(OH)_2$ per gram of natural zeolite, according to the Chapelle test). The incorporation of natural zeolite in Portland cement contributes to the consumption of $Ca(OH)_2$ formed during the cement hydration and the formation of cement like hydrated products.

Paper by presents experimental results on the compressive strength, degree of pozzolanic reaction, and porosity of natural zeolite modified Portland cement pastes (Lam *et al.* 1999). These results are compared with those obtained from similar blended cement pastes prepared with silica fume and fly ash replacements. Based on the experimental results, it can be concluded that natural zeolite is a pozzolanic material, with a reactivity between that of silica fume and fly ash. In blended cement pastes with a lower water-to-cementitious materials ratio, the natural zeolite contributes more to the strength of the pastes. But in the pastes with a higher water to cementitious ratio and a lower cement replacement level it undergoes a higher degree of reaction.

In resaeach study of natural zeolitic mineral admixture is made of the finely divided powder of natural zeolite with a bit of other agent such as triethanolamine (Nai-Qian *et al.* 1990). When natural zeolite admixture is used to displace about 10% of the ordinary Portland cement in concrete and mixed with a suitable amount of superplasticizer (W/C = 0.31 to 0.35), then a high-strength concrete with compressive strength of about 80 MPa and a slump of about 180 mm can be obtained. The strength of this concrete is about 10 to 15% higher than that of the corresponding concrete mixed with pure Portland cement, and its bleeding decreases greatly. It also results in no segregation or separation of the mix, and it satisfies the requirement of pumping concrete in construction. The natural zeolite admixture is suitable also for the slag Portland cement. The strengthening effect of the admixture is similar to that of silica fume. When natural zeolite admixture is used to displace a certain amount of the cement in the concrete, the cost of the concrete thus made will be 3 to 5% cheaper than that of the concrete with pure cement. The natural zeolite admixture can increase the amount of micropores (d<625 A) and decrease the amount of large pores (d>938 A) in the cement paste. The strength of concrete is increased and its other properties are also improved. Natural zeolite admixture can raise the SiO_2/ CaO weight ratio in the transition zone to increase its C-S-H phase and decrease its calcium hydroxide content and the strength and resistance to permeability of the concrete are increased.

In dissertation presents a study that investigated the potential of a modified zeolite additive known as PowerCem to improve the properties of cement mortar and concrete (Ikotun, 2009). The product, a blend of selected alkaloids and natural zeolite, is used in soil stabilization for road construction. The emphasis of study was on improvement of the strength and durability properties of Portland cement mortar and concrete using PowerCem additive. Tests carried out on mortar samples include flow, flexural strength, compressive strength, oxygen permeability, sorptivity, porosity, resistance to sulphate attack, and resistance to alkali silica reaction. In conclusion, additive showed the potential to effectively improve mortar, concrete strength and durability properties when used at optimum proportions between 0.4 % and 0.6 %.

In the present research work natural zeolite clinoptilolite were used like additive in Portland cement and physical mechanical properties was determined by measuring the compressive strength of the hardened cement paste samples.

MATERIALS AND METHODS

The Portland cement CEM II /A-LL 42,5 N (specific surface – 360 kg/m², paste of normal thickness – 25,0 %, initial setting time – 190 min., Na_2O eq.% <0,8) mineralogical composition C_3S – 56,60 %, C_2S – 15,76 %, C_3A – 8,59 %, C4AF – 10,85 % was used in this research study. The chemical composition of the natural zeolite clinoptilolite $(Na,K,Ca)_{2-3}Al_3(Al,Si)_2Si_{13}O_{36}\,12(H_2O)$ was SiO_2 – 71,5 %, Al_2O_3 – 13,1 %, Fe_2O_3 – 0,9 %, TiO_2 – 0,2 %, CaO – 2,1 %, MgO – 1,07 %, P_2O_5 – 0,033 %, K_2O+Na_2O – 5,03 %, (specific surface – 144

m²/g, density – 2370 kg/m³, compressive strength - 15 MPa, hardnes – 4, Wmoist. – 4 %, porosity – 34 %, ion exchange receptivity - 1,5 mg-ekv/g).The X – ray diffraction analysis was performed using DRON - 6 diffractometer. The investigations was perform with 2Θ angle range 4 - 70º with Ni - filtered the CuKα radiation. Termographic analysis was performed by using differential scaning calorimetr STA 409 PC Netzsch. Maximal temperature was 1500º and the velocity of the increase in temperature was 10º C/min. Natural zeolite clinoptilolite was finely ground in laboratory sphere ball mill. For the determine of the effect of natural zeolite clinoptilolite addition (0%; 5%; 7%; 10 % by weight) on the strength properties of Portland cement paste samples, the series of cement paste admixture were mix up in laboratory mixer and were formed in prisms of 40 X 40 X 160 mm in size, that hardened for 3, 7, 14, 28 days under the conditions regulated by the LST EN 196 - 1:2005 standart. With Toni Technik 2020 computerized press was determined the bending and compressive strengths of the hardened Portland cement paste samples.

RESULTS AND DISCUSSION

X-ray diffraction patterns analysis showed, that natural zeolite was crystalline with amorphous impurities, dominated by clinoptilolite peaks (Fig. 1) with small quantities of heulandite and quartz peaks.

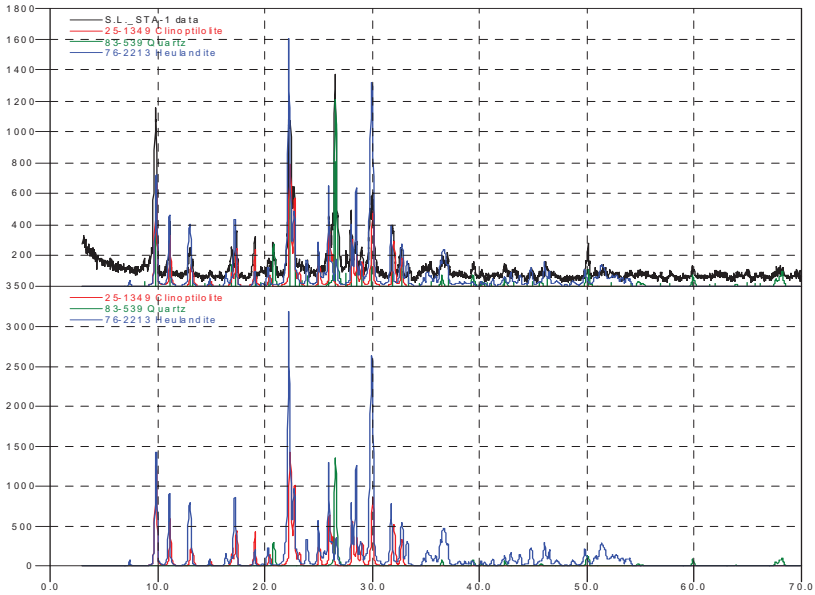

Figure 1. X-ray diffraction patterns for natural zeolite clinoptilolite

Thermogram analysis of natural zeolite showed, that thermal peaks are characteristic for mineral clinoptilolite and quartz (Fig. 2).

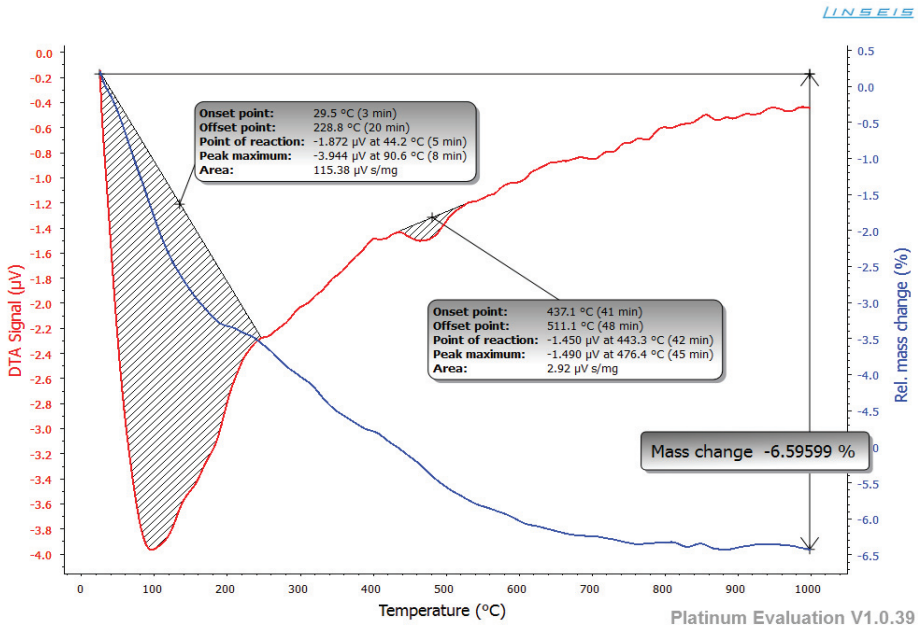

Figure 2. Thermogram analysis data DTA and corresponding (TG) data for natural zeolite clinoptilolite

Hardened Portland cement paste specimens density adding natural zeolite additive from 0 %; 5%; 7%; 10%; (by weight) should decrease, because a part of cement was replaced by fine grinding clinoptilolite (Fig. 3).

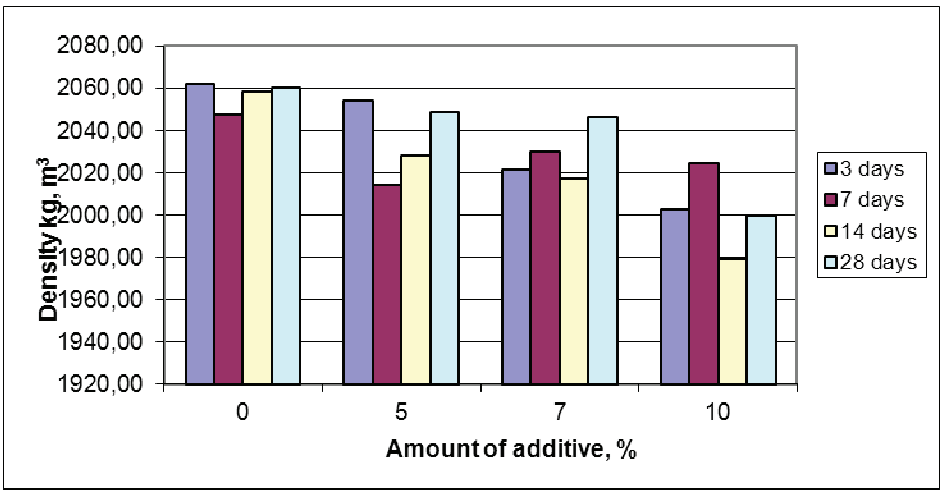

Figure 3. Density of hardened Portland cement paste samples on the natural zeolite clinoptilolite

Bending test of specimens with adittion of natural zeolite clinoptilolite showed, that the bending strenght of hardened Portland cement paste was the same (Fig. 4).

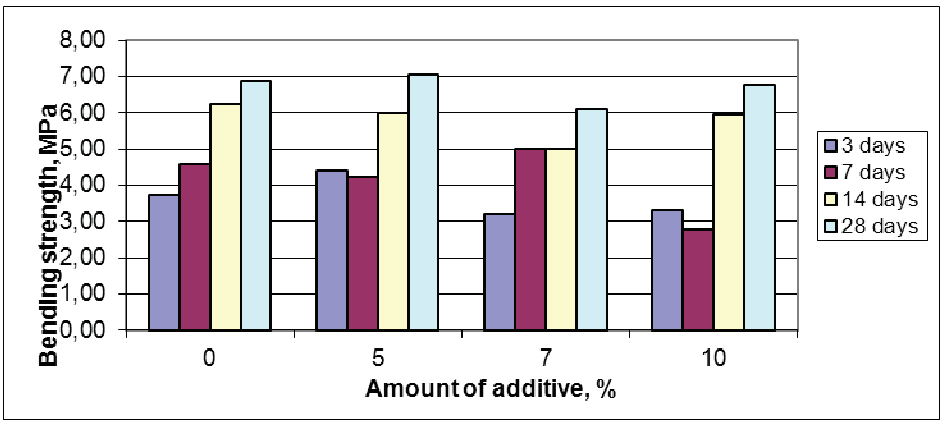

Figure 4. Bending strenght of hardened Portland cement samples with natural zeolite clinoptilolite additive

Adition of natural zeolite clinoptilolite to Portland cement slightly improved the compressive strenght of hardened cement paste samples (Fig. 5).

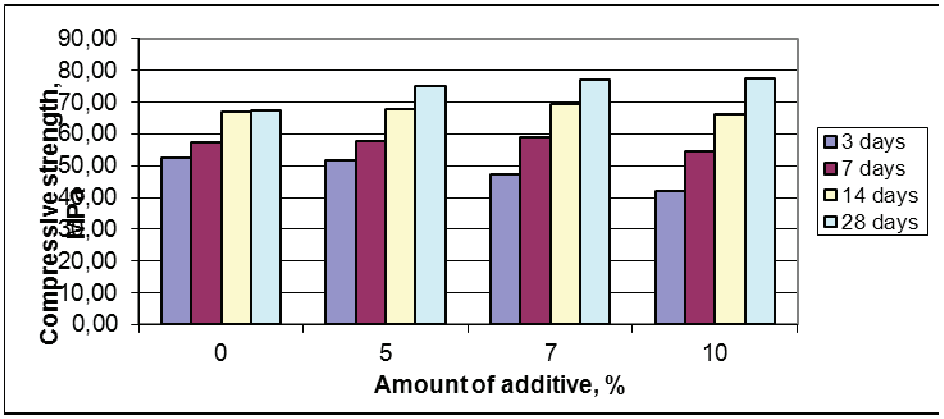

Figure 5. Compressive strength of hardened Portland cement paste with natural zeolite clinoptilolite additive

The strength of the Portland cement paste samples with natural zeolite additive clinoptilolite are similar to the strength of control samples without additive. The pozzolanic reaction take place between alkaline compounds and SiO_2, Al_2O_3 formations in Portland cement hydration process.

CONCLUSIONS

The objective of this study was to investigate the potential effect of natural zeolite clinoptilolite additive to Portland cement hydration process and compressive strength of the hardened cement paste speciments. X-ray diffraction patterns analysis of mineral has stated, that in the natural zeolite dominant compound is clinoptilolite and thermogram DTA (TG) analysis aproved this data. Bending test of samples with adittion of natural zeolite clinoptilolite showed that the bending strenght of hardened Portland cement paste was the same, but compressive strenght of specimens slightly improved. Natural zeolite clinoptilolite additive to Portland cement in hydration process reduces the quantity of portlandite mineral $Ca(OH)_2$. Hardened Portland cement paste minerals takes place in pozzolanic reaction, as oxides SiO_2 and Al_2O_3 reacts with alkaline compounds of hydration reactions, when different calcium hydrosilicates C-S-H minerals are formed.

REFERENCES

Mumpton, F.A. 1999. La rocca magica: Uses of natural zeolites in agriculture and industry. In: Proceedings of the National Academy of Sciences, PNAS, USA. http://www.pnas.org/content/96/7/3463.short

Poon, C., Lam, L., Kou S., Lin, Z. 1999. A study on the hydration rate of natural zeolite blended cement pastes. Construction and Building Material, 13, 427-432.

Yılmaz B., Ucar, A., Oteyakab, B., Uz, V. 2007. Properties of zeolitic tuff (clinoptilolite) blended portland cement. Building and Environmen, 42 , 3808–3815.
Canpolat, F., Yılmaz, K., Kose, M., Sumer, M., Yurduseva, M. 2004. Use of zeolite, coal bottom ash and fly ash as replacement materials in cement production. Cement and Concrete Research, 34, 731–735.
Caputo, D. , Liguori, B., Colella, C. 2008. Some advances in understanding the pozzolanic activity of zeolites:

The effect of zeolite structure. Cement & Concrete Composites, 30, 455–462.

Perraki, T., Kontori, E., Tsivilis, S. , Kakali, G. 2010. The effect of zeolite on the properties and hydration of blended cements. Cement & Concrete Composites, 32, 128–133.
Ahmadi, B., Shekarchi, M. 2009. Use of natural zeolite as a supplementary cementitious material. Cement & Concrete Composites, 32, 134–141.
Mertens, G. , Snellings, R., Van Balen, K., Bicer-Simsir, B., Verlooy, P., Elsen, J. 2009. Pozzolanic reactions of common naturalzeolites with lime and parameters affecting their reactivity. Cement and Concrete Reseach, 39, 233-240.
Uzal, B., Turanlı, L., Yucel, H., Goncuoglu, M., Culfaz, A. 2010. Pozzolanic reactions of common naturalzeolites with lime and parameters affecting their reactivity. Cement and Concrete Reseach, 40, 398-4.
Martinez-Ramirez, S., Blanco-Varela, M., Erena, I., Gener, M. 2006. Pozzolanic reactivity of zeolitic rocks from two different Cuban deposits: Characterization of reaction products. Applied Clay Science, 32, 40-52.
Habert, G., Choupay, N., Montel, J.M., Guillaume, D., Escadeillas, G. 2008. Effects of the secondary minerals of the natural pozzolans on their pozzolanic activity. Cement and Concrete Reseach, 38, 963-975.
Perraki, T., Kakali, G., Kontoleon, F. 2003. The effect of natural zeolites on the early hydration of Portland cement. Microporous and Mesoporous Materials, 61, 205-212.
Poon, C., Lam, L., Kou, S., Lin, Z. 1999. A study on the hydration rate of natural zeolite blended cement pastes. Construction and Building Materials, 13, 427-432.
Nai-Qian, F., Gui-Zhi, L., Xuan-Wu, Z. 1990. High-strength and flowing concrete with a zeolitic mineral admixture. Cement, Concrete and Agregates, 12, 61-69.
Ikotun, B. D. 2009. The effect of a modified zeolite additive as a cement and concrete improver. A dissertation submitted to the Faculty of engineering and the Built Environment University of Witwatwrsrand, Johannesburg. http://wiredspace.wits.ac.za/handle/10539/7923.

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The Impact of Climatic Factors to the Structure of Unprotected Expanded Polystyrene External Insulation on Building (Eps)

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EXTENDED ABSTRACT

With the arrival of the economic downfall in Lithuania, a number of construction projects, including facade thermal insulation work, were suspended. The abandoned thermal insulation layers are influenced by external factors (mostly humidity and temperature) for certain periods of time.

Expanded polystyrene or stone wool slabs are used as the thermal insulation layer. Very popular expanded polystyrene consist of polymerised polystyrol (1.5-2 %) and air (98-98,5 %) (Papadopoulos 2005). Interaction of expanded polystyrene and humidity mostly depends on the structure of polystyrene (Gnip and Kershulis 2004). In the publications mechanical properties of polystyrene foams have been analysed (Mihlayanhar *at al.* 2008, Ramsteiner *at al.*2001, Lin Hong-Ru 1997).

Testing was carried out with extended polystyrene slabs taken from an uncompleted apartment building whose construction was suspended for more than two years. All measurements (long-term water absorption, tensile and compressive strengths) were done according LST EN standards. Samples for testing the micro and macrostructure were taken from places that were the most damaged in visual terms.

With a view to determining the extent of damage of extended polystyrene granules, studies of the macro and microstructures were conducted. Damage to the surface of the granules was established. Then, long-term (28 days) water absorption testing was carried out. The results of water absorption testing obtained showed that water absorption of immersed polystyrene foam samples with damaged surface fluctuates between 1.4% and 2.7%, where density is relatively the same. The determination of the compressive strength of extended polystyrene samples did not reveal any clear destruction of the samples or any precisely expressed value of compressive strength. The results of tensile strength testing were unequal depending on the nature of breakage. Samples with even surfaces broke at the centre, average tensile strength were 84,3 kPa, while the nature of the breakage of damaged samples varied. Testing of compression strength of extended polystyrene samples damaged by the environment showed that these samples are destroyed quicker.

According to the materials used in external system, tensile and compression strengths do not fit into normative strength requirements. According to EN 13163 EPS boards' tensile strength has to be not lower than 100 kPa. In case to refund theses boards by plaster, it probably not reaches wanted result. Expanded polyester's boards' surface is too much damage and not fit normative requirements. Also it damaged by solar radiation, which will affect very low adhesion with plaster. It is advised to remove all boards damaged by climatic factors and change them into new ones or use on other product (for example stone wool).

Keywords: expanded polystyrene, climatic factors, mechanical properties, physical properties

REFERENCES

Gnip,I.J., Kershulis, V.I. 2004. Determination of water absorbtion of expanded polystyrene according European norm methodology. Building Materials,5, 6-7.

Lin Hong-Ru. 1997. The structure and properly relationships of commercial foamed plastics. Polym Test. 16(5), 429-443.

Mithlayanhar,E., Dilmaç, Ş., Gffner, A.2008 Analysis of the effect of production process parameters and density of expanded polystyrene insulation boards on mechanical properties and thermal conductivity. Materials and Design. 29, 344-352.

Papadopoulos, A.M. 2005. State of the art in thermal insulation materials and aims for future developments. Energy and Buildings, 37, 77-86.

Ramsteiner, F., Fell, N., Fosters, S. 2001. Testing the deformation behaviour of polymer foams. Polym Test. 20 (6), 661-670.

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Recycling Possibilities of Sewage Sludge from Water Purification

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EXTENDED ABSTRACT

Annually increasing amount of dry sewage sludge from water purification gradually increases their storage problem. Partly sewage sludge is used as fertilizer in the agriculture or forestry, while still unusable is the part of it containing the harmful admixtures or heavy metals.

As one of the most cheapest and safe methods of elimination of pathogenics in the purification sludge is their composting. The compost produced is used as fertilizer in agriculture and forestry if the pollution of dry matter with hazardous elements does not exceed the threshold limit value (Shinogi *et al.* 2003*;* Lu *et al.* 2008). As one of the possibilities for recycling of sludge containing large amount of heavy metals or other hazardous elements is their addition to concrete, for example, mix from half-and-half of Portland cement and sludge kept either in the autoclave or under pressure. The end-product could be used as building material (Cheilas*,* 2007).

In this paper the sewage sludge from water purification plant was analysed for recycling to the dense glass-ceramic materials using the powder technology route (Rawlings *et al.* 2006). The sewage sludge containing aluminium compounds and circa 50 % of organic matter was used as a filler, but as the matrix of glass-ceramic was examined an illitic clay from Liepa deposit (Sedmalis *et al.* 2002; Sedmale, 2010). The raw materials were investigated by differential-thermal (DTA) and X-ray diffraction analysis (XRD). The dense glass-ceramic was produced from the water purification sewage sludge and limeless clay in ratio 10-40 : 90-60. The optimal bulk density 2.28 g/cm^3 observed for composition S2 containing the 20 wt % of sewage sludge, while the composition with highest content of sewage sludge (40 wt %) resulted with high bulk density ratio 2.30 g/cm^3 by temperature 1180° C, subsequent increasing of density by higher temperatures until 1180° C and at the same time the rapid increase of thermal shrinkage 35 – 45 %.

The results of XRD analysis of material S4 sintered at temperature 1100° C indicate the following crystalline phases: microcline ($KAlSi_3O_8$), hematite (Fe_2O_3), quartz (SiO_2) and corundum (Al_2O_3) which is base for crystalline structure of novel materials. The direction of application of produced glass-ceramics – suitability for building materials could be better evaluated by microstructure studies and mechanical tests.

Keywords: Recycling, sewage sludge, glass-ceramics.

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REFERENCES

Cheilas, A., Katsioti, M., Georgiades, A., Malliou, O., Teas, C., Haniotakis, E. 2007. Impact of hardening conditions on to stabilized/solidfied products of cement–sewage sludge-jarosite/alunite. Cement & Concrete Composites, Vol. 29, 263–269.

Rawlings, R.D., Wu J.P., Boccaccini A.R. Glass-ceramics: Their production from wastes. Review. 2006. J. Mater. Sci, Springer, Vol 41, 733-761.

Sedmale G. Ceramics. Chemistry and technology. 2010. ISBN 978-9934-10-065-9, RTU press, Riga, 2010. 226 p.

Sedmalis, U., Sperberga, I., Sedmale, G. 2002. Latvijas minerālās izejvielas un to izmantošana (Latvian mineral raw materials and usage of them). 2002. RTU press, Riga, 2002. 196 p.

Shinogi, Y., Yoshida, H. Koizumi, T. 2003. Basic characteristics of low–temperature carbon products from waste sludge. 2003. Advances in Environmental Research, 2003. 661 - 665.

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The Suitability of Chemically and Thermally Activated Quaternary Clays of Latvia as Raw Material for Geopolymer Binders

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EXTENDED ABSTRACT

It is now accepted that new binders are needed to replace Portland cement (PC) for enhanced environmental and durability performance. The urge to reduce emissions of carbon and the fact that PC structures having built a few decades ago are already facing disintegration problems points out the handicaps of PC binders. Research works carried out in developing of alkali-activated binders show that this new type of binder could have a huge potential to become as alternative building material. Latvian Quaternary clays were studied from the point of view of the national economy, analysing the physical properties and chemical composition of those sediments in connection with the possibilities of their utilisation in the manufacture of geopolymer materials. Quaternary clay minerals dominate by illite with admixture of chlorite and typically is rich in fine, scattered carbonates (Kurshs and Stinkule, 1997).

The aim of this study was to synthesize geopolymer product from illite clays of Latvia under alkaline activation. Alkaline activation is a chemical process in which a powder material of an alumosilicate nature, such as clay, is mixed with an alkaline activator to produce a paste that is able to set and harden in short time (Duxson *et al*. 2007). Three Quaternary clays of Latvia (AP, SP and PR) characterised by different Si/Al ratio (from 2,8 -3,8) were used for geopolymer synthesis. In order to investigate the effect of the activator on the mechanical properties of material obtained from AP, SP and PR clays 5 and 6 M KOH solutions were used. XRD analysis reveals the formation of new phase (CSH) – only in activated samples. Furthermore it could be noticed the decrease of intensities of the present phases – kaolinite, illite and calcite. FTIR analysis shows the difference in absorption frequencies among activated clays confirming that transformations taking place during material synthesis.

It was concluded that depending on the different SiO_2/Al_2O_3 ratio in the used clays (2,8 for clay PR, 3,5 for clay SP and 3,8 for clay AP) decreases the initial rate of hardening. The best initial rate of hardening showed clay PR with smaller SiO_2/Al_2O_3 ratio. It can be also concluded that with the increase of Si/Al ratio in the source clays appears the difference in the mechanical strength measurements with the increasing of curing temperature higher than 20 ^{0}C. Curing temperature had not an essential influence on mechanical strength of activated clay AP and SP, but strength increased with increasing of curing temperature only for activated clay PR (using for activation both 5M and 6M KOH solution) reaching 60 and 65 MPa, accordingly. IR spectra and XRD results confirmed the differences among activated clays developing the diverse final strength of the obtained samples.

Keywords: alkaline activation, Quaternary clays, inorganic polymers, mechanical strength

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REFERENCES

Duxson, P. Fernández-Jiménez, A., Provis, J.L., Lukey, G.C., Palomo, A., Van Deventer, J.S.J. 2007. Geopolymer technology: the current state of the art. Journal of Materials Science, 42, 2917-2933.

Kurshs, V., Stinkule A. 1997. Mineral Deposits of Latvia. Riga: University of Latvia, 200 p.

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Self-Leveling Floors and Screeds Based on Gypsum Binders: Theory and Practice

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Abstract. The publication contains the results of theoretical and experimental studies of properties of the materials based on gypsum binders, such as self-leveling thin-layer screeds and self-leveling floors. It is determined that these materials demonstrate the technological, physical and mechanical parameters, meeting the applicable requirements for the materials intended for this purpose.

Keywords: Gypsum, carbonate filler, cellulose ethers, superplasticizers, polymer dispersive powders.

INTRODUCTION

To construct buildings and facilities with high level of reliability, high quality of materials is necessary, including the materials for installation, plastering and facing. For this purpose, the Construction Chemistry Department in the Institute BelNIIS RUE carries out the researches for the development of the new high-quality materials, and the enterprises improve their manufacturing facilities, increasing the amount of production of these materials annually.

The reduction of the building weight is quite an important problem for the housing and civil engineering construction in Belarus. Now, the average effective weight of the brick buildings is about 2.5 t/m^2 (in terms of their total area); for bearing-wall buildings, 2.0 t/m^2. However, in the world construction practice, this value is not higher than 1.0 t/m^2 for housing and public buildings. For high-rise buildings, this problem is even more important, because the buildings in Belarus are more than twice heavier than the similar buildings abroad. Therefore, several structures made of concrete, reinforced-concrete and brick, must be replaced by those made of lighter materials, such as gypsum.

Gypsum building mixes are widely applied in construction. The number of enterprises applying these materials grows stably. Following the imported products, the quite competitive similar domestic materials appear.

INITIAL MATERIALS

Gypsum-based materials and articles are the advanced building materials due to their easiness, cost efficiency and low energy consumption for manufacturing. Application of building mixes based on gypsum binders, in a large extent, is due to the combination of beneficial properties inherent for this group of binders only. These materials are free of shrinking deformation, they demonstrate rapid strength gain, good heat insulation and sound insulation properties (Ferronskaya, 2006).

Unlike the cement building mixes, gypsum ones can not only absorb moisture, but also deliver it, resulting in stable humidity in a room and, therefore, providing comfortable conditions in it.

Wide range of modifying additives is applicable for building mixes, providing opportunities to apply gypsum binders for such structures as a floor.

A floor is a multilayer horizontal structure, with each layer providing its specific functions. Special attention shall be paid to self-leveling floors and screeds; these materials, because of their complexity, shall be prepared at a factory and only as dry building mixes.

These building mixes are complex multi-component compositions with several specific characteristics, such as self-leveling and rapid strength gain. Coatings, based on these materials, must not be leveled after their hardening and are appropriate for subsequent application of various finishing materials, such as ceramic tiles, linoleum, parquet etc.

As a result of this research, the compositions were developed and studied, applicable to make thin-layer self-leveling screeds, 2…10 mm thickness, and self-leveling floors, 10…40 mm thickness. These compositions

are based on gypsum binders, G-4 (β-modification), manufactured by Belgips OJSC, and G-10 (α-modification), manufactured by Zabudova OJSC.

When water is used to temper α-hemihydrate, less amount of water is necessary for the required paste fluidity as compared with β-hemihydrate. As a result, hardened gypsum made of α-hemihydrate becomes more dense and strong than that made of β-hemihydrate. If the equal amount of water is used to temper α- and β-hemihydrates, the resulting strengths of gypsum rock are approximately equal (Uretskaya *et al.* 2006).

Articles made of gypsum demonstrate low water resistance: their strength significantly deteriorates in case of moistening. For the hardened gypsum, the softening coefficient is 0.35…0.45; this coefficient characterizes the gypsum water resistance and calculated as a ratio of the strength of water-saturated specimens to the strength of dry specimens. To solve the gypsum water resistance problem, it can be used in combination with hydraulic binders, active mineral additives, polymeric and chemical additives; also, the composite binders can be developed. This shall result in expansion of the relevant scope of application.

To improve workability, reduce the product cost and prevent cracking during operation, aggregates are added to the gypsum mixtures. The correct choice of the aggregate (with appropriate dispersion, moisture content and hardness) and appropriate "mineral binder / aggregate" ratio are necessary to ensure high quality of the final product.

For the widest range of building mixes, silica sand is used as the basic aggregate. It is known that clay and dust impurities in the cement-based building mixes negatively affect their quality. However, for gypsum mixes these impurities in the aggregate have no such a detrimental effect on the key properties of the hardened mortar.

To reduce the product cost and to prevent cracking during operation, fillers are also included in them, such as marshalit (quartz powder), dolomite powder or chalk. Carbonate microfillers have a common ion with calcium sulphate, resulting in their tight contact during the natural hardening process and, subsequently, in merging of the gypsum hydration products with fillers. Carbonate rocks have an important specific property: they actively interact with gypsum, both physically and chemically, and take part in the structure formation. Also, if 30% of the carbonate filler is added into the system, this results in growth of the gypsum binder's strength characteristics by 35%.

Thus, the correct choice of the aggregates and fillers (with appropriate dispersion, moisture content and hardness) and appropriate "mineral binder / aggregate / filler" ratio are necessary to ensure high quality of the final product.

To improve plastic properties and reduce shrinkage deformations, hydrated lime is added to gypsum-based mixes.

To reduce crack formation and to improve water resistance of the gypsum mixture, M 400 D 20 slag portland cement (SPC) was used in this study.

The characteristic of building materials' water resistance is the softening coefficient. To calculate it, the strength values of water-saturated specimens shall be divided by the strength values of dried specimens (the specimens must be dried to make their weight constant). It should be noted that when SPC is used in gypsum mixes, the softening coefficient grows from 0.30 (pure gypsum) to 0.50 (gypsum – SPC combination).

As a result of the study, it was demonstrated that if 3…5% of the SPC is added into the gypsum mix, this results in growth of the early strength by 40…50%.

Because gypsum mixes are rapidly-hardening, it's of high importance to study the hardening retarders influence on technological, physical and mechanical properties of the new mixes. In this study, citric acid and calcium salts of N-polyoxymethylenamine were used for this purpose. The effect of hardening retarders for gypsum binders is based on formation of pH-environment that suppresses the calcium sulphate hemihydrate solubility and, as a result, suspends the processes of formation and stabilization of primary calcium hydrates.

The moisture-absorbing base materials (such as brick, concrete, cement and sand mortar etc.) absorb moisture from the mortar mix very quickly that can result in water amount insufficiency for hardening. As a result, cracks arise when the mortar is still wet, and the mortar "burns" on the base material. To avoid this effect, i.e. to improve the water-retentive capacity and to make the mortar mix sufficiently viscous, cellulose ethers shall be used.

To modify the gypsum binders, methylcellulose of various types was used, with Hoeppler viscosity about 20 … 20,000 MPa·s. As a result, it was found that N 20 R2 methylcellulose is preferable for self-leveling floors and screeds, because the resulting gypsum mixes are optimal in terms of water-retentive capacity and consistency. Cellulose ethers play quite important role, although their amount added to the composition is small (about 0.02…0.7%) (Biits and Lindernau, 1998, Khrebtov *et al,* 2000, Lange, 1999).

Superplasticizers have a great effect on the water demand of mortars. If the mortar contains superplasticizers, less water is necessary to for the same consistency (as compared with the mortars not containing superplasticizers). Superplasticizers are used predominantly in building mixes for which the very good self-leveling characteristics are required (e.g. for self-leveling floors and screeds). Their amount to be added is about 0.15…1.0%.

Polymer powders were added into gypsum mixes to improve their adhesive strength (strength of bonding with the base material), flexural strength and water resistance. Also, polymer powders, when added to the fresh mortar, increase the consistency of air pores and promote the formation of uniform and homogeneous mortar layer. While the water is removed from the gypsum mortar, the polymer forms a thin film on the surfaces of pores, capillaries and gypsum grains. This film demonstrates good adhesion and improves the mortar solidity.

It should be noted that the behavior of polymers in mixes differs depending on the gypsum grade. For gypsum mixes based on G-10 gypsum, polymers effects are more expressed.

Thus, the materials used to develop the self-leveling screeds and floors were as follows: gypsum binders, slag Portland cement, mineral aggregates and fillers, various modifying additives, and polymer binding additives.

RESULTS

Great attention in this study was paid to the regulation of the gypsum grout consistency and setting time as functions of the type and amount of chemical additives included in the composition.

Due to optimal combination of polymer dispersive powders, superplasticizers and other chemical additives, spreadability was significantly improved, and acceptable setting times were achieved. Also, dispersive polymer powders, when added to the fresh mortar, increase the consistency of air pores and, as a result, promote the formation of uniform and homogeneous mortar layer.

To study the dispersive polymer powders' effects on the properties of materials based on gypsum binders, several polymer additives were used: acrylate copolymer (higher spreadability); vinyl chloride / ethylene / vinyl laurate copolymer; vinyl acetate / ethylene copolymer; vinyl acetate / ethylene copolymer (higher spreadability); butyl acrylate / styrene copolymer. The amount of polymer additives was 1% … 5% of the gypsum weight.

See Figures 1 and 2 for plots describing the gypsum grout consisyency as a function of the type and amount of the polymer additive.

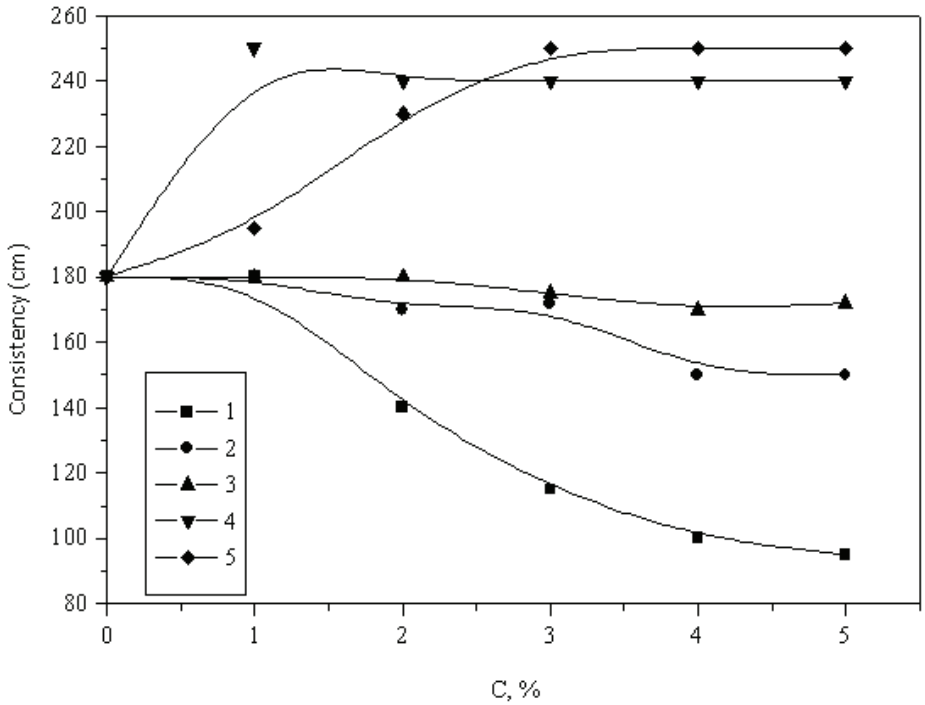

Figure 1. Gypsum grout consistency as a function of the polymer additive consistency (G-4 gypsum binder, water/gypsum ratio = const)
1 - acrylate copolymer (higher spreadability); 2 - vinyl chloride / ethylene / vinyl laurate ternary copolymer; 3 - vinyl acetate / ethylene two-component copolymer; 4 - vinyl acetate / ethylene copolymer (higher spreadability); 5 - butyl acrylate / styrene copolymer

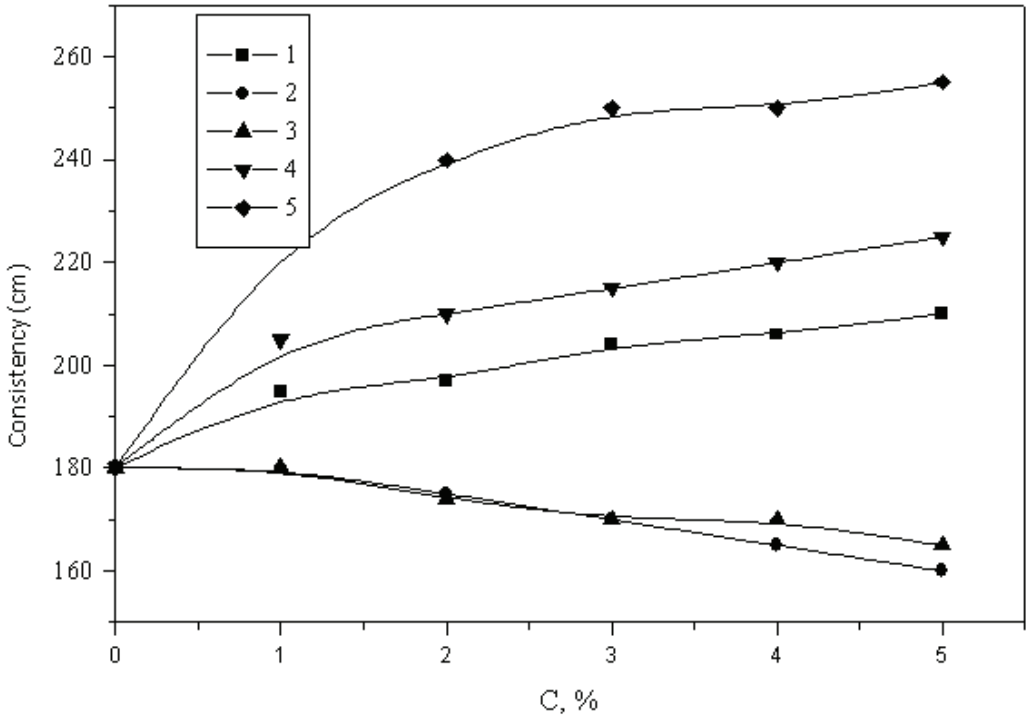

Figure 2. Gypsum grout consistency as a function of the polymer additive consistency (G-10 gypsum binder, water/gypsum ratio = const)
1 - acrylate copolymer (higher spreadability); 2 - vinyl chloride / ethylene / vinyl laurate ternary copolymer; 3 - vinyl acetate / ethylene two-component copolymer; 4 - vinyl acetate / ethylene copolymer (higher spreadability); 5 - butyl acrylate / styrene copolymer

These plots demonstrate that, due to the optimal consistency of polymer dispersions, such as butyl acrylate / styrene copolymer, acrylate copolymer (higher spreadability), vinyl acetate / ethylene copolymer (higher spreadability), gypsum-based compositions with high spreadability can be obtained. This is the important result for the development of the self-leveling thin-layer screeds.

It should be noted that the behavior of polymer dispersive powders in mixes based on G-4 and G-10 gypsum is quite different. This is because G-4 is the product of low-temperature annealing. It contains large amounts of impurities and, therefore, its crystalline hydrate lattice has many defects, resulting in 58% water demand. As for G-10, its crystalline lattice is more perfect, its molecule includes adsorption water and, resulting from its manufacturing technology (in saturated steam), its water demand is 45%.

For polymer powder redispersion, some amount of water is required. In mixes based on G-4 gypsum, larger amount of free water is used, and the mix rapidly thickens. In our opinion, for G-10, free water partially remains in it, but not in a free state; it is adsorbed on the crystal hydrate surface, resulting in higher mobility of the mix. As for G-4 gypsum binder, there is no adsorption water in it, as a result of its manufacturing technology.

While the water is removed from the gypsum mortar, the polymer forms a thin film on the surfaces of pores, capillaries, grains of gypsum, filler and aggregate. This film demonstrates good adhesion and improves the mortar solidity. As a result, the gypsum mortar has specific properties: flexural strength (higher than that for the mortar in which there are no polymer additives), high adhesion, improved water resistance.

Due to optimal combination of polymer dispersive powders with superplasticizers and other additives, high spreadability of gypsum mixes can be achieved.

The superplasticizers used for the gypsum binder modification were as follows: melamine formaldehyde-based (Melment F10, Germany); sodium salt of polymethylene naphthalensulfonic acid (C-3, Russia); polycarboxylate (Melflux 1641, Germany).

The effect of superplasticizers is based on their adsorption on the solid-phase surface. As a rule, with higher molecular weight, their adsorbability and plasticizing activity become higher.

It should be noted that the activity of C-3 and Melment F10 is based on electrostatic effects; as for Melflux 1641, its activity is based on the combination of electrostatic and steric (i.e. spatial) effects. The latter is provided by hydrophobic polyester side chains in the molecule of polycarboxylate ether. For such superplasticizers, there water-reduction activity is several times higher than for the plasticizers without this

effect. The steric effect results not only in higher mobility of the mortar in early times, but also in its preservation for a long time.

For G-4 gypsum binder, maximum spreadability of the gypsum grout was demonstrated with Melflux 1641 superplasticizer; for G-10, with Melment F10 (see Figures 3 and 4).

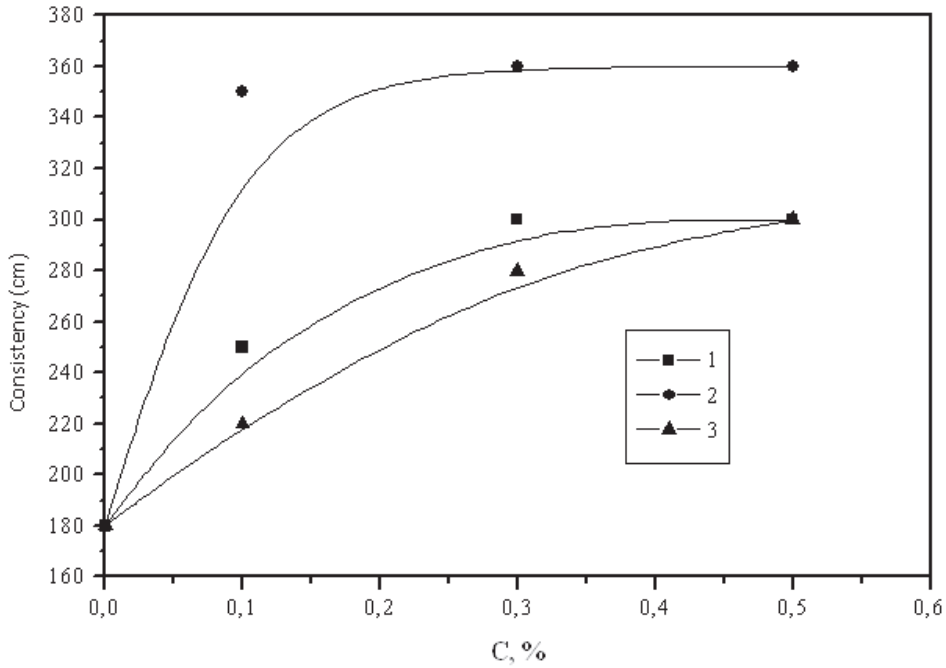

Figure 3. Gypsum grout consistency as a function of the superplasticizer consistency (G-4 gypsum binder)
1 – Melment F10; 2 - Melflux F 1641; 3 - C-3

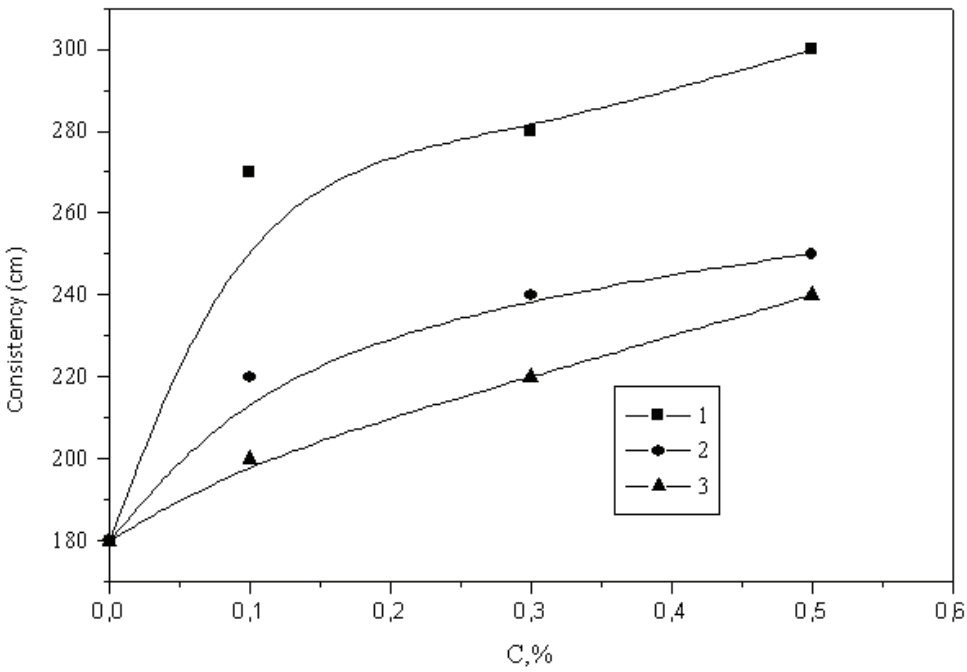

Figure 4. Gypsum grout consistency as a function of the superplasticizer consistency (G-10 gypsum binder)
1 – Melment F10; 2 - Melflux F 1641; 3 - C-3

These superplasticizers have significant influence on rheological, physical and mechanical properties of the gypsum grout and gypsum rock based on it.

Thus, due to optimal combination of polymer dispersive powders, superplasticizers and methyl cellulose, much better spreadability, glossy floor surface and mortar homogeneity (i.e. lamination-free structure) can be achieved.

G-4 is the low-grade gypsum binder. One of the ways to improve the physical and mechanical characteristics of the mortars is to fill the matrix of the gypsum binder with highly dispersed mineral fillers different in their type and fractional composition.

As a result of experimental studies, it was found that fine-dispersed carbonate filler in a system with low filling ratio (5-10%) behaves as a plasticizer. For higher filling ratio (30%), the water demand grows slightly, but the strength characteristics of the filled gypsum binder are about 35% higher than those for the reference combination. The strength characteristics become higher, because fine-dispersed particles of the carbonate filler fill the gaps between the coarsest grains of the gypsum binder.

When fine-dispersed carbonate filler is used to fill G-10, the high-strength gypsum binder, and the amount of the carbonate filler exceeds 20%, the strength characteristics deteriorate significantly. At our opinion, this is because the grains of the densely packed gypsum crystals are moved apart, and gaps appear between them.

To make a floor with high durability, a screed must be dry, with strong and smooth surface, and it must have high adhesion against the adjacent floor elements. Also, coatings must be used, with high tensile strength, compressive strength, elongation at break and bonding with the base material.

See Table 1 for the main technological, physical and mechanical properties of the developed compositions, based on gypsum binder, for making self-leveling floors and thin-layer screeds.

Table 1. Key characteristics of mixes

No.	Characteristic	Unit	Value	
			Self-leveling floor (G-4 / G-10)	Self-leveling screed (G-4 / G-10)
1	Mortar density	kg/m^3	1580-1620 1700-1750	1500-1550 1550-1600
2	Minimum consistency	mm	280 300	300 300
3	Minimum service life	minutes	40 45	40 45
4	Layer thickness	mm	10-40 10-40	2-10 2-10
5	Compressive strength	MPa	15.0-16.0 20.0-22.0	17.0-18.0 22.0-24.0
6	Bending tensile strength	MPa	5.0-5.5 4.5-5.5	5.5-6.0 6.0-7.0
7	Minimum bond strength (adhesion to base material)	MPa	0.80 0.80	0.80 0.80

The materials, developed within the scope of this study, has good heat insulation and sound insulation properties, fire resistance and flame resistance. If gypsum is used for fire protection, the risk of destruction of the protective concrete layer is reduced; in case of fire, only the protective gypsum layer must be restored after it.

It should be noted that gypsum-based materials used for indoor facings of buildings are favorable for the good climate in the rooms, due to the gypsum capability to “breathe”: it can readily absorb excessive moisture and then gradually release it, maintaining the air humidity balance. This property has a positive effect on the microclimate in the building as a whole, resulting in comfortable conditions for dwellers or personnel.

CONCLUSION

1. Within the scope of the work for the development of self-leveling screeds and floors based on gypsum binders, the situation in Belarusian and foreign industry was studied with regard to these materials manufacturing. In highly developed countries, these materials are widely applied.

2. As a result of the studies, optical compositions were developed for self-leveling screeds and floors. Optimal content of polymer dispersive powders, superplasticizers, cellulose ethers, hardening retarders and other chemical additives was selected.

3. SPC M 400 D 20 in the amount of 3-5% was added for the first time to the content of gypsum mixture with the aim to reduce crack formation and to improve water resistance of the self-leveling screeds and self-leveling floors.

4. It was determined that the developed self-leveling screeds and self-leveling floors demonstrate the technological, physical and mechanical parameters, meeting the applicable requirements for the materials intended for this purpose.

REFERENCES

Бийц Р., Линдернау Х., Химические добавки для улучшения качества строительных растворов. //Строительные материалы, №3, 1998, с. 13-15. [Biits R., Lindernau H. Chemical additives for mortars quality improvement // Building Materials Journal, No.3, 1998, p. 13-15].

Ланге В. Метилцеллюлоза «Walocel M» улучшает качество систем сухих строительных смесей. //Строительные материалы, №3, 1999, с. 38-39. [Lange V. Walocel M Methylcellulose improves quality of dry building mix systems // Building Materials Journal, No.3, 1999, p. 38-39].

Урецкая Е.А. , Плотникова Е.М., Кухта Т.Н. Теория и практика создания конкурентноспособных материалов на основе гипсового вяжущего. //Строительная наука и техника, №3, 2006, с. 70-74. [Uretskaya E.A., Plotnikova E.M., Kukhta T.N. Development of competitive materials based on gypsum binder: theory and practice // Construction Science and Engineering Journal, No.3, 2006, p. 70-74].

Хребтов Б.М., Кашин П.А., Генцлер И.В., Высококачественные материалы для сухих строительных смесей. //Строительные материалы, №5, 2000, с. 4-5. [Khrebtov B.M., Kashin P.A., Gentsler I.V. High-quality materials for dry building mixes // Building Materials Journal, No.5, 2000, p. 4-5].

Ферронская А.В. Гипс – вчера, сегодня, завтра //Сборник трудов III Всероссийского семинара с международным участием. «Повышение эффективности производства и применения гипсовых материалов и изделий» Тула, 2006, с.27-34. [Ferronskaya A.V. Gypsum: yesterday, today, tomorrow // Proceedings of the III All-Russian Workshop with International Participation: Improvement of the effectiveness of manufacturing and application of gypsum materials and articles. Tula, 2006, p.27-34].

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Production Waste of Granite Rubble Utilisation in Ultra High Performance Concrete

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EXTENDED ABSTRACT

Concrete has been a leading construction material for over a century. While during the last two decades Ultra High Performance concrete (UHPC) has been developed steadily (Nguyen Van Tuan et al. 2010). Some by-products or waste materials such as granite rubble could be incorporated in UHPC due to economic reasons (Nguyen Van Tuan et al. 2010, Nima Farzadnia1 et al. 2011). In this article researched, how waste of granite rubble is affecting main properties of UHPC: viscosity, density and compressive strength.

The materials used in experiments were: Lithuanian company AB "Akmenės cementas" Portland cement CEM I 52.5 R; „BASF" company SiO2 fume; company UAB „Granitas" granite rubble raw waste (S0) and grounded (S2); company AB „Anykščių kvarcas" ground quartz sand; quarry of „Anykščių kvarcas" sand of 0/2 fraction; superplasticizer „Glenium SKY 623" produced by company „BASF".

Dry fillers were used to prepare concrete mixtures. Cement, fillers and micro fillers were dosed by mass, while water and chemical additives – by volume. Some chemical additives were dissolved in water and mixed into the mixture together with water, some without water.

Mixing of concrete mixtures is made with the vibro-mixer. Mixing starts from the lowest frequency and during 15 seconds it is raised to the maximum. Dynamic viscosity of the mixture was measured using Falling ball method.

There were formed 6 non-conventional form cylindrical specimens and 7 different concrete mixtures of UHPC. Specimen 1 is called reference mixture. Granite rubble waste was grinding for some time (5, 10, 15 and 20 minutes) with laboratory vibro-mixer before the concrete mixing in order to determine the changes in particle fineness of granite and researched that effective grinding time is 10 minutes. Therefore, only two different particles sizes were used in further experiments (S0, S2). During the experiment three main characteristics (dynamic viscosity, density and compressive strength) were determined and compared with reference mixture. Instead of the quartz sand, in the specimens 2 and 3, granite rubble waste (S0 and S2, respectively) were used. Test shows that dynamic viscosity increases when an admixture is coarse. It is observed during the experiment that density generally decreased replacing different part of the cement with granite rubble waste. The reduction was negligible, while in the third specimen the density reduced more than 4 %. Specimens 3-7 were made with granite rubble waste as a partial cement replacement. Granite rubble waste used in these mixtures had the same specific surface area S2 and might be considered to be as micro filler. Using more percentage of granite instead of cement tends to increase W/C ratio. The mixture with up to 10% of cement replaced with granite rubble waste content reached a maximum compressive strength of 131 MPa. Using higher percentage of granite rubble waste, compressive strength tends to decrease slightly. Granite rubble waste can be used in UHPC.

Keywords: Ultra High Performance Concrete, UHPC, granite rubble waste.

REFERENCES

Nguyen Van Tuan, Pham Huu Hanh, Le Trung Thanh, Ye Guang, Marios N. Chris I. "Ultra High Performance Concrete Using Waste Materials for High-Rise Buildings". CIGOS-2010. High-rise buildings and Underground structures Paris, November 18&19, 2010.

Nima Farzadnia1, Abang Abdullah Abang Ali and Ramazan Demirboga. "Incorporation of Mineral Admixtures in Sustainable High Performance Concrete". International Journal of Sustainable Construction Engineering & Technology Vol 2, Issue 1, June 2011, 44-56.

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The Distribution Analysis of Concrete Horizontal Surface Air Pores

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EXTENDED ABSTRACT

The research was conducted in order:

- To perform the casting with one random, conventional concrete mixture using five different formwork materials.
- To calculate the number of blowholes at the specific concrete element surface.
- To establish the size (area) of the blowholes obtained after the concrete element has been formed;
- To perform the statistical analysis of the obtained blowholes.

Portland cement CEM II/A-LL 42.5 R was used for the test. Kvesu quarry sand with the fractions of 0/1 and 0/4 was used as fine aggregate. Gravel with the fraction of 4/16. Random composition of concrete mixture was prepared. Plasticizing admixture (SP) based on polycarboxylatether was used (MURAPLAST FK 801.1), dosage of 1,4 % of cement. Also form release agent was used (Ortolan SEP 711). To perform the casting five different formworks were used: wood impregnated with polymeric oil [WPO]; wood covered with rubber [WCR]; sawn timber [ST]; plastic [P] and metal [M] forms.

"ImageJ" method has provided visual information about the quality of concrete surfaces in respect to the ratio between area of blemishes and whole specimen. Concrete specimens were cured at the different formworks for 7 days at the temperature of 20±2 ^{o}C.

In addition, statistical analysis of the results was conducted. Three casting with each formwork's material were performed. Computer programs "Mathcad 15" and "Excel 2010" were used. Following statistical parameters of blemishes area were calculated: mean value (MV), dispersion (D), standard deviation (SD) and the coefficient of variation (CV). Also maximum (MAX) and minimum (MIN) values of experimental results are given. The biggest relative frequency of experimental results is provided.

Keywords: Concrete surface quality, air pores, formworks, decorative concrete, statistical analysis.

REFERENCES

ACI 309R. Guide of Consolidation of Concrete. 2005. ACI Committee 309, technical committee document 309R-05 2005, 35.

ACI 116R. Cement and Concrete Terminology. 2000. American Concrete Institute. 2000, 73.

ACI 309.1R. Behavior of Fresh Concrete During Vibration. 2008. ACI Committee 309, technical committee document 309.1R-08. 2008, 18.

CIB Report no. 24, commission W29. 1973. Tolerances on blemishes of concrete, 1973.

Coutinho, J. S. The Effect of Controlled Permeability Formwork (CPF) on white concrete. 2001. ACI Materials Journal. Vol. 98. No. 2. 2001, 148-171.

Duggan, T. Enhancing Concrete Durability Using Controlled Permeability Formworks. 1992. 17th Conference on Our World in Concrete and Structures. Singapure, August 1992: pp. 57-62.

Klovas, A., Daukšys., M. 2011. Apdailinio betono paviršiaus kokybė ir defektai // Statyba ir architektūra: jaunųjų mokslininkų konferencijos pranešimų medžiaga / Kauno technologijos universitetas. Kaunas: Technologija, 2011. ISBN 9786090202555, 99-108. [Quality and defects of the decorative concrete surface // Civil engineering and architecture: conference of the young scientists, proceedings / Kaunas university of Technology. Kaunas: Technology, 2011. ISBN 9786090202555, 99-108]

Lemaire, G., Escadeillas ,G., Ringot, E. 2005. Evaluating concrete surfaces using an image analysis process. Construction and Building Materials 19 2005, 604 – 611.

Menard, J.P. 1999. La qualite pour tous les usages. Construction Moderne 101 1999, 12. [Quality of all uses. Construction Modern 101. 1999, 12.

Price, W. F. Controlled Permeability Formwork. 2000. CIRIA Report C511. 2000, 102.

Reading, T.J. The Bug Hole Problem. 1972 ACI Journal, Proceedings V. 69, No. 22, Nov. 1972, 165-177.

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Conversion of Industrial Buildings to Residential Buildings

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Abstract. An old trend to adapt industrial building to housing prevails in the world. Such type of housing is called "loft". The results are quite impressive and loft-type apartment's prices keep rising, not mentioning the fact that during the time it even gains a collectible value. However, not all of the industrial buildings can be adapted for living. This article discusses the possibilities of industrial buildings to be converted to liveable housing facilities. With reference to the analysis brought out by investigating the provided list of literature the "loft" classification is derived. The work distinguishes the main industrial buildings adaptation forms; presents the factors, that influence the selection of housing adapted from industrial buildings; formulates the criteria, that determines the industrial building applicability for housing; analyses the possibility of changing the purpose of the industrial premises for residence usage; researches the impact of location and communication for "loft" establishment. The aim of this work is to suggest the builder (project manager) a comprehensive assessment tool, which would help one to choose the most rational and effective conversion option of industrial building to housing facilities.

Keywords: loft, industrial building, conversion

INTRODUCTION

Abandoned and unused for manufacturing purposes industrial buildings stand in central areas of cities, and few people think that they can be resurrected to new life. However, there is a long-term tendency in the world to use industrial buildings, which are in exclusive areas of cities, for housing. The results are impressive, the prices of such buildings never stop rising, and, in the course of time, they acquire great value even for collectors.

There is an old practice in the world to adapt old and abandoned industrial buildings for various non-industrial activities. Stylish offices, law firms and artist's studios take shelter in former workshops.

Michael Stratton (2000) distinguishes four main forms of usage of industrial buildings. All of them are presented in Figure 1 (Stratton, 2000):

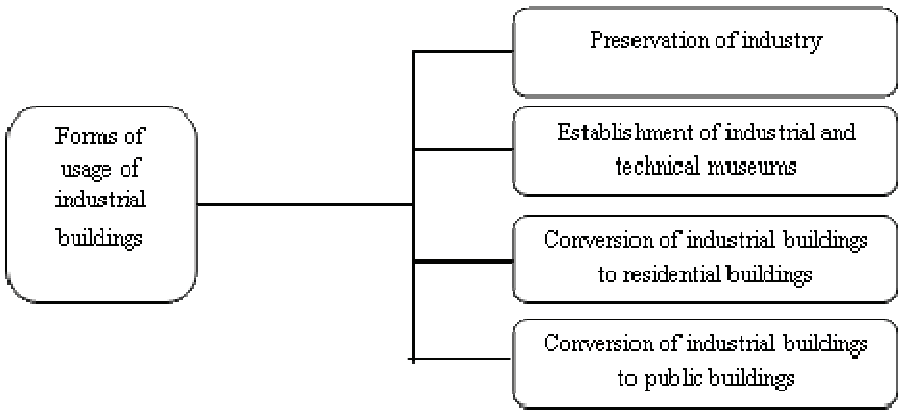

Figure 1. Forms of application of industrial buildings

Old industrial buildings often serve as brands and they become integral parts of trademarks of companies. The older the trademark, the more stable are the operations of companies. (Couch 2003) Declaration of long-standing traditions of production is a sort of guarantee of product quality. It also increases sales and market value of a manufactured product. This is due to the fact that any production, irrespective of the novelty of technologies applied, is inseparable from the long-term traditions of production. In order to advertise their name, companies have been using "antiquity" as their image for a long time. In advertisements, companies are eager to present as old date of their establishment as possible, they emphasize a long-term and trusted technology, prestige and reliability. Long-term experience is promoting consumer confidence in the firm‘s services. Imposing architecture of a factory enhances a prestige and good image (Kulevicius *et al.* 2004).

Historical technical museums with various exhibits and documentation are often established on industry heritage sites. Such British industrial towns like Bradford have become industrial tourist cities; ecomuseums (in Ironbridge) have been created and advertised as industry cradles in the areas of industrial heritage; individual industrial complexes have been transformed into work or lifestyle museums; in addition, large industry centers, such as New Lanark or Saltaire, have been memorialized and included into heritage. Most of such museums and sites emphasize ingenuity, craftsmanship and prowess of British business and technology. This encouraged one of the most common methods of preservation of former industrial companies – establishment of museums of technologies, industry, work, employees or sometimes of an individual company or a branch of industry. Rademacher Blacksmith museum in Eskilstuna, Sweden, is considered to be one of the first of such museums. It was founded in 1907.

Currently, there are at least 23 museums in Lithuania related to industrial heritage (since they are not directly museums of industrial heritage). The name of museum reflects its type, features of collections and activities. Although all industrial or museums of industrial heritage have different names, they can be attributed to the same group of technical or industrial museums (Stelbiene *et al.* 2005)

METHODS

Classification of lofts

Loft is a type of residential area, spacious apartment with high ceiling and without partitions; large abandoned industrial building (e.g. former workshop) converted into an apartment fabrikas.

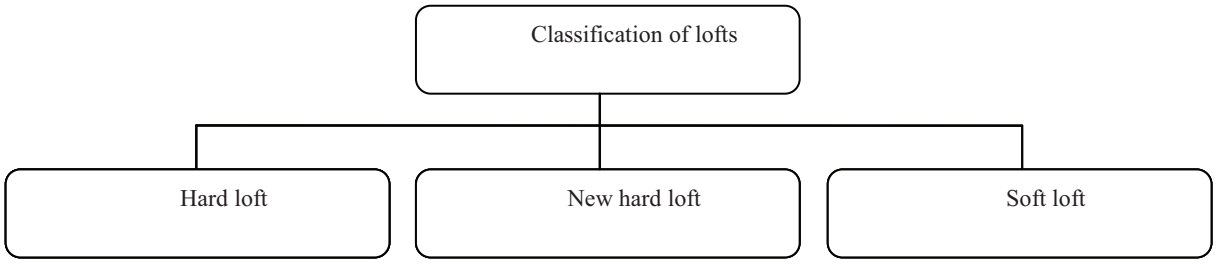

Figure 2. Classification of lofts according to type

Hard loft, which is also known as an "Industrial loft", is a former factory, warehouse or any other industrial site transformed into residential premises. Hard lofts typically have concrete ceilings and floors, untrimmed walls of old bricks, large windows, unhidden communications, ventilation and plumbing.

New hard loft – premises that comprise all the features of hard lofts, but they are newly reconstructed, mostly in luxurious areas, in accordance with all the energy saving requirements.

Soft loft is similar to a reconstructed hard loft, however, some details, which are characteristic of hard loft, are hidden or trimmed, for instance, wooden floor is installed instead of concrete floor, communications and ventilation installations are hidden. The same large space is prevalent, but these lofts are closer to traditional apartments.

Factors affecting choice of industrial buildings adopted for housing

Daily *Lietuvos Rytas* has carried out a survey and interviewed more than 200 residents of large cities. Internet consumer survey was conducted in March-April of 2011. According to this survey, more than a third of respondents (38%) will eagerly purchase loft-type apartments because of a good price. The second important reason of lofts popularity and investments into former industrialized areas is the uniqueness of the project. This is a major cause for at least the same number of buyers who buy lofts because of an attractive price – 35%.

According to the architects from the company *Devyni Architektai*, the survey data reveals that lofts are becoming much closer to people building individual house, as their priority is unlikeness and price. Among the buyers of flats only cost is the main criterion while purchasing an apartment.

The study shows that more than a half of respondents (59%) would pay 3000 LTL per square meter for accommodation in industrial buildings, one in five persons (20%). would pay up to 4000 LTL. Only 2% of respondents would pay up to 6000 LTL per square meter, but only after consideration of the level of home decoration.

The main factors promoting to choose an accommodation of this type are presented in Figure 3.

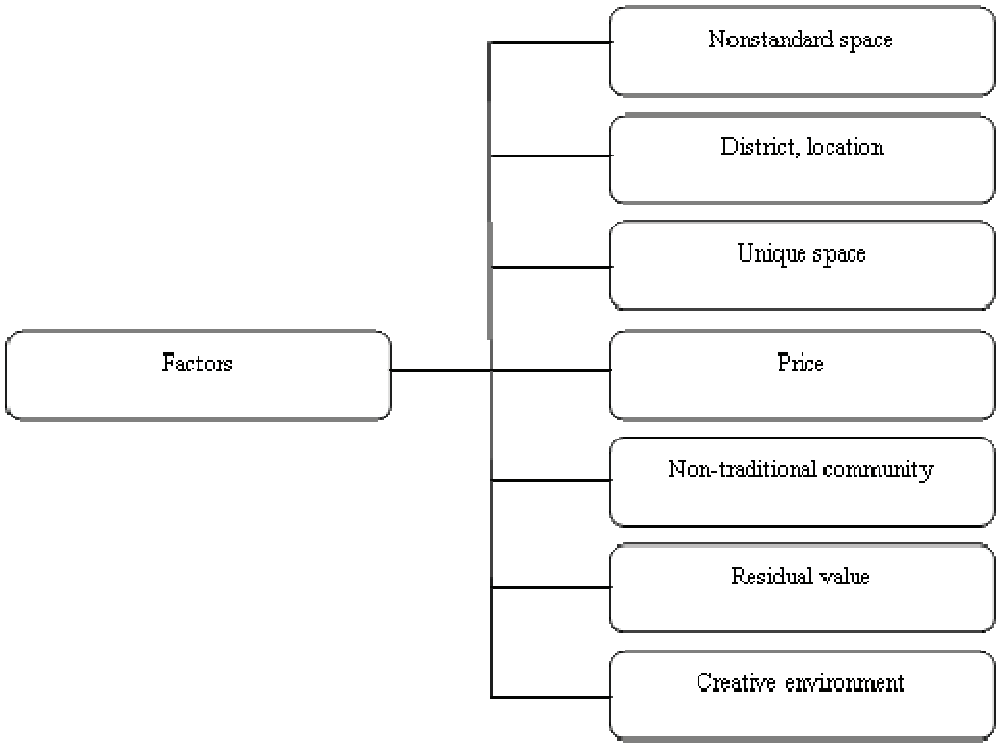

Figure 3. Main factors determining the choice of loft-type housing (created by the author)

Loft prices

Over the decade, when industrial facilities in Lithuania were started to adapt for housing, the price of housing space has increased about 10 times (e.g. at the end of the 20th century, the premises price in factory „555“ was about 500 LTL per one square meter ; in 2008, real estate companies proposed residential areas in industrial buildings for 5000 LTL per one square meter (Vilkauskaite, 2008). Currently, businessmen and real estate agents are eagerly investing in lofts. Located in attractive locations, once-abandoned factories have become a marketable product for real estate developers.

Lofts are particularly valued in the USA and Europe, since there are only few left. For instance, one square meter of a loft in New York City costs up to 12 000 U.S. dollars; in the Czech Republic it costs from 3000 to 4000 U.S. dollars; in Moscow, one square meter of a loft overlooking the Moscow River costs from 30000 to 50000 U.S. dollars. So far the experience of the largest cities reveals that investments in lofts are profitable, and real estate experts say that loft prices may rise even dozens of times (Balkunas, 2011).

Specific examples of loft prices in Lithuania are presented in Table 1.

Table 1. Loft prices in Lithuania

Serial No.	Name of a loft	Price, LTL/sq. m.
	Vilnius:	
1	Soho Lofts	3000 – 3500

2	Radio Lofts	3000 – 3300
3	Soho Mini Lofts	3000 – 3400
4	Loft Town	3500 – 4000
5	Lofts in Fuel Hardware Factory of Vilnius	2300 – 2500
6	Lofts in Vytenis street	2300 – 2400
7	River Lofts	3750 – 4150
8	Lofts in 555	3000 – 3100
	Kaunas:	
9	Žaliakalnis lofts in P. Kalpokas street	2200-2400
	Klaipėda:	
10	Loft Gigant	1950

Loft prices have been established on the basis of data collected by Inga Butkute (RE/MAX real estate agency), who works with loft projects in Vilnius.

On the basis of analysis of prices and taking into account the extent of reconstruction, it can be concluded that prevailing price of lofts in Vilnius is about 2300 LTL per square meter. If there is no major reconstruction of facades, if overhaul of the facade is carried out, loft prices start from 3000 LTL per sq. m. There are not many examples from other cities, but we may state that the price should be relatively lower considering lower prices of real estate in comparison to market prices in the capital city.

Area, site

As cities are growing and expanding, the land prices in the centre of the city are also rising. Industrial districts are increasingly being pushed behind the boundaries of the city center, leaving behind abandoned large industrial buildings. Industry began to settle down in former suburbs with available free land:

- On river coasts
- Near railway tracks
- Near major roads and highways

One of the major features of lofts is that the industrial buildings that are selected for conversion to residential dwellings are located in the very metropolitan centers, where land and apartments are very expensive. One of the greatest advantages of lofts is the possibility to live in the city center, large spaces and an affordable price.

Reconstructed industrial architectural objects often can be distinguished not only for their striking appearance and convenient location. Such buildings usually are located in picturesque locations – near rivers and canals and, in exceptional cases, even on the sea coast (typical to seaports).

Exclusivity, attractive way of life and the fashion factor

Since lofts attract people due to their nonstandard and exceptional appearance, the places where they are located also look exceptionally, e.g.:

- Water tower
- The clock tower on the upper floor of a factory
- The upper floor of a skyscraper

The number of industrial buildings in the central or picturesque parts of the city is limited, and, in the course of time, they acquire a long-lasting value. Located in exclusive areas, these lofts also acquire great collectible value, and that is also one of the reasons why their prices are rising so fast in the world.

To live in an exclusive apartment and to be the sole and exclusive owner of such an apartment is an attractive idea not only for artists but for businessmen as well. However, apartments in such exclusive areas cost a lot of money, e.g.: An apartment in Brooklyn, in the clock tower of the former factory of cardboard boxes, was sold for 25 million U.S. dollars - an amount which is more than twice bigger than that which was ever paid for and apartment in Brooklyn (Barbanel, 2009).

The loft wave, which becomes more and more popular, together with the proponents of this lifestyle involves those people who are chasing fashion as well. Living in a loft means to be fashionable, to have style and good taste. A loft-type apartment also reflects social and financial status of the owner.

Nevertheless, lofts are mostly preferred by the enthusiasts of bohemian lifestyle who do not want to be restricted and who seek to express themselves in raw industrial space. Although artists are mostly individualists, the sense of community is also a very important element. Loft owners gather into communities. Living together with their colleagues they can do much more: they can work collectively and generate new ideas. Vast spaces provide them with great opportunities: they can establish artist's studios, workshops and joint art centers next to their residential area.

RESULTS

Criteria determining applicability of industrial buildings for housing

Considering conversion of industrial buildings for living, the basic criteria determining the eligibility of the object for conversion are established. The criteria are presented in Figure 4.

Most of industrial buildings can be converted into living-space, however, not all of them are worth of such conversions. It is necessary to calculate if it will be financially beneficial, if a renovated building will be cost-effective, practical and economical. One of the most important criteria – former processes of production, their impact to environment and harm to human health – hazardous materials can penetrate into soil and parts of building. Biofield – past activities are also very important for its liquidity (e.g. prison, psychiatric hospital, crematorium) All these aspects must be considered prior to conversion of any industrial building.

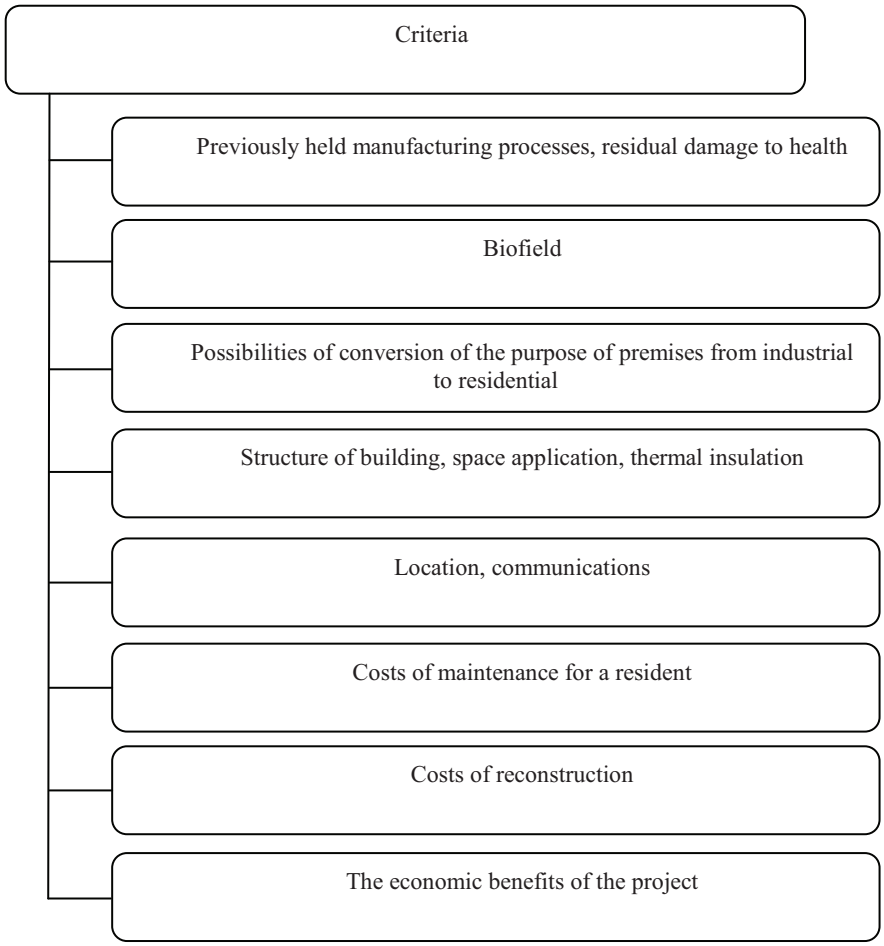

Figure 4. Essential criteria determining possibility of conversion of industrial buildings into living-space (compiled by the author)

A manufacturing process previously held in the building, its residual damage to human health.

Requirements for hygiene, health and environmental protection in residential buildings must comply with STR 2.01.01(3):1999 (3.4). Design and construction of residential buildings should correspond to all sanitation

conditions that are obligatory for residential buildings and humans without any threat for human health for the following reasons:

- Excretion of harmful gases
- Hazardous particles and gases occurrence in the air
- Dangerous radiation
- Water and soil pollution and poisoning of living organisms
- Inappropriate disposal of wastewater, smoke, solid or liquid waste
- Moisture of building constructions or internal moisture of buildings (STR 2.02.01:2004).
- Constructions of former industrial buildings and site soils, depending on the activities of the industrial object, may contain toxic, mutagenic or carcinogenic materials, which may eventually lead to health problems of residents of such premises (Labutyte, 2012).

Therefore it is necessary to analyze the production process which took place in that object, its effects and possible residual harm for human health. It is obligatory to inquire about the history of the industrial building and to find out information about incidents and accidents that could have contaminated the premises.

In order to determine harmfulness of the premises to human health, it is necessary to investigate the major potential pollutants and their quantity. The National Public Health Surveillance Laboratory (NPHSL) has named the basic research that should be done:

- Volatile hydrocarbons
- Ammonia
- Mercury
- Arsenic
- Chemical analysis of air (Vilkauskaite, 2008)

If pollution norms are exceeded, neutralization of pollutants and its costs should be considered and the following analysis carried out:

- Evaluation of the possibility of liquidation of hazardous materials from the future housing site
- Economic impact of clean-up on the profitability of the project

Prior to development of the project, all possible options must by analyzed.

Biofield

Influence of the biofield is also an important factor to be weighed before starting conversion of a building. This psychological factor may be very important for the quality of life of a future resident, thereby for the liquidity of the housing, market value and success of the project.

People may not want to live in premises where activities related to bad emotions had previously been carried out. For example:

- Detention facility
- Psychiatric hospital
- Crematorium
- Etc.

However, the biofield may dramatically increase the attractiveness of a building. Activities that were carried out in the building may have an additional charm and at the same time to increase the uniqueness of the building and its value. Previous activities associated with good emotions can be used as a marketing item causing desire to live in industrial buildings. For example:

- Chocolate factory
- Brewery
- Mill
- Noodle factory
- Etc.

The former type of activities and the resulting biofield possess a psychological factor for people. It encourages their determination and desire to acquire accommodation in former industrial premises. Therefore it affects the quality of life and the future market value, as well as the economic profitability of the project.

Possibilities of transforming industrial premises into residential premises

Changing real estate purpose from industrial to residential premises is a lengthy and complicated process, so, according to the data collected by the Center of Registers, most of lofts in Vilnius are transformed into creative workshops.

The main problem faced by Lithuanian people living in lofts is the real estate tax applicable to commercial premises, which, under the laws of the Republic of Lithuania, is obligatory for all owners of commercial premises, no matter that commercial activities are not carried out any more.

Problems arise for those who buy residence with a bank loan.

Bank loans as a percentage of market value of property according to the purpose of premises:

- For industrial premises - up to 20 %
- For creative workshops – up to 50-60%;
- Residential premises – up to 80 %.

Buyers purchasing a loft with the remaining industrial purpose for residence face limited opportunities to buy it.

Structure of a building, space application, thermal insulation

An essential requirement for residential buildings – "Mechanical Resistance and Stability" must be assured in accordance with STR 2.01.01 (1): 1999 (3.2) requirements.

Residential buildings (their parts) must be designed and constructed from such products of construction, which correspond to the requirement of mechanical strength and stability during the whole length of building life, i.e. the loads which can affect the building during the period of construction and usage would not cause the following consequences: Collapsing of the whole building or some of its parts, higher deformation than permitted, damage to other parts, fittings or installed equipment due to circumstances that can be avoided or restricted without great difficulty and expenses (explosion, shock, overload, human errors).

Mechanical strength and stability of residential buildings are ensured with the aggregate measures envisaged during the period of projecting, designing, construction, reconstruction and usage of the building, as well as with the qualitative indicators of construction products, usage characteristics and requirements (STR 2.02.01:2004).

One of the most important factors preventing conversion of industrial buildings into living-space is their thermal insulation.

Standard thermal insulation for industrial buildings used for manufacturing is much lower than thermal insulation used for residential buildings.

All industrial buildings reconstructed into living premises should be insulated in accordance with requirements set for residential buildings.

Windows, gates and doors also must meet the following requirements applicable to thermal insulation. Windows and external doors of the building should be designed in such a way that the following essential requirements were ensured during the entire life cycle of the building: Mechanical strength and stability, hygiene, health and environmental safety, noise insulation, energy saving and heat retention (STR 2.05.20:2006).

Large spaces and high ceiling is a positive feature for lofts: you can apply various non-standard solutions.

High ceilings can be exploited to install entresols while at the same time they provide additional space, which can be used effectively. The optimum ceiling height is about 5-6 meters. If the ceiling is lower than 4.5 meters, installation of entresols becomes impractical.

Industrial buildings with large integral spaces and high ceilings (e.g. 1000 m^2; ceiling height of 12 meters) can also be converted to a residential area however, it is necessary to install floor and partitions to create separate spaces. Therefore, reconstruction costs greatly increase, but the usable space is increased twice.

Location, communications

Aleknavicius in his book *Real Estate Assessment* (2008) states that one of the main factors determining market value of apartments and houses is the attractiveness of their location. The main element of lofts in the real estate market is also their location. Former factories were mostly built in the city centers, near water bodies, major roads or railroads. Docklands in seaports make a unique type of buildings. Suburban factories and entire industrial areas were also created in scenic areas adjacent to water bodies, and they were connected with the city centre by convenient roads (Garrick, Alistrovaite, 2005). Namely this type of industrial buildings is the most suitable alternative for conversion to residential accommodations.

The economic benefits of the project

Before deciding to invest in real estate, it is important to analyze the reversibility of your investment. According to specific objectives of each investor, different assessment according to various factors and limitations is possible.

You can make big mistakes while choosing the most appropriate object for investment. Such errors result in great losses. Therefore, it is necessary to complete comprehensive profitability analysis of the project (Zilinskas 2009, Ginevičius 2009).

Influence of improvements – any object is worth of improvement so far as this improvement increases the total value of real estate, regardless of what are the costs of such improvement (Aleknavicius, 2008).

CONCLUSIONS

1. After the review of Lithuanian and world literature it is found that the long-abandoned and not carried out industrial processes, industrial buildings, workshops, factories stands in central cities areas and has long been a tendency to adapt them to the preservation of the industry, industrial and technical museums in the setting up of industrial buildings for conversion to residential and public buildings.
2. It was found that non-standard space, area, location, unique space, cost, non-traditional community, the enduring value of a creative environment - the key factors that influence the choice industrial buildings adapted for residential housing.
3. When choosing a home in the former industrial buildings, industrial buildings it is necessary to consult the history, held to analyze the production process and facilities to carry out research and identify potential pollution and their quantity.
4. To choose the best accommodation in a former industrial building, the authors followed the criteria proposed conversion of a building eligibility determination.

REFERENCES

Aleknavicius, A., 2008. Real Estate Assesment. Kaunas: Ardiva.

Balkunas, V., 2011. Survey: for lofts some are ready to pay as for houses. In: Lietuvos rytas, 2011.06.01 Access via the Internet - http://www.lrytas.lt/-13069390381305626024-apklausa-u%C5%BE-loftus-kai-kurie-pasiry%C5%BE%C4%99-mok%C4%97ti-kaip-u%C5%BE-namus.htm.

Barbanel, J., 2009, No need to Wear a watch. In: New York Times. Access via the Internet - http://www.nytimes.com/2009/08/09/realestate/09deal1.html.

Couch, C.; Fraser, C.;Percy, S. 2003. Urban Regeneration in Europe. Blackwell Science, 11-15.

Dremaite, M., ir Stelbiene, A. 2004. Industrial Heritage Hosting. Archiforma,. Vol. 2, 52-57.

Dremaite, M., Kulevicius, S., Soms H., Trimoniene R., Salatkienė B., 2007. Industrial heritage of the needs of today's Hosting: best practice analysis report. Siauliai.

Garrick, E., Alistrovaitė, I., 2005. Industrial facilities in the coastal zone conversion experience of the Sydney model. Journal Urbanistika ir architektura. Vilnius: Technika. 2005, Vol. 29(2), 91.

Ginevicius R., Zubreckas V., Ginevičius T. 2009. Real estate investment projects efficiency evaluation methodology. Vilnius: Technika.

I love loft. Access via the Internet – http://www.iloveloft.lt/.

Jana, R., 2006. Starwood Hotels Explore Second Life First. BusinessWeekOnline, 2006.08.23.

Kaklauskas, A.; Zavadskas, E. K., Banaitis, A., Satkauskas, G., 2007. Defining the utility and market value of real estate multiple criteria approach. International Journal of Srategic Property Management Vol. 11(2): 107–120.

Labutytė, I., 2012. Primer on which we live: as the pollution in the long term impacts on human health. Access via the Internet - http://www.technologijos.lt/p/spausdinti?name=S-24984.

Construction Technical Regulation 1.01.09:2003 Statinių klasifikavimas pagal jų naudojimo paskirtį.

Construction Technical Regulation 2.01.01(3):1999. Essential requirements of buildings. Hygiene, health and environmental protection.

Construction Technical Regulation 2.02.01:2004 Residential buildings.

Construction Technical Regulation 2.05.01:2005 Technology of therman building barriers.

Construction Technical Regulation 2.05.20:2006 Windows and external pedestrian doors.

Stelbiene, A., ir Dremaite, M., 2005. Heritage study and documentation: international practice in Lithuania. Monuments of culture, Vol. 12, Vilnius, Savastis, 96-106.

Stratton, M., 2000. Industrial Buildings: Conservation and Regeneration. Taylor & Francis.

Ustinovicius, L., 2004. Determination of efficiency of investments in Construction. International Journal of Strategic Property Management Vol. 8(1).

Vilkauskaite, K., 2008. Dream home. In: Busto Vizija, 2008 04 04. Access via the Internet - http://www.bustovizija.lt/Straipsniai/5181/.

Zilinskas, V., J., 2009. Investment projects in the optimal sampling method. Business, Management and Studies, VGTU publications, 21-36.

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The Assessment Model of a High-Rise Building the Initial Structural System by Applying Multi-Criteria Methods

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Abstract. The aim is to select the efficient structural system for high-rise building. Structural system selection for further building structural system design remains a complex task requiring a large number of evaluation data, including approximate structural system parameters, architectural, building engineering systems requirements and building construction process peculiarities. Decision - making problems in construction management often involve a complex decision making process in which multiple requirements and conditions have to be taken into consideration simultaneously. Multi-attribute analysis is a popular tool in many economical, managerial, constructional, etc. problems. The accuracy of performance measures in COPRAS (COmplex PRoportional ASsessment) method assumes direct and proportional dependence of the significance and utility degree of investigated versions on a system of attributes adequately describing the alternatives and on values and weights of the attributes. The objective of this research is to demonstrate how simulation can be used to reflect grey inputs, applying COPRAS-G method, which allows more complete interpretation of model results. The research has concluded that the COPRAS-G method is appropriate to use for the high-rise building structural system.

Keywords: MCDM, expert‘s judgment, COPRAS-G, grey numbers, structural system, high rise building.

INTRODUCTION

While designing high-rise buildings structural system it is very important to choose the right one. It’s important not only to calculate existing loads affecting building structural system, but at the same time estimate other factors like architectural solutions, building engineering systems, construction process features and price. The aim is to create a technique for high rise building preliminary structural system selection, using multiple attribute methods. Multiple attribute optimization is a process of determining a feasible solution for the decision maker according to the established attributes (e.g. a set of the quantitative and qualitative attributes). All decisions involve choosing one from several alternatives. In this paper, the authors present a methodology that allows to reach a decision by designing alternatives of a building's structural system and to evaluate attributes both qualitative and quantitative contained in the process.

High rise building preliminary structural system selection

In the beginning structural system is enough to show schematically, but on this stage, when we know building architectural solutions must take decision about its structure structural elements type and materials (Parasonis, 2008). Usually this task solve using in approach way, using precursors gathered experience. To create task using approximate initial data taken from tables about structural systems and various building materials and structural elements. In 1969 Fazlur Khan classified structural system for tall buildings relating to their heights (Ali and Moon, 2007). This marked the beginning of a new era of skyscraper multiple structural system (Ali and Moon, 2007). Selecting the most efficient structural system is not enough to invoke for buildings or separate structural elements raised three basic requirements: structural system load-bearing capacity, usability and comfort, to avoid defects which reduce longevity. Every structure, just like other human creation, has an aesthetic value. To create an expressive structure it should be correctly designed building form, façade tectonics and internal space. The floor-to-floor height of an office building is typically the same for all occupied floors except for the lobby and floors for special functions. In high-rise office buildings, additional floor-to-floor height significantly entails greater cost on structural elements, cladding, mechanical risers, and vertical transportation. This classification is based on the distribution of the components of the primary lateral load-resisting system over the building. Massive use of these structural elements on site means lower labor costs on site at a relatively high quality of prefabricated structural elements, shorter building process on construction site. This section describes the structural optimization problems posed and solved in this paper.

Methodology

The aim of these investigations is to create a technique for the choice and selection of different and effective versions of high-rise buildings structural systems. The purpose is to be achieved by using various indicators effectiveness, which have different dimensions, different significances as well as direction of optimization. The main steps of multiple attributes decision-making are as follows:

- Selection of possible structural system by efficient structural height;
- Provide structural systems according efficient height;
- Possibility to provide building desired shape;
- Establishing system evaluation attributes those prelate system capabilities to goals;
- Developing alternative systems for attaining the goals (generating alternatives);
- Evaluating alternatives in terms of attributes (the values of the attribute functions);
- Applying a normative multiple attributes analysis method
- Accepting one alternative as "optimal" (preferred);
- If the final solution is not accepted, gather new information and go into the next iteration of multiple attributes optimization.

The solving of each multi-attribute problem begins with constructing of decision-making matrix (Fig. 1).

Alternatives	Attributes			
	C_1	C_2	...	C_m
A_1	a_{11}	a_{12}	...	a_{1m}
A_2	a_{21}	a_{22}	...	a_{2m}
	...	...	...	
A_m	a_{n1}	a_{n1}	...	a_{nm}

Figure 1. Decision-making matrix for multi-attribute decision - making problems

In the matrix (Fig. 1) values of the attributes a_{ij} may be:

- real numbers;
- values expressed in intervals;
- fuzzy numbers;
- probability distributions;
- possibility distributions;
- linguistic variables;
- verbal variables.

Multiple attributes decision aid provides several powerful and effective tools for confronting sorting problems (Hwang and Yoon 1981, Zavadskas 1987). There can be used very simplified techniques for the evaluation of a decision support methods base including methods such as the Simple Additive Weighting — SAW; TOPSIS — Technique for Order Preference by Similarity to Ideal Solution (Hwang, Yoon, 1981; Zavadskas, 1987; Chang, *et al.* 2005), and methods of the ELECTRE (Elimination and Choice Translating Reality) family, such as ELECTRE and UTA (Utilités Additives, cf.). A variant of the UTA method is the UTADIS method (Utilités Additives DIScriminantes). The Preference Ranking Organization MeTHod for Enrichment Evaluations (PROMETHEE) can be applied to the solution too. For a more detail survey of Multi criteria decision making methods see for applications in the construction context (Ustinovichius *et al.*2007).

Ranking of the alternatives applying copras method

In order to select the best alternative, it is necessary, to have formed the decision matrix, to perform the project's multiple attributes analysis. MCDM refers to making preference decisions on the alternatives in terms of multiple attributes. Typically, each alternative is evaluated on the established set/system of attributes. Multi-attribute analysis is a popular tool in many economical, managerial, constructional, etc. problems. To determine the weights of the attributes, the expert's judgment method is applied (Kendall 1970) which has been successfully used in research by the authors since 1987 (Zavadskas, 1987; Zavadskas and Kaklauskas 1996). Commonly to determine the quality indicators of significance expert's judgement method is used. Expert's judgment method evaluation of the theoretical aspects and practical application investigated by many areas (Chang *et al.* 2005; Hearn *et al.* 2012; Sivilevicius, 2011a; Sivilevičius, 2011b; Zavadskas *et al.* 2008a,b, 2009, 2010, 2011) so here is just a description of the method at work. The expert's judgment method are used in this research for the determination of the attributes weights. The assessment of efficient building structural system selection is solved by applying COPRAS-G (COmplex PRoportional ASsessment of alternatives) method with

the values expressed in intervals. The accuracy of performance measures in this method assumes direct and proportional dependence of the significance and utility degree of investigated versions on a system of attributes adequately describing the alternatives and on values and weights of the attributes. The objective of this research is to demonstrate how simulation can be used to reflect fuzzy inputs, which allows more complete interpretation of model results. COPRAS method was developed by Zavadskas and Kaklauskas (1996). The COPRAS method determines a solution with the ratio to the ideal solution and the ratio with the ideal - worst solution. It applied in many different fields such as management, building construction etc. (Hashemkhani Zolfani *et al.* 2011; Kildienė *et al.* 2011; Bitarafan *et al.* 2012; Fouladgara *et al.* 2012; Das *et al.* 2012; Chatterjee *et al.* 2011; Chatterjee and Chakraborty, 2012; Albiñana and Vila, 2012; Fiaschi *et al.* 2012; Kaklauskas *et al.* 2012; Zavadskas *et al.* 2012). The main problem involving multiple attributes are often too large data for a decision - maker (Choi *et al.* 2012). The idea to COPRAS-G method comes from real conditions of decision-making and from applications of the Grey systems theory (Deng, 1982). The grey system has been applied in many fields, such as economics, agriculture, geography, weather, earthquakes, science etc. (Zavadskas *et al.* 2009, 2010, 2011; Maity *et al.* 2012).

The decision approach proposed in this section allows evaluating the direct and proportional dependence of the significance and utility degree of alternatives in a system of attributes, weights and values of the attributes.

Case study: assessment of initial structural system for office hight rise building

The aim of the research is to select the efficient building structural system from several possible alternatives. In literature structural system efficiency is usually defined intervals (Taranath, 1998; Ali and Moon, 2007; Ražaitis, 2004; Moon, 2008; Naik, 2008). Therefore it is possible to use methodology that allows reaching a decision by designing alternatives of a building's structural system and evaluating attributes both qualitative and quantitative contained in the process. As a research object 24 story administrative building in Vilnius was selected. Analyzed high-rise buildings structural systems alternatives shown in Table 1. In order to select the best alternative, it is necessary to create the decision matrix and to perform the project's multiple attributes analysis.

MCDM refers to making preference decisions on the alternatives in terms of multiple attributes. All decisions involve choosing one from several alternatives. The purpose is to be achieved by using various indicators effectiveness, which have different dimensions, different significances as well as direction of optimization. The initial data of this problem are taken from construction manuals and research papers (Taranath, 1998; Ražaitis, 2004; Ali and Moon, 2007; Parasonis, 2008). Selected attributes do not cover all-important characters of building structural system. In order to establish the importance indicators, a survey has been carried out and 10 experts have been asked to prioritize 7 attributes:

- Effective structural system height x_1 - $[w_{i1}; b_{i1}]$;
- Typical floor to floor height (m) x_2 - $[w_{i2}; b_{i2}]$;
- Columns cross-section area (m²) x_3 - $[w_{i3}; b_{i3}]$;
- Columns step (m) x_4 - $[w_{i4}; b_{i4}]$;
- Terms of performance (m³/w.d.) x_5 - $[w_{i5}; b_{i5}]$;
- Building construction price (€/m³) x_6 - $[w_{i6}; b_{i6}]$;
- Structural system design price (€/m³) x_7 - $[w_{i7}; b_{i7}]$.

Respondents were civil engineers, which have long-term experience in multistory building structural system design. These experts had to rate indicators of effectiveness starting with the most important ones in regard to their knowledge, experience and intuition. The rating was done on a scale from 1 to 7, where 7 meant "very important" and 1 "not important at all".

Optimization directions of selected attributes are as follows:

$$x_1, x_4 \xrightarrow{\text{optimization direction}} \max;$$

$$x_2, x_3, x_5, x_6, x_7 \xrightarrow{\text{optimization direction}} \min;$$

According data expert's priorities were given to high rise building structural system important parameters are given in table 2.

The final choice of efficient building structural system from selected possible alternatives was made by COPRAS-G method. In Table 2 the normalized weighted decision-making matrix is given. On the basis of the efficiency priority of alternatives, a rank R_j of each alternative is established. According to the calculation results, alternative 1 is the best one (Table 4).

Table 1. High rise buildings structural system alternatives

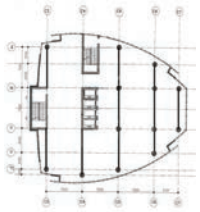
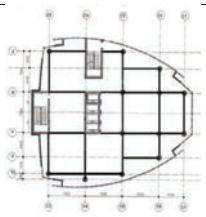
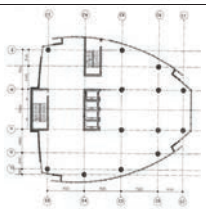
Structural system alternatives	Structural elements	Material of building structural system	Building frame columns step (m)	Floor to floor height (m)	Efficient building height (m)	Efficient building height (floor)	Spatial stability elements	Building façade material	Character	High rise buildings structural systems arrangement
Semi – rigid frame	Beams Columns Span	Sectional monolithic concrete	6-12	3.7-4.1	74-123	20-30	Vertical concrete plate elements	Glass	DH-1	
	Beams Columns Span	Monolithic concrete	6-12	3.7-4.1	74-123	20-30	Vertical concrete plate elements	Glass	DH-2	
	Beams Columns Span	Steel Concrete	6-12	3.3-3.9	66-138	20-30	Vertical concrete plate elements	Glass	DH-3	
Rigid frame	Beams Columns Span	Concrete	4,5-9,0	3.6-3.9	72-156	20-30	Vertical concrete plate elements	Glass	DH-4	
	Beams Columns Span	- Concrete	4,5-9,0	3.4-3.6	68-126	20-35	Vertical concrete plate elements	Glass	DH-5	

Table 2. Initial decision making matrix with values expressed in intervals

Alternative	Effective structural system height (m)		Floor to floor height (m)		Columns cross-section area (m²)		Columns step (m)		Terms of performance (m³/w.d.)		Building construction price (€/m³)		Structural system design price (€/m³)	
Optimization direction	max		min		min		max		min		min		min	
Attribute weight q_j	0.161		0.149		0.146		0.140		0.134		0.142		0.128	
Attribute	x_1		x_2		x_3		x_4		x_5		x_6		x_7	
Attribute values expressed in intervals	w_1	b_1	w_2	b_2	w_3	b_3	w_4	b_4	w_5	b_5	w_6	b_6	w_7	b_7
DH-1	20	30	3.7	4.1	0.35	0.9	6	12	0.5	1	275	350	27.5	35
DH-2	20	30	3.7	4.1	0.35	0.9	6	12	3	4	450	550	45	55
DH-3	20	30	3.3	3.9	0.51	1.1	6	12	2	3	500	650	50	65
DH-4	20	40	3.6	3.9	0.55	0.8	4.5	9	4	5	350	400	35	40
DH-5	20	35	3.4	3.6	0.35	0.6	4.5	9	4	5	450	600	45	60

Table 3. Weighted normalized decision – making matrix according to a COPRAS-G method

Alternative No.	Weighted normalized values of the attributes describing the compared alternatives – matrix X													
	$\hat{w}_1$	$\hat{b}_1$	$\hat{w}_2$	$\hat{b}_2$	$\hat{w}_3$	$\hat{b}_3$	$\hat{w}_4$	$\hat{b}_4$	$\hat{w}_5$	$\hat{b}_5$	$\hat{w}_6$	$\hat{b}_6$	$\hat{w}_7$	$\hat{b}_7$
1	0.032	0.029	0.031	0.031	0.024	0.031	0.031	0.031	0.005	0.007	0.019	0.019	0.017	0.018
2	0.032	0.029	0.031	0.031	0.024	0.031	0.031	0.031	0.030	0.030	0.032	0.031	0.028	0.028
3	0.032	0.029	0.028	0.030	0.035	0.037	0.031	0.031	0.020	0.022	0.035	0.036	0.032	0.033
4	0.032	0.039	0.030	0.030	0.038	0.027	0.023	0.023	0.040	0.037	0.025	0.022	0.022	0.020
5	0.032	0.034	0.029	0.027	0.024	0.020	0.023	0.023	0.040	0.037	0.032	0.033	0.028	0.030

Table 4. Initial decision making matrix with values expressed in intervals

Alternative No	Total sum of maximizing normalized indices P_j	Total sum of minimizing normalized indices R_j	Alternative's significance Q_j	Alternative's degree of efficiency N_j	Rank R_j
1	0.124	0.203	0.499	100.0	1
2	0.124	0.295	0.383	76.6	2
3	0.124	0.308	0.372	74.5	4
4	0.118	0.291	0.380	76.1	3
5	0.113	0.301	0.367	73.4	5

The first alternative is also the best in terms of its utility degree that equals 100 %. The second alternative with utility degree 76.6 % has rank 2. The forth alternative with utility degree 76.1 % has rank 3. The third alternative with the utility degree 74.5 % has rank 4. The fifth alternative with the utility degree 73.4 % is the worst choice has rank 5. Vector of optimality criterion values is N_j = [100.0; 76.6; 74.5; 76.1; 73.4]. According this vector N_j the alternatives rank as follows: $K_1 \succ K_2 \succ K_4 \succ K_3 \succ K_5$.

CONCLUSIONS

Research showed that expert's judgment and COPRAS-G method can be used on building design stage for efficient structural system selection, when initial data must be expresed in intervals.

Structural system selection is approximate, final decision taken, after variant design. This methodology could help to reduce count of approaches, assessing large number of criterions.

It allows structural engineers to make decision concerning multiple attributes, when values of initial data of structural system possible parameters variation are given in the intervals.

The analysis of the problem according to selected criteria showed that semi-rigid frame (DH-1), which consists of prefabricated reinforced concrete products is more preferable than another four alternatives under investigation.

REFERENCES

Albiñana, J.C., Vila, C., 2012. A framework for concurrent material and process selection during conceptual product design stages. *Materials & Design*, 41, 433-446.

Ali, M.M., Moon, K.S., 2007. Structural Developments in Tall Buildings: Current Trends and Future Prospects. *Architectural Science Review,* 50 (3), 205-223.

Bitarafan, M., Zolfani, H.S., Arefi, S.L., Zavadskas, E.K., 2012. Evaluating the construction methods of cold-formed steel structures in reconstructing the areas damaged in natural crises, using the methods AHP and COPRAS-G. *Archives of Civil and Mechanical Engineering*, 12 (3), 360-367.

Chatterjee, P., Athawale, V.M., Chakraborty, S., 2011. Materials selection using complex proportional assessment and evaluation of mixed data methods. *Materials & Design*, 32 (2), 851-860.

Chatterjee, P.; Chakraborty, S., 2012. Material selection using preferential ranking methods. *Materials and Design*, 35 384-393.

Chang, J.R., Chen, D.-H., Hung, Ch.-T., 2005. Selecting preventive maintenance treatments in Texas. Using the technique for order preference by similarity to the ideal solution for specific pavement Study-3 sites, Transportation Research Record. *Journal of the Transportation Research Board,* 1933, 62-71.

Das, M.C., Sarkar, B., Ray, S., 2012. A framework to measure relative performance of Indian technical institutions using integrated fuzzy AHP and COPRAS methodology. *Socio-Economic Planning Sciences*, 46 (3), 230-241.

Deng, J.L., 1982. Control problems of grey system. *Systems and Control Letters*, 1 (5), 288-294.

Ding, G.K.C., 2008. Sustainable construction – the role of enviromental assessment tools. *Jornal of Enviromental management*, 86, 451-464.

Fiaschi, D., Bandinelli, R., Conti, S., 2012. A case study for energy issues of public buildings and utilities in a small municipality: Investigation of possible improvements and integration with renewable. *Applied Energy*, 97, 101-114.

Fouladgara, M.M., Chamzinia, A.Y., Lashgaria, A., Zavadskas, E.K., Turskis, Z., 2012. Maintenance strategy selection using AHP and COPRAS under fuzzy environment pages. *International Journal of Strategic Property Management*, 16 (1), 85-104.

Hashemkhani Zolfani, S., Zavadskas, E.K., Turskis, Z., 2011. Forest roads locating based on AHP and COPRAS-G methods: an empirical study based on Iran. *E+M Ekonomie a Management*, 14 (4), 6-11.

Hearn, G., Wise, D., Hart, A., Morgan, C., 2012. Assessing the potential for future first-time slope failures to impact the oil and gas pipeline corridor through the Makarov Mountains, Sakhalin Island, Russia. *Journal of Engineering Geology & Hydrogeology*, 45 (1), 79-88.

Hwang, C.L., Yoon, K., 1981. *Multiple Attribute Decision Making, in Lecture Notes in Economics and Mathematical Systems.* Springer - Verlag, Berlin, 186 p.

Kaklauskas, A., Rute, J., Zavadskas, E.K., Daniunas, A., Pruskus, V., Bivainis, J., Gudauskas, R., Plakys, V., 2012. Passive house model for quantitative and qualitative analyses and its intelligent system. *Energy and Buildings*, 50, 7-18.

Kendall, M.G. 1970. *Rank correlation methods* (4th ed.). London: Griffin.

Kildienė, S., Kaklauskas, A., Zavadskas, E.K., 2011. COPRAS based comparative analysis of the European country management capabilities within the construction sector in the time of crisis. *Journal of Business Economics and Management*, 12 (2), 417-434.

Maity, S.R., Chatterjee, P., Chakraborty, S., 2012. Cutting tool material selection using grey complex proportional assessment method. *Materials & Design*, 36, 372-378.

Naik, T., 2008. Sustainability of Concrete Construction. *Practice Periodical on Structural Design and Construction*, 13 (2), 98-103.

Parasonis J., 2008. Buildings structures design basics. VGTU leidykla technika (in Lithuanian).

Ražaitis, V., 2004. *Building construction basics*. Vilnius: Dailės akademijos leidykla. (in Lithuanian).

Rezaeiniya, N., Zolfani, S.H., Zavadskas, E.K., 2012. Greenhouse locating based on ANP-COPRAS-G methods – an empirical study based on Iran. *International Journal of Strategic Property Management*, 16 (2), 188-200.

Sivilevicius, H., 2011a. Modelling the interaction of transport system elements. *Transport*, 26 (1), 20-34.

Sivilevičius, H., 2011b. Application of Expert Evaluation Method to Determine the Importance of Operating Asphalt Mixing Plant Quality Criteria and Rank Correlation, *The Baltic Journal of Road and Bridge Engineering*, 6 (1), 48-58.

Taranath, B., 1998. *Steel, Concrete, & Composite Design of Tall Buildings*. New York: McGraw-Hill, 1998.

Ustinovichius, L., Zavadskas, E. K., Podvezko, V., 2007. Application of a quantitative multiple criteria decision making (MCDM-1) approach to the analysis of investments in construction. *Control and Cybernetics*, 36 (1), 251-268.

Zavadskas, E.K., Vainiūnas, P., Turskis, Z., Tamošaitienė, J., 2012. Multiple criteria decision support system for assessment of projects managers in construction. *International journal of information technology & decision making*, 11 (2), 501-502.

Zavadskas, E.K., Kaklauskas, A., Turskis, Z., Tamošaitienė, J., Kalibatas, D., 2011. Assessment of the indoor environment of dwelling houses by applying the COPRAS-G method: Lithuania case study. *Environmental Engineering and Management Journal*, 10 (5), 637-647.

Zavadskas, E.K., Turskis, Z., Tamošaitienė, J., 2010. Risk assessment of construction projects. *Journal of civil engineering and management*, 16 (1), 33-46.

Zavadskas, E.K., Kaklauskas, A., Turskis, Z., Tamošaitienė, J., 2009. Multi-attribute decision-making model by applying grey numbers. *Informatica*, 20 (2), 305-320.

Zavadskas, E.K., Turskis, Z., Tamošaitienė, J., 2008a. Contractor selection of construction in a competitive environment. *Journal of business economics and management*, 9 (3), 181-187.

Zavadskas, E.K., Turskis, Z., Tamošaitienė, J., Marina, V., 2008b. Multicriteria selection of project managers by applying grey criteria. *Technological and economic development of economy*, 14 (4), 462-477.

Zavadskas, E.K., Kaklauskas, A., 1996. *Multiple criteria evaluation of buildings*. Vilnius: Technika, 1996.
Zavadskas, E.K., 1987. *Complex estimation and choice of resource saving decisions in construction*. Mokslas, Vilnius (in Russian)

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Properties of the Cement Stone Containing Steel Shaving Waste

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Abstract. The following research is done in order to find the influence of steel shavings to the properties of cement stone such as: spread of cement slurry, physical and mechanical properties as well as porosity parameters. Portland cement, as a bonding material, was used. The ratio of water and cement was the same during this research and it was at the level of 0.4. It must be stressed out that during the research various shape and length steel shavings haven't been cleaned or sorted, therefore other steel additions could be found. The amount of steel shavings was between 10 and 60 % in respect to the amount of cement. On the basis of the research, the results show that by increasing the steel shavings up to 60 % in respect to the amount of cement, the spread of cement slurry decreases up to 35 % in respect to the control specimen. On the other hand, the density of cement stone increases by 4 %, but the compression strength decreases up to 61 %. The biggest flexural strength of the cement stone is achieved by using 30 % of steel shavings in respect to the amount of cement. Porosity parameters of cement stone were obtained by the water absorption kinetics. Total and open porosity of cement stone has decreased about 23 % by increasing the amount of steel shavings up to 60 % in respect to the amount of cement. The biggest closed porosity of cement stone was obtained by adding 10-20 % of steel shavings. Prognosticated cement stone's resistance to freezing – thawing was around 215-230 of cycles.

Keywords: steel grinding waste, cement slurry, hardened cement paste, physical and mechanical properties, porosity, frost resistance.

INTRODUCTION

To begin with, the management, sorting and the secondary usage of industry waste is becoming more and more important. One of the best options is to use these industry wastes as the additions for the modification of concrete properties. The secondary usage of the industry wastes is a very accurate problem concerning the storage and maintenance of them. In addition, the usage of secondary wastes is cheaper than compared with the primary materials. This is one of the reasons why more and more companies are choosing to use secondary wastes instead of primary materials. It is also advisable to use these wastes for the concrete production (Uselyte *et al*. 2008, http://eur-lex.europa.eu (2011)).

Concrete is not an elastic material, therefore it doesn't reach a high level of resistance to tension. On the basis of the experimental results it is obvious that steel fibers influence physical and mechanical as well as the technological properties of the concrete (Martin *et al*. 2007, Wang *et al*. 1998, Tlemat *et al*. 2006, Šalna *et al*. 2007). Steel fibers increase the concrete resistance to flexural forces, reduce the amount of reinforcement, improve the elastic properties, minimize the possibility for cracks to occur. These are the factors why the concrete becomes more durable (higher resistance to abrasion as well as to the freeing-thawing cycles). Steel fibers are mainly used for the reinforcement of industry floors, for the building of tunnels, for the strengthening of slopes and other constructions. The properties of steel fibers differ depending on the material of which they are made, the type of the production, the roughness of the surface, form, length, diameter and other (Wang *et al*. 1998, http://www.stewols.com (2011), Banthia *et al*. 2004).

Scientists (Puertas *et al*. 1999) have tested physical and chemical interactions between a solid industrial waste from aluminum refining and saturated $Ca(OH)_2$ solution, as well as the effects of substituting siliceous sand for the waste on the physical and mechanical properties of mortars. The results have shown that cement/aluminum-rich waste mixes require a higher water/cement ratio than cement/sand mixes. The result is that cement/waste mixes show a decrease of mechanical strengths and an increase of the total porosity. However, their average pore size decreases. A calorimetric study revealed that the waste retards hydration reactions in cement. There is an extension of more than 2 hours for the initial and final setting time. The high surface area of the waste makes it able to absorb a rather large amount of liquid. The presence of Cl^- and Na^+ ions in the liquid modifies the activity of the solution, decreasing the hydration rate of the main clinker phases.

Steel shavings are obtained by the processing of metal. They are very similar (if referred to the form) to the steel fibers. The aim of this research was to establish the influence of steel shavings to the properties of cement stone.

The aim of the research – to investigate the influence of steel shavings (metal industry waste material) to physical and mechanical properties as well as porosity parameters of cement stone.

METHODS

JSC "Akmenes cementas" (Lithuania) Portland cement CEM II/A-LL 42.5 R (MA) (A) was used for the test. Specific surface area of the cement particles was 360 m^2/kg, density of the particles was 3110 kg/m^3, normal consistency of cement paste was 23,8%, initial setting time was 185 min, compressive strength after 28 days was 44,1 MPa.

For this research steel shavings were used (figure 1).

Figure 1. Steel shavings that were used in this research

Steel shavings were not cleaned and sorted therefore other metal impurities such as: aluminum or copper could take place. The density of steel shavings which was established in the laboratory was around 6556 kg/m^3. The average density of the steel, as we know, is around 7870 kg/m^3, therefore the biggest part of shavings was made from steel, thus the amount of other material was not of a big importance. As there is shown at figure 1 the form and the dimensions of steel shavings are very different.

Cement slurries were mixed with the forced mix mixer - "Automix". Cement and steel shavings were dosed by the mass, while water – by volume. During the research the ratio between water and cement was constant. The quantity of steel shavings was increased from 10 to 60 % in respect to the amount of cement.

"Suttard" viscometer was used for the establishment of the spread parameters of cement slurries (figure 2).

Cement stone specimens (40×40×160 mm) were formed in the metal forms. 6 specimens of each cement slurry compositions were made. Specimens were cured in the forms for about 20 hours, while the environment temperature was 20±2 °C. Specimens that were taken out of the forms were cured for 28 days in the water, which temperature was 20±2ºC. The compression and flexural strengths were established according to the requirements of LST EN 196-1 standard. The porosity parameters of cement stone were established according to water absorption kinetics provided by the requirements of GOST 12730.4 standard. According to this methodology open (capillary), closed (entrained air) and total porosities are established. Also the rates that describe the size of pores are evaluated: λ – the rate of average pore sizes; α – rate of pores inequality.

RESULTS

The compositions of cement slurries that were used in this research are presented at table 1.

Table 1. Compositions of cement slurries

Material	Cement slurries as well as the amounts of materials per 1 m^3						
	C1	C2	C3	C4	C5	C6	C7
CEM II/A-LL 42,5 R (MA), kg	1384	1384	1384	1384	1384	1384	1384
Water, l	554	554	554	554	554	554	554
V/C	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Steel shavings, kg	0	138	277	415	554	692	830

Establishment of the spread of cement slurries using "Suttard" viscometer is presented at figure 2 and the spread of cement slurries according to the compositions is presented at figure 3. According to the figure 3 by increasing the amount of steel shavings, spread of cement slurry decreases. The spread of cement slurry decreases from 168 mm (reference C1 cement slurry composition without the steel shavings) to 110 mm (C7 cement slurry composition with 60 % of steel shavings). The reduction of cement slurry was about 35 %.

Figure 2. Establishment of the spread of cement slurries using "Suttard" viscometer

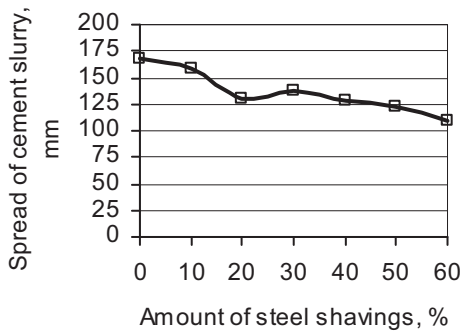

Figure 3. The spread of cement slurry depending on the amount of steel shavings

Figure 4 shows the change of cement stone density depending on the cement slurry composition. The least density of cement stone - 1973 kg/m^3 (C2 composition) is obtained by adding 10 % of steel shavings. That is about 1 % less density than compared with the reference C1 cement slurry. The density of cement slurries could be influenced by the different composition of steel shavings or other metal impurities. When the amount of steel shavings is increased up to 60 % in respect to the quantity of cement, the density of cement stone is increased by 4 % up to 2080 kg/m^3 compared with the reference C1 specimen.

Figure 5 shows the change of cement stone compression strength depending on the amount of steel shavings. This figure reveals that the compression strength of cement stone is constantly decreasing while adding more steel shavings. When the amount of steel shavings reaches 20 %, the compression strength drops rapidly up to 56 % compared with the reference C1 specimen. When the amount of steel shavings is between the limits of 30 and 60 %, the compression strength of cement stone is decreasing at the low rate: from 30.5 MPa (C4 composition) to 23.3 MPa (C7 composition).

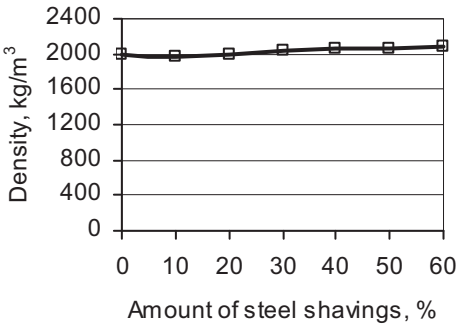

Figure 4. The dependence between the density of cement stone and the amount of steel shavings

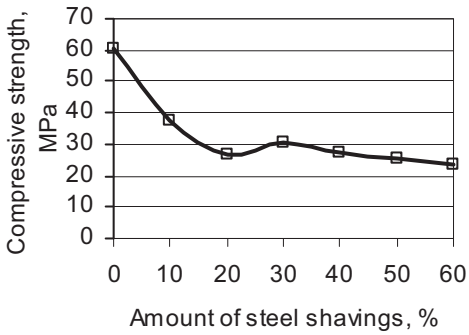

Figure 5. The dependence between the compression strength of cement stone and the amount of steel shavings

Figure 6 shows the change of cement stone flexural strength. When the amount of steel shavings is increased up to 30 %, the flexural strength is increased about 70 % from 2.3 MPa (C1 composition) to 3.9 MPa (C4 composition). Further increasing of steel shavings up to 60 % results the decreasing of flexural strength at low rate for about 3 %. It is obvious that the optimal amount of steel shavings in order to obtain the biggest flexural strength of cement stone is 30 % in respect to the amount of cement.

Figure 7 shows the change of yield deformation as well as the destruction force of cement stone in respect to the amount of steel shavings. It is clear that yield deformation changes accordingly from 101.8 μm to 172.4 μm. When the amount of steel shavings is up to 60 %, then the yield deformation of cement stone increases about 69.4 % compared with the reference specimen C1. The biggest destruction force (1.82 kN) is obtained by adding 30 % of steel shavings, therefore this certain amount is optimal in order to achieve the biggest destruction force.

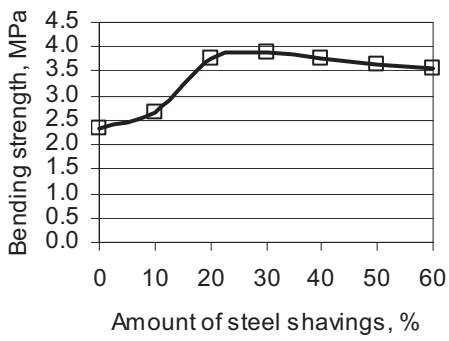

Figure 6. Dependence between the flexural strength of cement stone and the amount of steel shavings

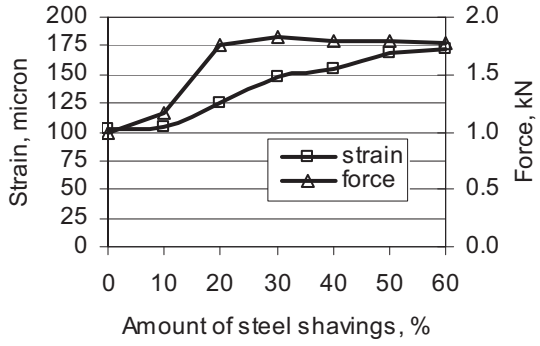

Figure 7. Dependence between the yield deformation and destruction force of cement stone and the amount of steel shavings

The biggest water absorption is obtained by the reference C1 cement slurry composition – 20.19 %. From the information which is given at table 2 it is obvious that water absorption is decreasing while increasing the amount of steel shavings up to 60 %. The least water absorption is obtained by adding 60 % of steel shavings (C7 composition) – 13.63 %. All in all, if compared with the reference specimen, by adding steel shavings water absorption decreases about 32.5 %.

Table 2. The porosity parameters of cement stone

Composition	Water absorption	Porosity, %			Rate of average pore size, λ	Rate of pores inequality,α
		total	open	closed		
C1	20.19	36.78	33.83	2.95	5.04	0.69
C2	18.81	36.58	31.61	4.96	4.21	0.73
C3	17.88	35.29	30.66	4.62	2.71	0.63
C4	16.12	32.34	28.90	3.45	2.58	0.55
C5	14.51	30.11	26.87	3.24	2.26	0.46
C6	14.44	30.23	26.70	3.53	1.45	0.38
C7	13.63	28.31	25.89	2.42	1.45	0.37

As there is shown at table 2, the open porosity of cement stone with steel shavings varies between 31.61 % and 25.89 %. Cement stone without the steel shavings has the biggest open porosity (33.83 %). It is obvious that by increasing the amount of steel shavings up to 60 % according to the mass of cement, open porosity decreases. The least open porosity – 25.89 % is obtained by adding 60 % of steel shavings (C7 composition). In average, open porosity of cement stone with steel shavings decreases about 23.5 % comparing with the reference C1 specimen. On the other hand, closed porosity (entrained air) varies between 4.96 % and 2.42 % according the cement slurry composition (table 2). The biggest closed porosity (4.96 %) is obtained by adding 10 % of steel shavings (C2 composition). Further increasing the amount of steel shavings up to 60 %, the closed porosity starts to decrease. In the case of 60 % of steel shavings, the closed porosity is obtained at the value of 2.42 %, which is lower than the porosity of the reference specimen C1 (2.95 %).

According to the rate of average pore size - λ, it is clear that the biggest pores (λ=5.04) are obtained by the C1 reference specimen (without steel shavings).The rate of average pore size - λ decreases accordingly from 4.21 to 1.45, while the amount of steel shavings increases up to 60 %. The finest pores (λ=0.72) are obtained by adding 60 % of steel shavings (C7 composition). Rate of pores inequality shows that pores have bigger distribution by size (0.37 to 0.63) with steel shavings added accordingly from 20 to 60 % in respect to the amount of cement.

The concrete's resistance to freezing-thawing cycles mainly depends on porosity, since water can only be frozen at the certain pores of concrete (Skripkiūnas, 2007; Шейкин and Добшиц, 1989; Tumosa *et al*. 2010). Capillary pores have the biggest influence to the concrete's resistance to freezing-thawing cycles, since they are

open and can be easily filled by water. On the other hand, closed pores (entrained air) increase the concrete's resistance to freezing-thawing cycles, since they are closed and water can't get into them. Scientist (Naujokaitis, 2007) says that the hydration degree of cement stone as well as the porosity changes in time. It is noticed, that the concrete's micro-porosity is decreasing and the concrete becomes more resistance to freezing-thawing.

CONCLUSIONS

1. Steel shavings as the secondary waste, can be used for the modification of cement stone properties.
2. The spread of cement slurry with 60 % of steel shavings decreases about 35 % compared with the reference slurry without steel shavings.
3. The density of cement specimens could be influenced by the different composition of steel shavings as well as by other metal impurities.
4. The optimal amount of steel shavings is about 30 % of cement mass in order to obtain the biggest flexural strength as well as the biggest destructive force. The flexural strength is increased by 70 % compared with the reference specimen.
5. Cement stone (c1 reference) without the steel shavings possesses bigger pores and bigger their distribution by size.
6. By the increase of the amount of steel shavings from 10 % to 60 % of the cement mass, the cement stone closed porosity was reduced.

REFERENCES

Banthia, N., Gupta, R. Hybrid fiber reinforced concrete (HyFRC): fiber synergy in high strength matrices. 2004. Materials and Structures, Vol. 37, pp. 707-7016.

http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:094:0002:01:LT:HTML (information taken from the internet on 2011-11-01).

http://www.stewols.com/steelfibre.htm (information taken from the internet on 2011-09-20).

Martin, J., Stanton, J., Mitra, N., Lowes., L. Experimental testing to determinate concrete fracture energy using simple test setup.2007. ACI Materials Journal, Vol. 104, No. 6, pp. 575-584.

Naujokaitis, A. 2007. Statybinės medžiagos. Betonai. Mokomoji knyga, Vilnius: Technika. 356 p. [Civil engineering materials, Concretes].

Puertas, F; Blanco-Valera, M. T; Vazquez, T. 1999. Behavior of cement mortars containing an industrial waste from aluminum refining. Cement and Concrete Research , Vol. 29, pp.1673–1680.

Skripkiūnas, G. 2007. Statybinių konglomeratų struktūra ir savybės. Vadovėlis, Kaunas: UAB „Vitae Litera". 334 p. [The properties and structure of building conglomerates].

Šalna, R., Marčiukaitis, G. The influence of shear span ratio on load capaticy of steel fibre reinforced concrete elements with various steel fibre volumes.2007. Journal of Civil Engineering and Management,, Vol. 13, No. 3, pp. 209-215.

Шейкин, А; Е., Добшиц, Л. М. 1989. Цементные бетоны высокой морозостойкости [Šeikin, A. E. Durable cementitious concretes]. Ленинград: Стройиздат. 128 с.

Tlemat, H., Pilakoutas, K., Neocleous, K. Stress-strain characteristic of SFRC using recycled fibres.2006. Materials and Structures,, Vol. 39, pp. 365-377.

Tumosa, M; Daukšys, M; Ivanauskas, E. 2010. Granito atsijų įtaka apdailinių skelto paviršiaus betono plytų savybėms. Mokslas – Lietuvos ateitis. Konferencijos pranešimų medžiaga. Vilnius: 1-7 psl. [The influence of granite screenings to the properties of decorative concrete bricks].

Uselyte, R., Silvestravičiūtė, I., Šleinotaitė-Budrienė, L. Antrinių žaliavų perdirbimo plėtros prioritetų ir priemonių 2009-2013 metams studija. Ataskaita. 2008-12-31. „UAB Ekokonsultacijos".[The study of priorities and development of secondary raw materials recycling for 2009-2013].

Wang, Y. Toughness characteristics of synthetic fiber-reinforced cementitious composites. 1998. Fatigue & Fracture of Engineering Materials & Structure, Vol. 21, pp. 521-532.

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Renovation of Multi-Apartment Houses: Legal, Social and Technical-Technlogical Aspects

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Abstract. In the article the problems of the renovation of dwelling-houses are discussed according these aspects: juridical, social, ecological, technical-technological and economical. When the decision to renovate the dwelling-house is made, first the juridical problems have to be solved. These problems involve planning of investment project, social problems of individual flat dwellers and the infringement of their rights. In many cases the renovation of dwelling-house is suspended because of the improper solution of juridical and social questions. Other renovation problems are: unqualified house energy audit making, technically unsound heating insulation and architecture of house facade decisions, and final approximation all decisions. The house energy audit is performed superficially or not performed at all before renovation, just the theoretical heat transfer coefficient and resistance of resistance of external walls are calculated and heat transfer coefficient according the standard STR 2.05.01:2005 is noted. The decision of architects to cover the external attached piers for architectural expression is controversial. The external attached piers (staircase entrances, separate house parts) made of good and beautiful decorative bricks are covered by such solutions. The research show that these solutions don't save the heat, but increase the expenditures for heating installation, and the attached pier of decorative bricks may be matched up to the renovated facade. The renovation of external walls of dwelling-house performed according the present valid law doesn't pay off; it just improves and unifies the living conditions of individual flat dwellers.

Keywords: multi-apartment houses, renovation, technical-technological solutions, legal, social aspects, economic evaluation.

INTRODUCTION

Modernisation of multi-apartment houses is a topical issue, huge funds are allocated for its advertisement, but this didn't stimulated to perform rational planning, design, renovation and to solve ecological, economical and social problems. Recently according to the programme for renovation (modernisation) of multi-apartment houses approved by the Government of the Republic of Lithuania, just 30 % of renovation is implemented. This means, that it is necessary to look for causes of the failure, and the programme for renovation of multi-apartment houses must be improved.

The research projects were performed, the programmes for renovation of multi-apartment houses were developed evaluating the following aspects: technical – technological, thermal resistance increase and heat consumption decrease, possibility of alternative sources. Recently many research works are performed about the evaluation of the multi-apartment house renovation efficiency (Biekša et al. 2011A, Biekša et al. 2011, Martinaitis et al. 2007, Rapcevičienė 2010, Ruseckas 2009). The calculations of heat energy impact are revised, evaluating the influence of heat flow and the presence of people (Monstvilas et al. 2010). The problems of thermal comfort and energy demand are analysed, applying radiant ceiling panel heating-cooling systems (Miriel, 2010). In other works it is proposed to renovate residential districts in complex and thus achieve the most effective results (Zavadskas et al. 2008). Practically there are insufficiently analytical works about the heat energy producers and suppliers' energy production costs (Lukoševičius, 2011), and the validity of profits. Practice shows, that monopolistic heat production plants make a profit of several million Litas, but the heating price of 1 kWh supplied for residents is the highest (for example, the average heating price in Lithuania is 29,64 ct; in Kaunas – 31,11 ct, in Vilnius – 28,38 ct). The heating price of heat energy producers and suppliers that are supported by municipalities as a rule is less (e.g. in Elektrėnai – 17,69 ct, Utena – 19,72 ct, Tauragė – 19,76 ct.). The problem is why the majority of residents who get minimum wage have to pay a larger part of wage for heating, and heat energy producers collect huge profits and pay themselves large salaries and bonuses. The crisis doesn't exist for them; they change the price of heat energy to make a profit. These negative factors stop the renovation process and don't socially motivate the residents to renovate their houses.

Organizing the multi-apartment house renovation, in the initial phase it is necessary to solve legal problems correctly, considering the social aspects of home-owners, and to design renovation stages according to the interests of home-owners majority.

The investment-technical project is designed without calculation of heat loss before and after renovation, workload is incorrect according to the insulation solutions made for the renovated house.

The Housing and urban development agency coordinates the performed renovation (insulation) works according to the three work groups: insulation of external partitions, roof insulation and replacement of windows. The application of the performed large work acts enables the foremen to act unfairly.

The majority of Lithuanian multi-apartment houses are built according to the standards that do not ensure an effective use of heat energy. According to the data of the Programme for Renovation of Multi-apartment Houses, approved by the Government, 28 % of multi-apartment houses in Lithuania are built before 1940s, 10 % during 1941–1960, 56,5 % during 1961–1992 year. Improper heat insulation of multi-apartment houses, old common use equipment for heat energy transmission increase the heat energy input, which determine the heating costs. In order to decrease the heating costs it is necessary to take legal and financial actions that ensure the efficient use of heat energy in multi-apartment houses (Legal news, 2012**)**. The renovation of multi-apartment houses is one of the main actions ensuring the efficient use of heat energy. This action is not new in Lithuania, as in 2009 the legal basis for house renovation was developed and models of state support for renovation were foreseen.

The renovation of multi-apartment houses is regulated by:

- EU legal acts;
- Lithuanian Law (Figure 1);
- Legal regulations.

Promoting the renovation of the dwelling houses, the state provides support for preparing and implementing the renovation (modernisation) projects. The State provides assistance to residents in the preparation of technical documentation for renovation projects, organising their implementation. Up to 100 % expenses needed for documentation preparation are reimbursed for residents, if the building energy efficiency level (not less than class D) is achieved according to the implemented measures (http://www.atnaujinkbusta.lt).

At present the state will provide financial support that constitutes 15 % of the renovation project if the energy saving is 20 %. If the saving is not less than 40 %, then 30 % of the performed contract work will be reimbursed (http://www.atnaujinkbusta.lt).

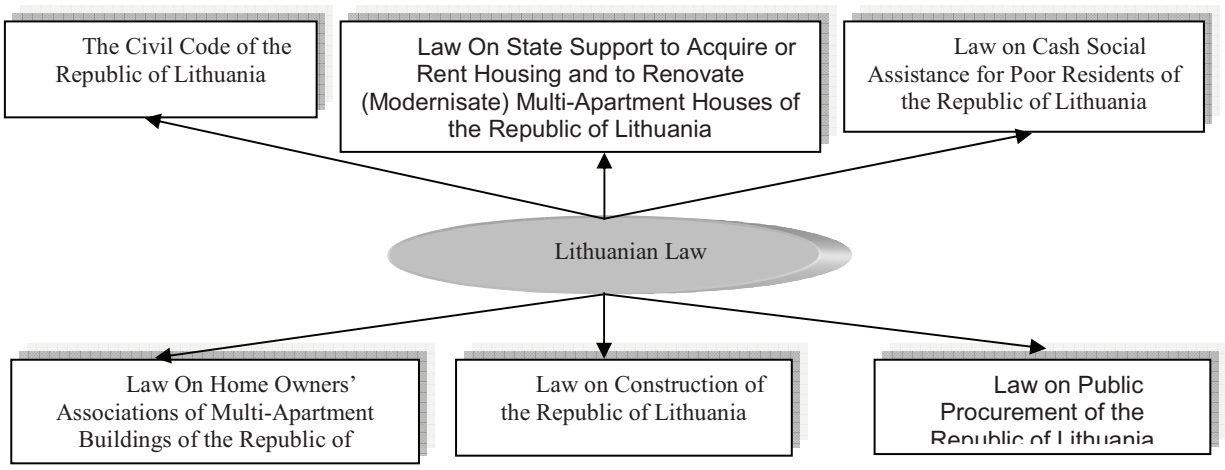

Figure 1. Lithuania Law that regulate the renovation of multi-apartment houses

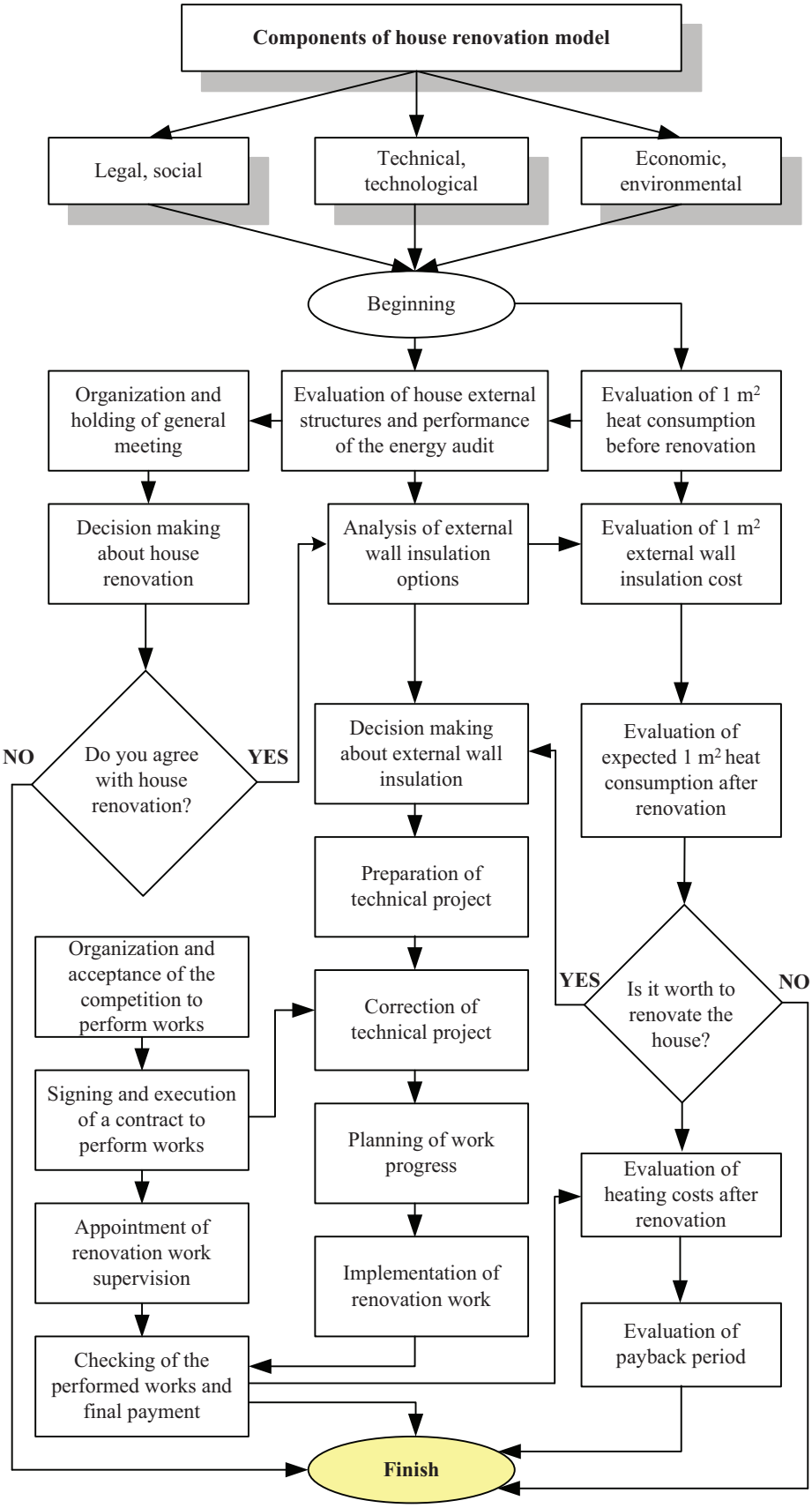

Figure 2. Algorithm of multi-apartment house renovation model

Seeking to speed up the renovation process of multi-apartment houses, the Government developed a financial model for the renovation (modernisation) of multi-apartment houses. There different financial sources for the renovation of multi-apartment houses are foreseen: European Union‘s, State Budget‘s and residents’ funds. Possibilities to use the EU funds for the renovation of multi-apartment houses are provided by the EU initiative JESSICA (*Joint European Support for Sustainable Investment in City Areas)*.

JESSICA initiative was developed by the European Investment Bank (EIB) together with European Commission in cooperation with the Council of Europe Development Bank. (Jessica, 2012).

Making use of this initiative, Member States may allocate part of their EU structural funds for repayable investments in projects of sustainable cities. When the possibilities of the initiative application in Lithuania were analysed, first it was decided to invest into energy efficiency, so into the renovation (modernisation) of old multi-apartment houses.

Lithuania is one of the first states in European Union that applied JESSICA initiative to increase energy efficiency.

According to the developed model the funds for the renovation of multi-apartment houses will be allocated from the Holding Fund. The Holding Fund was established by the Ministry of Finance and the Ministry of Environment of the Republic of Lithuania and EIB (the latter is appointed as a fund manager). The bank has prepared the competition conditions to select financial intermediary of the Holding Fund. The Fund controlled by EIB will provide long-term low-interest loans for residents who want to renovate their houses via the financial intermediary. The funds invested into the projects for renovation of multi-apartment houses will return to the fund and they will be re-invested. The project‘s payback is caused by the efficiency of implemented energy efficient measures (e.g. roof and wall insulation, renovation of heating system, replacement of windows with new ones, balcony glazing, etc.) and therefore the reduced fee for heating.

The state will help the residents by reimbursing a part of renovation (modernisation) works. Up to 31 December, 2013, the owners of apartments and other premises will get 100 % reimbursement for the preparation of renovation (modernisation) project and for construction supervision costs. From 1 January, 2014, 50 % of costs will be reimbursed organizing the project implementation. The state will pay the loan repayment and interests for people who have a right to compensation for heating (http://www.atnaujinkbusta.lt).

Up to 31 December, 2013, 100 % of actual costs (not exceeding 0,35 Lt/m^2 without VAT per month of living area or other premises area) for renovation (modernisation) project administration will be reimbursed for home-owners. From 1 January, 2014, 50 % of expenses will be reimbursed (http://www.atnaujinkbusta.lt)

If the calculated heat energy consumption is reduced not less than 20 % in comparison to previous heat energy consumption, then 15 % of contract work will be reimbursed. From 1 January, 2012 additionally 15 % will be reimbursed if the heat energy consumption is reduced not less than 40 % (http://www.atnaujinkbusta.lt).

All the necessary preparatory works related to the renovation of a dwelling house may be performed in three main stages:

1. A preliminary proposal for residents about the house renovation (modernisation) expedience is prepared;
2. The owners decision is made;
3. The house renovation (modernisation) project is designed.

A decision on a house renovation (modernisation) is made at the general meeting of home-owners, organized by the manager of common use equipment in accordance with the community statutes or agreement of the apartment and other premises owners joint action, and if the joint action agreement is not available or absent, then according to the Civil Code.

The problem of multi-apartment houses renovation has to be analysed in complex, evaluating legal, social, technical-technological, economic and ecological aspects. The complex solution model of multi-apartment house modernisation is presented in Figure 2. The components of complex solution model are analysed, the causes of renovation stagnation are analysed and solution measures for house modernisation problems and disturbances are proposed.

Before the final decision about the renovation of a dwelling house is made, it is very important to find out its expediency. It is recommended to make and prepare the decision of the house renovation (modernisation) according to the developed algorithm of multi-apartment house renovation model, presented in Figure 2.

Technical-technological solutions for renovating a multi-apartment ceramic brick house

When the renovation is performed to the multi-apartment house of complicated configuration, with protruding attached piers and parts of building, then several solutions for wall insulation must be made. When multi-apartment ceramic brick house with attached piers and parts of building are renovated, 3-6 solutions for external wall insulation can be made, and 1-3 solutions can be made for socle. This type of house in Kaunas, Žiemių str. 4, is insulated with expanded polystyrene of 150, 100 and 50 mm, the wall of the first floor – with stone wool of 130, 80 mm, socle with stone wool of 80 mm and expanded polystyrene of 100 mm (Figure 3).

The finishing is made of two layers: the main layer which is reinforced with mesh and the structural decorative plaster. The total width of both layers is 3 mm. Decorative fiber cement panels („Minerit“ 8 and 12 mm) were used for the first floor and the socle.

Figure 3. Fragment of wall renovation

Renovating this type of a house, it is necessary to evaluate, whether it is expedient to insulate the protruding attached piers. The insulation of protruding attached piers increases the insulation area up to 35 %, as well as the renovation expenses. The primary calculations were performed (Kazlauskas 2009) and tentatively it was stated that when external walls are insulated qualitatively and when protruding attached piers of landing are not insulated, the heat losses are insignificant, and there is no danger for dew point formation. In the future this question must be researched elaborate. When the roof is renovated, the following solution is made: 150 mm expanded polystyrene + 40 mm stone wool insulating layer and 2 layers of hydro-insulating coating.

Evaluating the work quality of external wall insulating, it is found that facing with stone wool is often performed not qualitatively, gaps between stone wool pieces are left, a windproof, diffusion-permeable membrane is not applied (Figure 4). The insulation under the iron window sills is performed not thoroughly (just spot gluing with foam). Evaluating the work quality of structural layer application, it was found that the structural layer at the beginning of renovation was just 0.9-1.2 mm thick, when according to the standards it must be 3 mm. The foremen had to perform qualitative work and increase the structural layer thickness up to 3 mm after the repeated inspections and constant control. The scientific sources (Šadauskienė 2007) show that when the structural layer is not optimal , a few years later it starts cracking and humidity penetrates into insulating material, therefore its thermal insulation properties become worse. So, in this investigation case the decrease of heat consumption for1 m^2 after the renovation depends on the fact whether the external wall insulation was performed qualitatively.

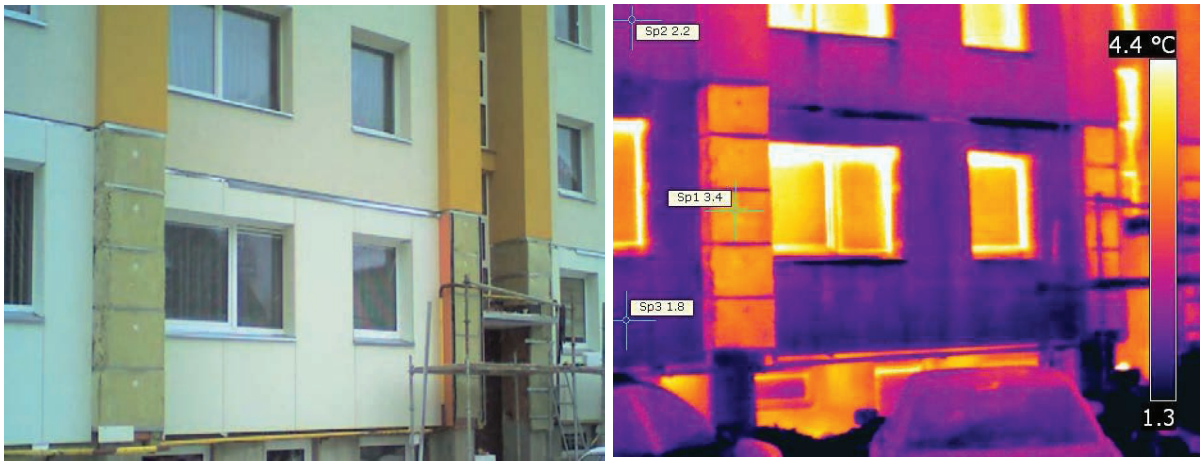

Figure 4. Fragment of renovation and defects of insulation

Economic evaluation of house renovation

Economic evaluation of the house renovation is performed according to the expenses for renovation of 1 m^2 of living area, heat consumption kWh/m^2 and heating cost Lt/m^2. The dynamics of heat consumption kW/m^2, heating cost Lt/m^2 and 1 kWh cost is presented in Figure 5. Until the renovation the heat consumption during the coldest months was 15-20 kWh/m^2, after the renovation the heat consumption was 10-15 kWh/m^2. Until the renovation the heat consumption of the heating season was 76,50 kWh/m^2, after the renovation – in 2010/2011 the heat consumption of the heating season was 63,74 kWh/m^2, and in 2011/2012 - 54,57 kWh/m^2.

The average heat consumption after the renovation decreased 29,1%. Before the renovation the average heating cost was about 15, 95 Lt/m^2, after the renovation the heating cost in 2011/2012 heating season was 15,53 Lt/m^2, and in 2011/2012 year – 15,78 Lt/m^2, and the average reduction of the heating cost is just 1,88 %. It is seen, that after the renovation the heat consumption decreased significantly, but due to the rising heat selling prices the heating cost practically didn't change. In the future, predicting the increasing heat energy cost, the comparative heat consumption of the heating season will increase and the renovation won't payback for home-owners. In the analysed case, according to the Table 1 data, the renovation cost of multi-apartment ceramic brick house for the home-owner constitutes 195,05 Lt/m^2 of living area. The renovation cost with the 50 % state subsidy constitutes I= 390,1 Lt/ m^2.

According to the STR 2.05.01:2005, the renovation payback period is calculated. Before the renovation the house wall's coefficient of heat transmission was U_1= 0,909 W/(m^2·K), after the renovation it is U_2 = 0,243 W/(m^2·K). The temperature difference between indoor air and outdoor air is taken 20°C for heating season; the duration of heating season is 3600 h. Annual savings are calculated, if the insulation is installed in the first year, this constitutes 15,28 Lt/m^2 for year. Simple payback period is calculated by formula:

$$PB = I / \Delta S \quad (1)$$

$$\Delta S = 0{,}001 \times \Delta U \times \Delta\Theta \times t \times E \quad (2)$$

$$PB = I/\Delta S = 390{,}1/15{,}28 = 25{,}53 \text{ years.}$$

here I – resources of 1m^2 external wall insulation, Lt/m^2; ΔS – annual savings after insulation by value of the first year, Lt/m^2·year; ΔU – decrease of heat transmission coefficient after insulation, W/m^2·K; ΔΘ – the average temperature difference on both sides during the heating period, °C; t – duration of the heating season, h; E– energy prices during insulation, Lt/kWh.

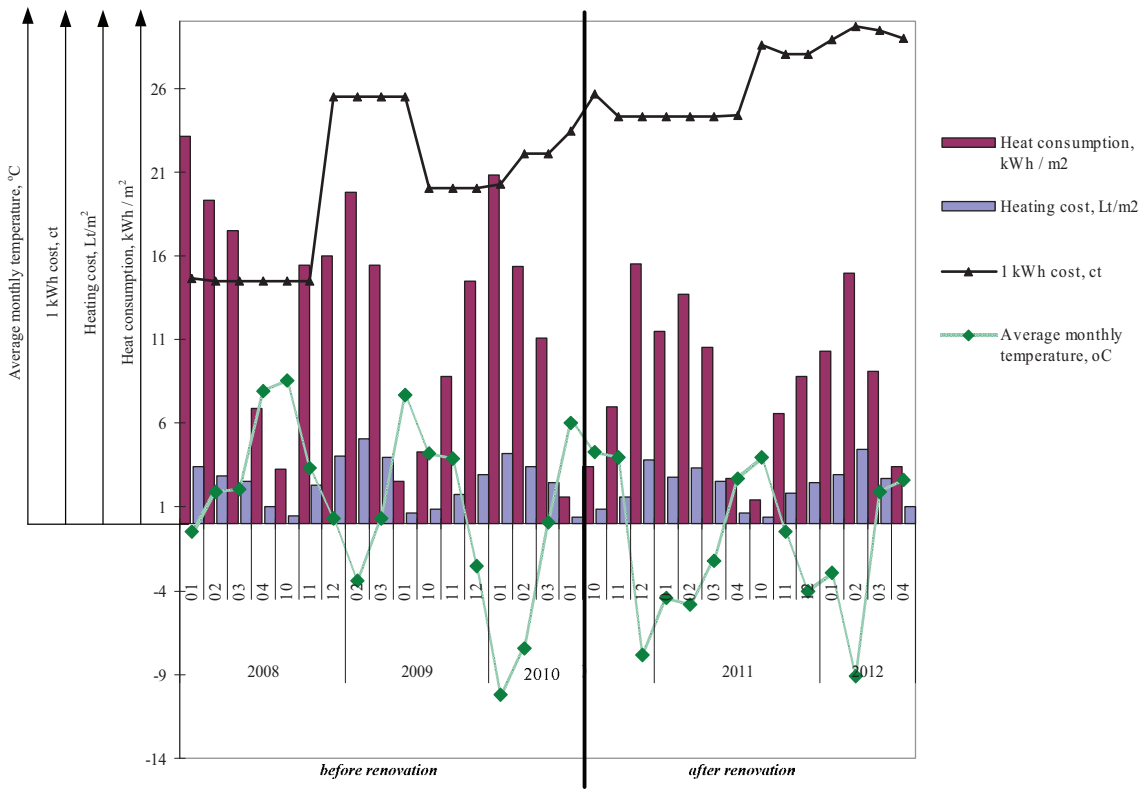

Figure 5. Dynamics of heat consumption, heating cost, 1 kWh cost and environment temperature

Having calculated the rate of fund loss r_n=4 %, and minimum rates of heat energy cost e_n= 5 %, the real payback period is calculated:

$$PO = \frac{-\ln\left(1 - r \cdot \frac{I}{\Delta S}\right)}{\ln(1+r)} \tag{3}$$

here r= $(r_n-e_n)/1+e_n$; r = -0,0095

Table 1. Renovation expenses for living area Lt/1m^2 of multi-apartment ceramic brick house (according to the performed work estimate; without state subsidy)

Title of general works	Renovation works	Lt/1m^2	Percent, %
Design, organization, supervision	Technical project	3,371	
	Public tenders	0,173	
	Administration	4,109	
	Technical supervision	4,159	
	Total:	11,798	6,14
Tubing	Valves	3,72	1,937
Windows	Apartment windows	25,30	
	Balcony glazing	15,11	
	Cellar windows	1,41	
	Staircase windows	6,51	
	Total:	48,33	25,16
External walls	External walls (expanded polystyrene 150, 11 and 50 mm, stone wool 75 mm)	113,09	58,88
Roof	Roof insulation (150 mm expanded polystyrene and 50 mm stone wool, coating installation (2 layers)	15,10	7,915
	Total:	**195,05**	**100**

The real payback period is PB= 23,57 years. It is a long period and during the period it will be necessary to renovate the facade at least once – to spray with structural mixture, therefore the home-owner will have additional expenses again. So, the home-owner will not have any economic benefit, because the renovations will not payback. Of course, living conditions in the renovated house will improve, heat energy will be saved state-wide, builders will have work and environmental pollution will be reduced.

CONCLUSIONS

1. Designing a technical project for the multi-apartment house renovation, it is necessary to make a precise evaluation of heat loss before and after the renovation, to calculate the renovation workload and the expected decrease of heat consumption.
2. Performing the renovation works constant and qualified supervision must be performed. The improperly attached and unsealed insulation material must be repaired, and decorative structural plaster must be of the designed thickness.
3. The renovation of multi-apartment houses that are built of ceramic perforated bricks and cellular concrete base will payback in 25 years. Actually home-owners do not have any economic benefit because of the rising heat selling prices. But after the renovation the living conditions are improved, heat energy is saved state-wide, and environmental pollution is reduced.
4. In the future the renovation expenses for home- owners must be calculated according to insulated area.
5. In the future the analysis and supervision of heat producers' and suppliers' large profits validity must be performed, as the performed renovation must be beneficiary for home-owners too, the payback period should decrease and the renovation become less stagnant.

REFERENCES

Atnaujink būstą. Teisės žinios. [Renew dwelling. Legal basis] http://www.atnaujinkbusta.lt.

Biekša, D., Šiupšinskas,G., Martinaitis,V., Jaraminienė, E. 2011. Energy efficiency challenges in multi-apartment building renovation in Lithuania. Journal of Civil Engineering and Management, No. 17(4), 467-475.

Biekša, D., Jaraminienė, E., Martinaitis,V. 2011. Daugiabučių namų renovacijos verinimas atsižvelgiant į trejopą naudą [Evaluation of refurbishment in multi-flat buildings considering ternary benefit]. Mokslas- Lietuvos ateitis, 3(5), 98-104.

JESSICA.- web access: http://www.eib.org/products/technical_assistance/jessica/.

Kazlauskas,R. 2009. Daugiabučių gyvenamųjų namų renovacijos ir rekonstrukcijos technologijų analizė. Magistro baigiamasis darbas (Analysis technology of renovation and reconstruction of apartment house.Master s degree handout of civil engineering). KTU, 111 p.

Legal news.- GLIMSTEDT, 2012 05 (Nr.1). http://www.lsta.lt/files/seminarai/2012-05-22_Glimstedt/6_GLIMSTEDT%20Teises%20zinios%202012-05.pdf.

Lukoševičius, V., Balaišytė, B. 2011. Centralizuotai tiekiamos šilumos kainų Lietuvos savivaldybėse priežastingumo tyrimai. [Causality tests of district heat prices in Lithuanian municipalities] Vilnius. Lietuvos energetikos konsultantų asociacija. 39p.

Martinaitis,V., Kazakevičius, E. 2007. A two factor method for appraising building renovation and energy efficiency improvement projects. Energy Policy, 192-201.

Miriel, J., Serres, L., Trombe, A. 2002. Radiant ceiling panel heating-cooling systems: experimental and simulated study of the performances, thermal comfort and energy consumptions. Applied Thermal Engineering, No. 22, 1861-1876.

Monstvilas E., Banionis, K., Stankevičius,V., Karbauskaitė, J., Bliūdžius, R. 2010. Heat gains in building –limit conditions for calculating energy comsumption. Journal of Civil Engineering and Management, No. 16(3), 439-450.

Ruseckas, J. 2009. Kompleksinis daudiabučių gyvenamųjų namų rekonstrukcijos metodikos principai [Methodical principles of complex multistorey apartment buildings reconstruction]. Mokslas- Lietuvos ateitis, 1 tomas, Nr.5, 72-78.

Rapcevičienė, D. 2010. Daugiabučių namų renovacijos efektyvumo vertinimas [Evaluation of multi residential house renovation efficiency], Mokslas- Lietuvos ateitis, 2 tomas, Nr. 2, 83-89.

STR 2.05.01:2005. Pastatų atitvarų šiluminė technika. Lietuvos Respublikos Aplinkos ministerija, 2005, 113 p. http://www3.lrs.lt/pls/inter2/dokpaieska.showdoc_l?p_id=260821.

STR 2.01.09.:2005. Pastatų energinis naudingumas. Energinio naudingumo sertifikavimas. Lietuvos Respublikos Aplinkos ministerija, 2005, 54 p. http://www3.lrs.lt/pls/inter3/dokpaieska.showdoc_l?p_id=268553.

STR 2.09.04.:2008.Pastato šildymo galia ir šilumos poreikis šildymui.Lietuvos Respublikos Aplinkos ministerija, 2008, 33 p. http://www3.lrs.lt/pls/inter3/dokpaieska.showdoc_l?p_id=320473&p_query=&p_tr2=

Šadauskienė,J., Monstvilas,E., Stankevičius, V. 2007. The impact of exterior finish vapour resistance on the moisture state of building walls. Journal of Civil Engineering and Management. 2007, Vol XIII, No 1, 73-82.

Zavadskas, E.K., Raslanas,S., Kaklauskas, A. 2008. The selection of effective retrofit scenarios for panel houses in urban neighborhoods based on expected energy savings and increase in market value. The Vilnius case, Energy and Buildings, 40(4), 573-587.

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Lithuanian Standard Climate Model for the Prediction of Energy Consumption in Buildings

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Abstract. According to the provisions of the Directive 2002/91/EC, Lithuania has committed to increase the energy efficiency of buildings taking into account climatic local conditions as well as requirements to indoor microclimate and cost-effectiveness. In order to construct the energy saving buildings („nearly zero-energy buildings"), it is necessary to evaluate the dynamics of climate impacts. Therefore, one of the goals is to compose the Lithuanian hourly dynamic reference meteorological year. For this reason, we have to analyze the principles of composition of the reference meteorological year and practices of this subject in other countries. According to LST ISO EN 15927-4, the reference (average) meteorological year is composed by using the hourly long-term database of essential climate parameters: dry bulb thermometer temperature (ºC), global solar radiation (W/m²), relative humidity of air (%) and wind speed (m/s). The constructed reference year will be used for analysis and prediction of thermal-hygric state of enclosures, energy use in building for heating and cooling, dates of beginning and ending of the heating season and also other scientific research activities.

Keywords: reference meteorological year, climatological values, cumulative distribution function.

INTRODUCTION

In European Union the reduction of energy consumption and the use of energy from renewable sources in the building sector are the important measures necessary to reduce the EU's energetic dependence (Directive 2010/31/EC, 2010; Energy…2010).

According to the provisions of the Directive 2002/91/EC, Lithuania has committed to increase the energy efficiency of buildings taking into account climatic local conditions as well as requirements to indoor microclimate and cost-effectiveness. This can be done by optimizing the building envelopes. Seeking to achieve this objective, it is necessary to assess properly the dynamics of meteorological conditions that determine the proper selection of the building envelope in order to ensure, with a certain confidence level, the microclimate of building (STR 2.09.02:2005).

The design and selection of systems for heating, ventilation and air conditioning are applied using software that models the microclimate of the building, parallelly assessing the energy needs for a building. The dynamics of meteorological conditions affect the results of building modelling and design. Ongoing changes in the climatological parameters values have a significant impact on power of the heating and ventilation systems, duration of the heating season and for energy costs.

The Lithuanian Building Code "RSN 156-94 Building Climatology" (RSN 156-94) provides limited quantities of climatological parameters values. These climatological values are insufficient for accurate assessment of the dynamics of meteorological conditions in the design and selection of heating and ventilation systems of buildings.

Therefore it is necessary to generate the Lithuanian TRY for the calculation of the building energy demand. The annual model requires the hourly values of climatological parameters. This set of the basic climatological parameters will consist of the following values: dry-bulb air temperature (DBT), direct normal solar irradiance and diffuse solar irradiance on a horizontal surface (DSR), relative humidity (RH) and wind speed (WSP). The constructed reference year will be used for analysis and prediction of thermal-hygric state of enclosures, energy use in building for heating and cooling, dates of beginning and ending of the heating season and also other scientific research activities.

Overview of the construction of standard climate (try) model

Over the past 50 years several hourly dynamic standard climate annual models of this type were proposed throughout the world. The Test Reference Year (TRY) model in each case is to be evaluated individually. It depends on climatic conditions, specific terrain defined by geographical latitude, longitude, as well as terrain altitude above sea level, building type, the accuracy of measuring the multi-year climatic parameter values during observations in meteorological stations and the duration of data capture period. The annual model of the climatological parameter values of the (TRY) for the calculation of the building energy demand is composed of 8760 hours. The rates of these parameter values must represent the long-term average occurrence.

In 1976 one of the first arrays of climatic parameter values Test Reference Year (TRY) was constructed by the National Climatic Data Centre (NCDC) for building simulation and energy calculations The selected method distinguished the years with the most extreme values of the months which have maximum or minimum average monthly temperature values. The selection principle was based on the rejection of years with the highest and lowest average monthly temperature until the last one year remains. This climate model was designed by using the hourly values of climatic parameters of the 1948-1975 period. The array of the climatic parameter values of weather for energy calculations consists of 12 typical meteorological months. The „Historical Climatology Standard" arrays characterize the synoptic situations of 60 areas in the USA. (Lund, 1975, NCDC, 1976).

In 1981 the Typical Meteorological Year (TMY) was constructed by the joint forces of laboratories, the National Climatic Data Centre (NCDC) and Sandia National Laboratory (SNL). This statistical analysis method is based on four climatic parameters: dry bulb thermometer temperature, dew point temperature, global solar radiation on a horizontal surface, and wind speed values. Typical meteorological months (TMMs) were selected from the multi-year climatic values of the 1952-1975 period (Drury, 1998, NCDC, 1981). Later, the TMY array was updated with new versions TMY2 (NREL, 1995) of the National Renewable Energy Laboratory (NREL) with new 1961-1990 period characterizing the synoptic situations of 239 areas in the USA. National Solar Radiation Data Base NSRDB developed TMY3 (Wilcox, 2008). array with new periods: 1976-2005 30 years, 1991-2005 15 years, 1998-2005 8 years. These versions updated and combined periods of the TMY arrays which characterize the synoptic situations of 1400 areas in the USA. The TMY, TMY2, TMY3 array of climatic parameter values of TMY consists of 12 typical meteorological months. The months were selected in accordance with the complex Finkelstein-Schafer statistical method (Finkelstein, 1971), by evaluating the coefficients of different weighting factors. The calculated rates of values of selected months with weighting factors were close to the multi-annual observational values.

The Weather Year for Energy Calculations (WYEC) was constructed in 1985 by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), which is intended for building energy calculations. This climate model was designed by using the hourly values of climatic parameters of the 30-year period (WYEC, 1985). To create a weather data set to represent typical weather patterns than either a single representative year or an assemblage of months. The basic method used to select data for (WYEC) was to determine, for each month of the year, the single, real month of hourly data whose mean dry-bulb air temperature (DBT) was closest to the average (DBT) of that month during the 30-year period. The month selected in this way will have the climatic parameter values of the days of that month but of different years. The WYEC data were prepared in 51 North American locations, 46 locations in United States and 5 in Canada (Crow, L.W. 1983). Later, NREL updated the set of data array WYEC of the climatic parameter values by creating a new version of the climatic data model WYEC2 (Stoffel, 1993).

Canadian Weather for Energy Calculations (CWEC) and International Weather for Energy Calculations (IWEC) consists of 12 typical meteorological months. The months were selected in accordance with the complex Finkelstein-Schafer statistical analysis method, as with the TMY method but only evaluating the coefficients of different weighting factors in determining the climatic parameter values. The (CWEC) climatic parameter values characterizing the synoptic situations of 145 areas in the Canada (CWEC, 1999). The International Weather for Energy Calculations (IWEC) consists of typical meteorological months selected from the 1982-1999 period and characterizes the climatic conditions in 227 locations in the USA and Canada. (Thevenard, 2002a, Thevenard, 2002b).

According to LST EN ISO 15927-4:2005 the Test Reference Year (TRY) represents 365-day series of hourly values of the selected meteorological variables, which are necessary for the calculation of the energy balance of a building. The TRY is constructed by using the hourly values of climatic parameters: dry-bulb air temperature (DBT), direct normal solar irradiance and diffuse solar irradiance on a horizontal surface (DSR), relative humidity (RH), wind speed (WSP). TRY model includes the months with the least deviations from the average values, the characteristic month is selected according to the statistical rate value Finkelstein-Schafer (Finkelstein, 1971, LST EN ISO 15927-4:2005). International standard recommendations on development of the TRY model in each case are evaluated individually. TRY model is developed in Italy, France, United Kingdom, Ireland, Belgium, The Netherlands, Denmark, Portugal, constructed under the rules in force in the European

Union. With the small differences for Try model construction applied in Turkey, Russia, Slovakia and Slovenia (Lund, H. 2001).

Some countries of the world present their own standard climate construction methods in addition to the above reviewed.

Joseph C. Lam developed the Typical Meteorological Year TMY pattern for Hong Kong. The TMY model is constructed for the 16-year period (1979-1994). The principle of the TMY model construction differs from the original TMY developed by the joint forces of laboratories, the National Climatic Data Centre (NCDC), Sandia National Laboratory (SNL), as they have differences in monthly statistical sampling procedures. The TMY model was designed by using the hourly values of climatic parameters and the nonparametric Kolmogorov-Smirnov test, but not the average climatic parameter values and the Finkelstein-Schafer test. (Lam, et al., 1996).

Currently, Lithuania has no standard dynamic climate model for the energy cost prediction, building design by simulation, duration of the heating season, selection of power of the heating and ventilation equipment.

Meteorological data

The territory of Lithuania is located in the climatic zone of middle latitudes and, according to the B. Alisovas'classification of climates, is attributed to the south-western sub-area of the Atlantic continental forest area. Only the Baltic Sea coast climate is closer to the Western Europe climate and could be ascribed to the separate climate sub-area of the Southern Baltic (Galvonaitė, et al., 2007). Due to the different distribution of climatic conditions, the territory of Lithuania is classified into four districts and ten sub-districts (Fig 1).

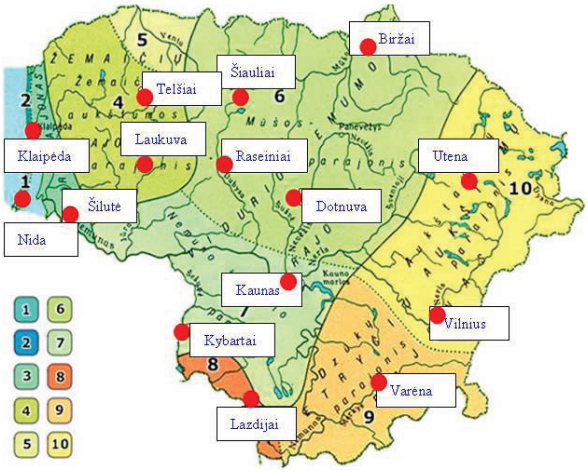

Figure 1. Meteorological stations and climate zones of the territory of Lithuania

Each of these districts has its own dynamics of meteorological conditions, for this reason, those fifteen meteorological stations were selected Table 1, in which the climatic parameter values were recorded for the construction of the Lithuanian TRY.

Table 1. Location of the meteorological stations

Serial No.	Districts	Meteorological station of the city	Geographical latitude	Geographical longitude	Altitude, m
1	Coastal	Nida	55°19'	21°10'	2,1
2		Klaipėda coast	55°44'	21°10'	6,2
3		Šilutė	55°21'	21°12'	2,7
4	Žemaičiai	Telšiai	55°58'	22°21'	153,3
5		Laukuva	55°37'	22°21'	165,4
6	Central Lowland	Šiauliai	55°56'	23°31'	105,9
7		Dotnuva	55°24'	23°35'	96
8		Kaunas	54°53'	23°35'	76,1
9		Kybartai	54°38'	22°24'	57,7

10		Raseiniai	55°23'	23°30'	110,7
11		Biržai	56°12'	24°44'	60,2
12	Southeast Upland	Vilnius	54°38'	25°50'	162,1
13		Varėna	54°15'	24°43'	109,1
14		Lazdijai	54°15'	23°31'	133,2
15		Utena	55°32'	25°53'	104,8

The data of sequences of the meteorological parameter values are statistically interdependent. The main subject of discussion is the period of observation of climatic values which evaluates those factors of statistical effects of recorded values which determine the statistical parameters values. According to the guidelines and recommendations of the technical regulation (General…, 1988) of the World Meteorological Organization (WMO), the standard climatic norms are created for the 30-year period. Climatological data averages are calculated for the following consecutive periods of 30 years: from 1 January 1901 to 31 December 1930, from 1 January 1931 to 31 December 1960, from 1 January 1961 to 31 December 1990, from 1 January 1991 to 31 December 2020.

For the construction of the Lithuanian TRY, the 1961-1990 period of time equal to 30-year cycle is adopted in accordance with the provisions of the WMO. The construction of the Lithuanian TRY requires the main measured hourly values of climatic parameters: dry bulb thermometer temperature, air relative humidity, solar radiation, wind speed at a height of 10 m above ground (LST EN ISO 15927-4:2005). All the climatic data is provided by the Lithuanian Hydrometeorological Service.

Figure 2 shows the climatic parameter values of dry bulb thermometer temperature and air relative humidity, wind speed were recorded four times a day every six hours (01, 07, 13, 19) during the period from 01.01.1961 to 31.12.1965, during the period from 01.01.1966 to 31.12.1990 – eight times a day every three hours (00, 03, 06, 09, 12, 15, 18, 21). The values of these climatic parameters were measured at all stations given in the table below. Actinometric observations of solar radiation in Lithuania have been performed since 1955 at Šilutė and Kaunas meteorological stations, six times a day every four hours (0.30, 6.30, 9.30, 12:30, 15:30, 18:30), at mean solar time The hourly values of climatic parameters of direct solar radiation on the surface perpendicular to the direct beam, diffuse solar radiation and total solar radiation are recorded by the self-recording devices.

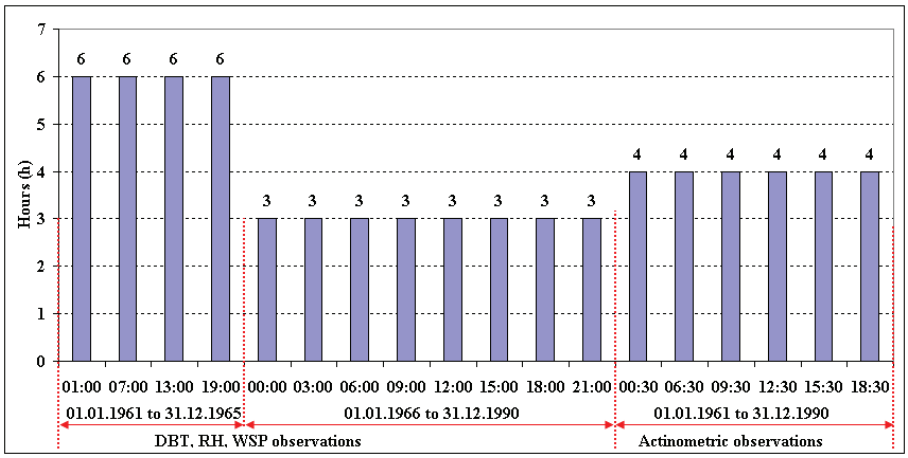

Figure 2. The climatic parameter values of dry bulb thermometer temperature, air relative humidity, wind speed and actinometric observations

The construction of the TRY model requires the hourly values of climatic parameters characterizing the local meteorological conditions. In Lithuania, the hourly values of both total and diffuse solar radiation were measured only at Kaunas and Šilutė meteorological stations. Meteorological conditions correlate with each other, and for this reason, the city of Kaunas was selected as representing the average Lithuanian climate.

Method description - test reference year

In the following the construction of the Test Reference Year is described according to the standard LST EN ISO 15927-4:2005 (LST EN ISO 15927-4:2005). The TRY for Kaunas is constructed by using the hourly values of climatic parameters p, where p is the dry-bulb air temperature (DBT), direct normal solar irradiance and diffuse solar irradiance on a horizontal surface (DSR), relative humidity (RH) and wind speed (WSP).

For each climatic parameter p, the values of daily average, $\overline{p}$ of are calculated from hourly values of the 1961-1990 period. For each calendar month, the cumulative distribution function of the daily average parameter p is calculated by sorting all the values of the data set (total period) in, is used Eq. (1):

$$\Phi(p,m,i) = \frac{K(i)}{N+1} \qquad ((1)$$

For each year, from the data set, the cumulative distribution function of daily means within each calendar month is calculated by sorting all the values of that month and year in ascending order is used Eq. (2):

$$F(p,y,m,i) = \frac{J(i)}{n+1} \qquad ((2)$$

For each corresponding calendar month, the Finkelstein-Schafer statistic for parameter p, for each year of the data set is used Eq. (3):

$$F_S(p,y,m) = \sum_{i=1}^{n} \left| F(p,y,m,i) - \Phi(p,m,i) \right| \qquad ((3)$$

For each calendar month, the individual months are then ranked from the multi-year record in order to increase the size of $F_S(p,y,m)$

In the same order, for each calendar month and each year, there are separate categories of climatic parameters – dry bulb thermometer temperature, global solar radiation, relative humidity of air.

For each calendar month and each year, the separate ranks for the three climatic parameters are added.

For each calendar month, out of three months with the lowest overall rating, the wind speed deviation of the monthly average from the corresponding values of wind speed averages of multi-year calendar months. The month with the lowest wind speed deviation is chosen as the “best” month. The month selected in this way is included into the composition of the standard year model of dynamic climate.

The hourly values of climatic parameters – air temperature and relative humidity – of selected twelve characteristic months must be evenly combined with each other in order to avoid a sudden drop of values between the end of one month and the beginning of another one. The wind speed and direction change during the day, the value of total solar radiation is equal to zero at midnight, therefore, the values of these climatic parameters between months are not being adjusted. The last eight hours of a month and the first eight hours of a day of the subsequent month are adjusted by interpolation, through the even distribution of the values between months.

Kaunas’ test reference year

The construction of the TRY model requires the hourly values of climatic parameters characterizing the local meteorological conditions. These climatic data are submitted by the Lithuanian Hydrometeorological Service. The TRY model is constructed in accordance with the procedures described in previous Chapter.

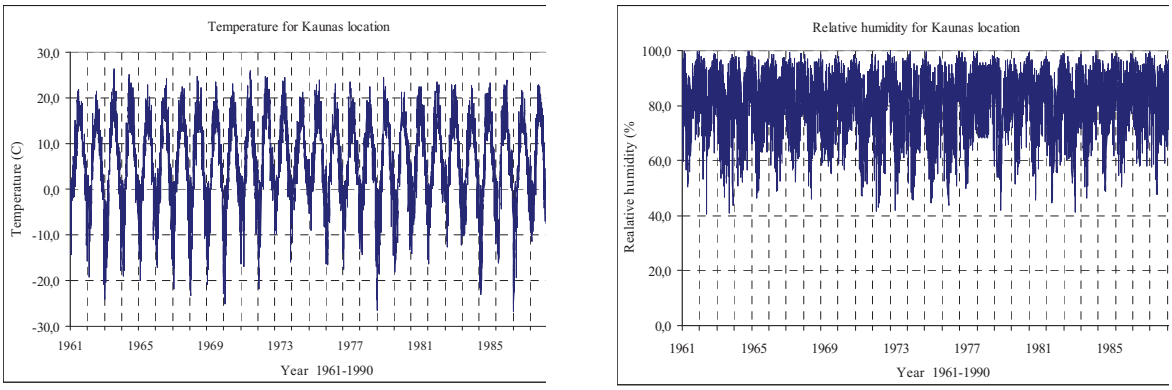

Figure 3. Annual dry-bulb air temperature and relative humidity for Kaunas.
The figure on the left shows the air temperature and the figure on the right shows the relative humidity

Figure 3 shows the DBT and RH values of climatic parameters in Kaunas: the day average values were calculated using the hourly values of the 1961-1990 period of time equal to 30 years.

In order to construct the standard climatic annual model, 12 months were selected in accordance with the Finkelstein-Schafer statistical method (Finkelstein, 1971). Also the distribution of general set of average cumulative function of parameter values is compared with the partial cumulative distributions, thus the differences in frequency of particular parameter values are determined.

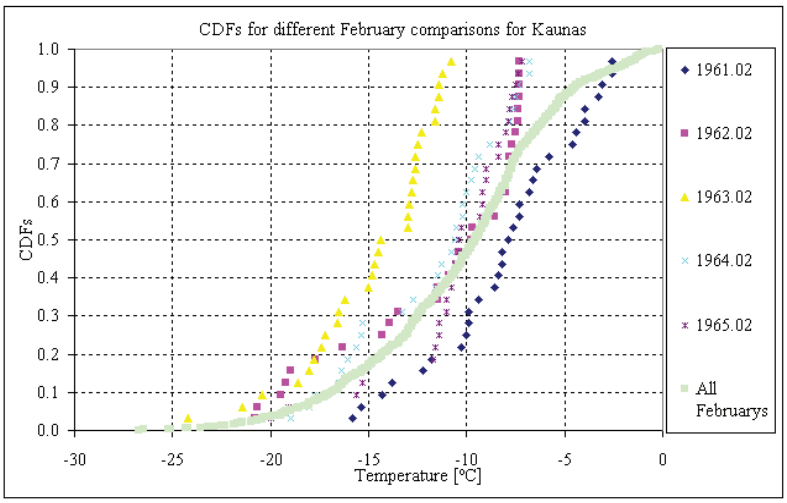

Figure 4. CDFs for different February's comparisons for Kaunas from 1961-1965 year of data set

Figure 4 shows the principle of the selection process. The green curve shows the 30 year daily average temperature data obtained from Kaunas Meteorological Station in February. The dotted curve shows the variation of months over the cumulative distribution function curve. For each calendar month, out of three months with the lowest overall rating, the wind speed deviation of the monthly average from the corresponding values of wind speed averages of multi-year calendar months. The month with the lowest wind speed deviation is chosen as the "best" month. The month selected in this way is included into the composition of the standard year model of dynamic climate.

Upon the selection of DBT and RH climatic parameters of twelve characteristic months, the hourly values must be evenly combined with each other in order to avoid a sudden drop of values between the end of one month and the beginning of another one (Bruzgevičius et al., 2012). The figures 5 show the smooth consolidation between the months of January and February. The dotted blue line describes the measured values of climatic parameters, and the red one – the smooth consolidation of these values between months.

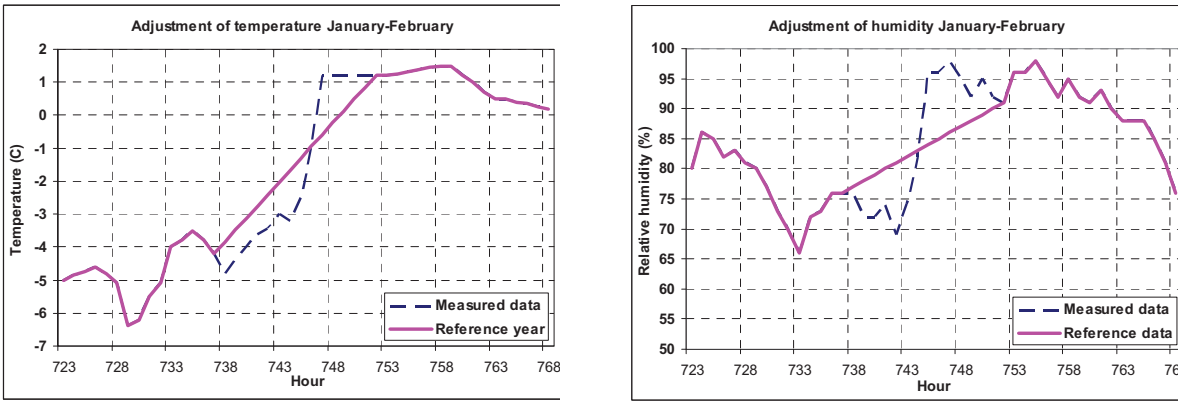

Figure 5. Example of smoothing between two months of January and February. The figure on the left shows the smoothing of dry-bulb temperature and the figure on the right – of relative humidity

The TRY model for Kaunas will be finished after setting up the data on the hourly parameters of solar radiation and wind speed values from manuscripts to the digital environment. Hourly data for processing of statistical analysis will be prepared in accordance with the procedure described in previous Chapter.

CONCLUSIONS

The presented hourly values of climatic parameters were prepared for the TRY model for Kaunas: outdoor air temperature and relative humidity for the 30-year period.

The Lithuanian TRY will enhance the accuracy of prediction of thermal-hygric state of building envelopes, the energy use for heating and cooling, the average dates for beginning and ending of the heating season of different types of buildings. This climatic model will allow to evaluate the impact of building‘s thermal inertia to average duration of heating season. It could be used in building design and modeling, scientific research.

The Lithuanian standard climatic model will complement the database of the IWEC (International weather year for energy calculations) with hourly values of climatic parameters of the 1961-1990 period.

Abbreviations

DBT-dry-bulb air temperature
DPT-dew-point air temperature
RH- relative humidity
GSR-global solar radiation
WSP-wind speed
ASHRAE-American Society of Heating, Refrigerating and Air-Conditioning Engineers
HVAC - Heating, Ventilation and Air Conditioning
TRY - Test Reference Year
TMY, TMY2, TMY3-Typical Meteorological Year
TMM- Typical Meteorological Months
WYEC-Weather Year for Energy Calculation
IWEC-International Weather for Energy Calculation
CWEC-Canadian Weather for Energy Calculation

Nomenclature

F(p) – cumulative distribution function of p within each individual month.
F – Finkelstein-Schafer statistic.
J – rank order of daily means within a calendar month in one year.
K – rank order of daily means within that calendar month in the whole data set.
N –number of days in any calendar month in the while data set.
M – month of the year.
n – number of days in an individual month.
p – climate parameter (temperature, solar radiation or humidity).
$\overline{p}$ – daily mean of any climate parameter.
y – year.

Φ(p) – cumulative distribution function of p within each calendar month in all the years in a sample.

REFERENCES

Bruzgevičius, P. Burlingis, A. Stankevičius, V. 2012. The construction of Lithuanian hourly meteorological data for building energy simulation. In Procceedings of the 9th International Conference of Young Scientists on Energy Issues, Kaunas, 2012.

Crow, L.W. 1983. Development of Hourly Data for Weather Year for Energy Calculations (WYEC), Including Solar Data, at 29 Stations throughout the United States and 5 Stations in Canada, Research Project RP 364 Final Report, November 1983. Atlanta, Georgia.

CWEC, 1999. Canadian Weather for Energy Calculations (CWEC Files), User‘s Manual. Environment Canada, Waterloo, ON: Numerical Logics Inc.

Directive 2010/31/EC of the European parliament and the Coucil of 19 May 2010 on the energy performance of building. Official Journal of the European Communities. 2010.18.6.2010, 13-35.

Drury, B. C. 1998. Which weather data should you use for energy simulations of commercial buildings. ASHRAE Transactions, 104 Part 2.

Energy Performance of Buildings Directive, 2010. European Commission. Link to the internet <http://www.euractiv.com/en/energy-efficiency/energy-performance buildingsdirective/article-187130>.

Finkelstein, J. M., Schafer, R. E. 1971. Improved goodness-of-fit tests. Biometrika, No. 58., 641–645.

General Meteorological Standards and Recommended Practices, 1988. Technical regulations Volume I. Secretariat of the World Meteorological Organization – Geneva – Switzerland. No. 49.

Galvonaitė, A., Misiūnienė, M., Valiukas, D., Buitkuvienė, M.S. 2007. Lietuvos klimatas. [The climate in Lithuania] Lithuanian Hydrometeorological Service. Vilnius, 208 p. ISBN 178-9955-9758-2-3.

Lund, H. 1975. Test Reference Year, weather data for environmental engineering and energy consumption in buildings. Thermal Insulation Laboratory Technical Universkty of Denmark. September 1975 report No. 67.

LST EN ISO 15927-4:2005. Higroterminės statinių charakteristikos. Klimatinių duomenų apskaičiavimas ir peteikimas. 4 dalis. Valandiniai duomenys šildymui ir vėsinimui per metus sunaudojamai energijai įvertinti. [Hygrothermal performance of buildings. Calculation and presentation of climatic data - Part 4: Hourly data for assessing the annual energy use for heating and cooling], Brussels, 2005. 5p..

Lund, H. 2001. Design Reference Years and Test Reference Years in Europe, Turkey and Israel. Technical University of Denmark Department of Civil Engineering. February electronic Cib Publication No. 262.

Lam, J.C., Hui, S.C.M. and Chan, A.L.S.A. 1996. Statistical approach to the development of a typical meteorological year for Hong Kong. Architectural Science Review, vol. 39, No. 4., 201–209.

NCDC, 1976. Test Reference Year (TRY), Tape Reference Manual, TD-9706. September 1976. Asheville, North Carolina: NCDC, U.S. Department of Commerce.

NCDC, 1981. Typical meteorological year TMY use’s manual. TD-9734, hourly solar radiation-Surfase meteorological observations. The National Climatic Data Centre, U.S. Department of Commerce. Asheville, North Carolina.

NREL, 1995. Users Manual for TMY2s (Typical Meteorological Year) NREL/SP-463-7668 and TMY2s, Typical Meteorological Years derived from the 1961-1990 National Solar Radiation Data Base. National Renewable Energy Laboratory. United States of America, Golden, Colorado.

RSN 156-94 Statybinė klimatologija [Building Climatology]. Vilnius, 1995. p. 17-33.

STR 2.09.02:2005 Šildymas, vėdinimas ir oro kondicionavimas [Heating, Refrigerating, and Air-Conditioning Engineers]. Vilnius: Ministry of environment of the republic of Lithuania, 2005.

Stoffel, T.L. 1993. Production of the Weather Year for Energy Calculation version 2 (WYEC2). NREL TP- 463-20819. National Renewable Energy Laboratory.

Thevenard, D.J., Brunger, A.P., 2002a. The development of typical weather years for international locations. Part I, algorithms. ASHRAE Transactions, 108, 376–383.

Thevenard, D.J., Brunger, A.P., 2002b. The development of typical weather years for international locations. Part II, production. ASHRAE Transactions, 108, 480–486.

Wilcox, S., Marion W. 2008. Users Manual for TMY3 Data Sets. National Renewable Energy Laboratory. Operated for the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy by Midwest Research Institute Battelle. Revised May 2008 Technical Report NREL/TP-581-43156.

WYEC, 1985. Weather Year for Energy Calculation. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta: Inc.

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The Durability Test Method for External Thermal Insulation Composite System Used in Cold and Wet Climate Countries

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EXTENDED ABSTRACT

The paper proposes the durability prediction method for ETICS, which could be applied in cold and wet climate regions. This improved method is based on the international and nowadays applicable standards for systems service life assessment (ETAG 004, ISO 15462), and completes them with other necessary impact criteria. This study examines the main climate exposures and how these impacts reproduced in the laboratories. The paper analyses the extreme air temperature and rainfall changes, the intensity ultraviolet radiation (UV) in Lithuania. The analysis is based on evaluation of daily and yearly data recorded by meteorological stations.

The aim of the research is to compose the accelerated ageing cycle for ETICS taking into account the characteristics of building materials and identifying the potential degradation factors and indicators. In order to establish the combinations of impacts in ageing cycles, it is necessary the adequate evaluation of intensity of environmental exposures of a certain locality. The basic goal is to create the reliable accelerated ageing cycle which would be as similar as natural ageing.

In order to predict service life of ETICS, the accelerated climatic cycle was composed on the basis of earlier scientific research and the statistic data of the Lithuanian climate). The whole accelerated ageing cycle lasts for 28 days which corresponds to about one natural year in the most unfavorable conditions.

For determination of durability of ETICS four evaluation indicators have been chosen: macroscopic analysis, water absorption rate, mechanical adhesive strength and visual monitoring, because these are the sufficient indicators for durability evaluation of systems.

The offered accelerated weathering cycle could be useful for ETICS manufacturers and it could be used for testing and proof of highly frost-resistant products. The accelerated climatic testing continues and the results will be presented later. Correlation between the results obtained from artificial accelerated ageing and the natural weathering will be established.

Keywords: ETICS, durability method, service life prediction, cycle, external render.

REFERENCES

Bochen, J., Gil, S., Szwabowski, J. 2005. Influence of ageing process on porosity changes of the external plasters. Cement and Concrete Composites, 27, 769-775.

Bochen, J., Gil, S. 2009 Study on the microstructure of thin-layer facade plasters of thermal insulating system during artificial weathering. Construction and Building Materials 23, 2559-2566.

Daniotti, B., Paolini R. 2008. Experimental programme to Assess ETICS cladding Durability. In: Procceedings of the 11DBMC International Conference on Durability of Building Materials and Components Istanbul Turkey, 11-14 May 2008

ETAG 004.2000. Guideline for European Technical Approval of External Thermal Insulation Composite Systems with Rendering, European Organisation for Technical Approval. Brussels, 2000. 114 p.

Norvaišienė, R., Burlingis, A., Stankevičius, V. 2010. Durability Tests on Painted Facade Rendering by Accelerated Ageing Materials Science. Vol. 16, No. 1, 80-85.

NT BUILD 495. 2000. Nordtest Method. Building materials and components in the Vertical position: Exposure to accelerated climatic strains. Finland, 2000. 4 p.

RSN 156-94. 1995. Building Climatology. Ministry of Building and Urban Development of the Republic of Lithuania. Vilnius, 1995. 136 p.

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Research of Composite Constructions' Impact on the Energy Efficiency of Buildings

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Abstract. Powerful air conditioners and heaters in winter are used to provide necessary temperature level in the buildings, that's why building life costs are significantly expensive. Clever construction solutions can reduce heating and cooling costs providing good comfort conditions for the human living at the same time. The aims of this research are to create multiphysical 3D model of the one small building using ANSYS CFX software, and to analyze different solutions of composite constructions. Only steady state conditions are often used for the analysis and only the thermal conductivity is used for the heat balance analysis, but in this work the dynamical simulations are made and as the results show, that the heat capacity and the structure of multilayered walls are very important to take into account and dynamical temperature change effects needs to be included in detailed thermal analysis of a living buildings. Results for different multi-layered wall constructions are shown in one physical geometry to easily analyze material properties and advantages for each composite solution. Modelling results are based on transient calculations and compared with steady state solutions. The obtained results show that it is possible to maintain needed thermal comfort conditions in the room and reducing the total energy consumptions at the same time by appropriate choosing of materials and composition of various layers.

Keywords: Multi-layered structure, heat capacity, heat transfer, energy efficiency, mathematical modelling.

INTRODUCTION

Building constructions are influenced by the environment and changes of temperature. To maintain optimum comfort in a room or other space, conditioners and heaters are used, but these appliances have high operation costs. There are ways to increase the efficiency of building and reduce construction heat loss. One of the ways is to build the building with composite materials that could lessen the power needed to run heaters and conditioners – to save power.

In this research, simulations of 2D and 3D heat exchange processes with ANSYS CFX computer simulation software were done. The program was used to create study for optimal building surrounding construction solutions for climatic conditions of Latvia. Models of air flow and heat exchange were created for testing purposes. The total thermal balance estimation was done, and analysis of thermophysical processes of rooms and buildings for the further studies was started. In similar researches only steady state conditions and thermal conductivity are used mostly, but in especially changeable environmental conditions like it is Latvia (for example in some period outside temperature in day time is +30°C, but +10°C in night), essentially important is to take dynamical effects in to account also and do transient analysis. So in this case it is possible to produce more detailed thermal analysis of a small living building.

Work with numerical simulation results is focused on research in temperature field, air velocity and vector fields, composite constructions' dew point and total thermal balance. Physics interpretation and validation of the whole model by doing results critical analyze were made.

In first geometry models with simple two material composite wall constructions already can make reviews about dependent wall heat capacity, about importance of material sort in construction, about total change of temperature inside the building and complete energy consumption. In low temperature conditions and without hot heaters thermal radiation impact is relatively low so thermal radiation wasn't taken in to account.

Methods

To figure out software compatibility with thermophysical problems, first studies of this research were performed using 2D model geometry, see figure 1. Typical symmetrical geometry dimensions are 3 m wide and 5 m high. Were used 20000 mesh elements, 5cm inflation layers close to wall, -20°C outside temperature, +25°C constant floor heating, monolithic one material constructions. In this case steady state and transient computer simulations were done.

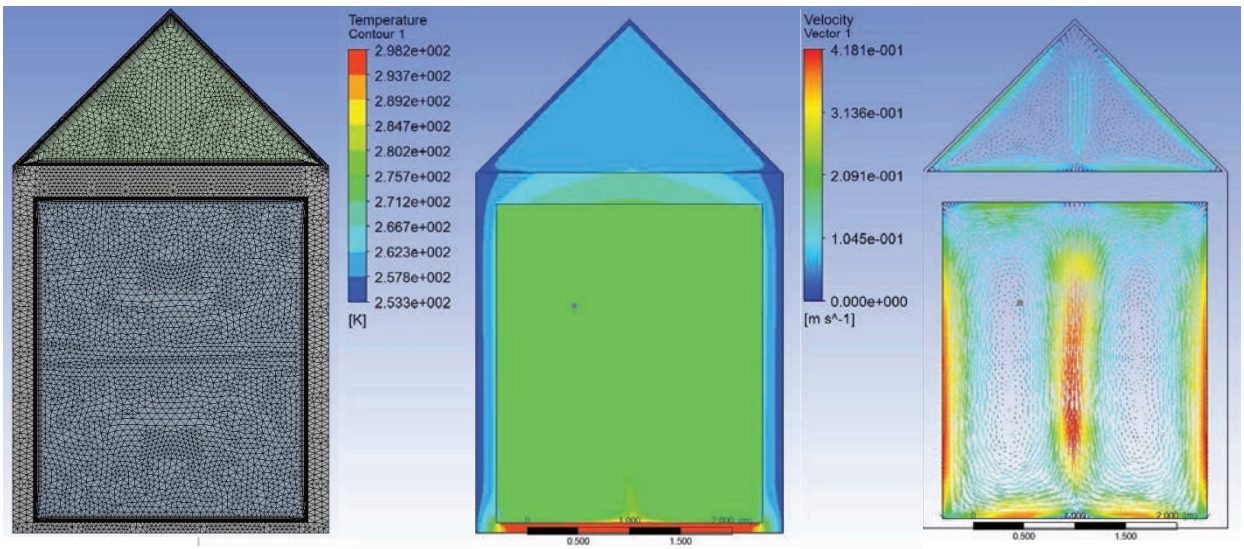

Figure 1. 2D model mesh, temperature field and air flow velocity field examples

In further work was used test model house geometry similar with one from the Dr. Juha Vinha doctoral dissertation (J. Vinha, 2007) Colleges from Tampere University of Technology were built a polygon with small test houses for climatic condition analyze in Finland. And searching for our numerical simulation result validation opportunities this meant to be useful experience. Aim here was to build 3D model using ANSYS CFX software, using simplified monolithic brick wall constructions in the start. Glass wool was used for insulation in the floor and ceiling, door and attics constructions built from wood material, floor heating with constant temperature +25°C, free ventilated attics. For simulation growth preview see figure 2, where a) is photo from the test building area at Finland, b) is building sketch and c) is ANSYS CFX model geometry. Several steady state simulations for different set ups and first 3D transient simulations were done and analyzed.

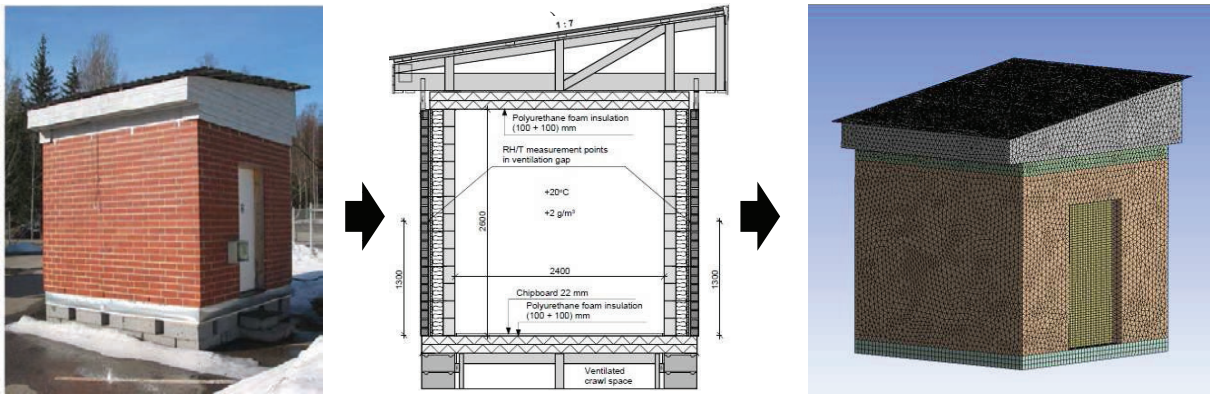

Figure 2. Test building from Tampere University of Technology

After work with previously here mentioned training models first research about composite constructions' impact on the energy efficiency of the building was made using geometry from Tampere University of Technology test building, but with differences in the wall constructions. Two similar models were made with conceptual difference – construction walls are split in the middle and using two materials, for one simulation

variant glass wool is inside and brick outside, for second it is conversely. Aim here was to analyze material arrangement impact in composite constructions. For upper view see figure 3 and in tables 1; 2 there are a summary of used values and physical parameters in numerical model. Dimensions for the inside room are 2.4 m x 2.4 m x 2.6 m and wall thickness 0.4 m. Base for research and analysis was numerical simulation with constant initial temperature in all test buildings' constructions and environment, with constant temperature for floor heating, without mass exchange between room and environment and without heat radiation in physical model.

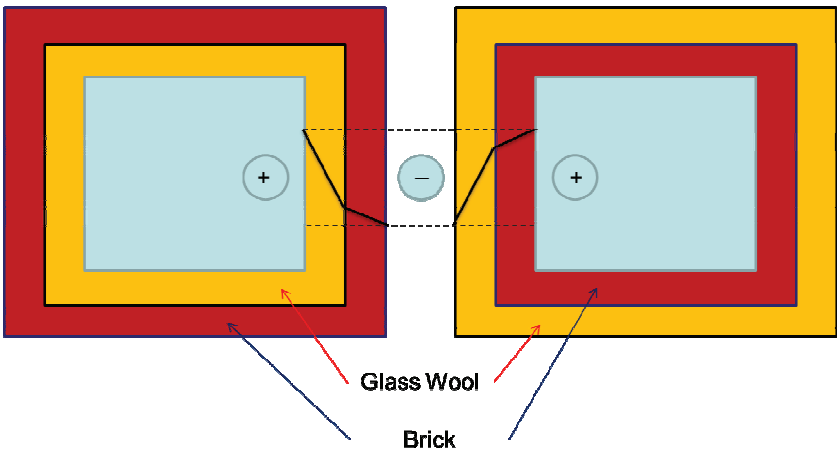

Figure 3. Two modelling versions, upper view with expected steady state temperature distribution in constructions (scale is not observed)

Table 1. Used values and parameters in numerical model

Position	Value
Wall material 1	Brick
Wall material 2	Glass Wool
Floor and ceiling insulation	Glass Wool
Roof constructions	Hard wood
Doors	Hard wood
Fluid in room, attic	Air
Initial temperature fluid and constructions	$T_0 = 0°C$
Constant outside temperature	$T_e = 0°C$
Floor heating temperature	$T_{fl.} = +25°C$
α on vertical surfaces (R=0,04 [m^2K/W])*	25 $W/(m^2 \cdot K)$
α on space under floor (R~0,07 [m^2K/W])*	14 $W/(m^2 \cdot K)$
Flow turbulence model	*Shear Stress Transport k-ω*
Reynolds number in room, Re	>3000
Air pressure in room, environment	1 atm
Number of mesh elements	~1 000 000
Earth's gravity, g (on Z axis)	-9.81 m/s^2

* *α - convective heat transfer coefficient*

Table 2. Used physical parameters

Material	Density, (kg/m^3)	Specific heat capacity J/(kg · K)	Thermal conductivity W/(m · K)
Glass Wool	50	1030.0	0.0400
Brick	1600	880.0	0.6400
Hard wood	720	1255.0	0.1600
Air	1.185	1004.4	0.0261

Equations used in mathematical modelling are as follows:

Heat conduction (1), where λ is coefficient of material's thermal conductivity:

$$q_{cond.} = -\lambda \cdot gradT \tag{1}$$

Heat diffusion equation (2) in the control volume shows the thermal balance:

$$\int_V \gamma c_p \frac{\partial T}{\partial t} dV = \oint_S \lambda \cdot \mathrm{grad}T \cdot d\mathbf{S} + \int_V q_{vol} dV \tag{2}$$

The continuity equation in differential form (ANSYS, 2001):

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \cdot U) = 0 \tag{3}$$

Navier–Stokes equations in non-dimensional form (4), where Re is Reynolds number and Fr is Froude number:

$$\frac{\partial \mathrm{v}}{\partial t} + (\mathrm{v} \cdot \nabla)\mathrm{v} = -\nabla p + \frac{1}{Re}\Delta \mathrm{v} + \frac{1}{Fr}\mathbf{f}^{ext} \tag{4}$$

Momentum equation (5) in general form, where $\tau = \mu\left(\nabla V + (\nabla V)^T - \frac{2}{3}\delta \nabla \cdot V\right)$

$$\frac{\partial(\rho V)}{\partial t} + \nabla \cdot (\rho V \otimes V) = -\nabla p + \nabla \cdot \tau + S_M \tag{5}$$

Energy equation (6) for low speed flows

$$\frac{\partial(\rho h)}{\partial t} + \nabla \cdot (\rho V h) = \nabla \cdot (\lambda \nabla T) + \tau : \nabla V + S_E \tag{6}$$

As turbulence model is used two parameter $k-\omega$ Shear Stress Transport equation (Menter, F. R, 1994), based on kinetic energy k and specific dissipation coefficient $\omega = \varepsilon / k$, $[\omega] = s^{-1}$. This approach is combination of $k-\varepsilon$ and $k-\omega$ turbulence models with help of function F_1 that activate each model in the different zones for the best flow representation.

Boundary conditions used in mathematical modelling are as follows:

Adiabatic boundary condition $q_W = 0$

The temperature distribution at the surface $T = T_{surf}$

The distribution of thermal flux $q_W = q_{spec}$

The convective cooling $q_W = \alpha(T_b - T_{nw})$, where α - specific heat transfer coefficient, T_b - outside temperature T_b - temperature inside close to surface (Tu el al., 2008).

If we analyze one non-dynamical system using two different calculations – steady state calculation and transient calculation, we expect that transient calculations' results in sufficient time will conform to steady state calculation. Temperature monitoring points in transient calculation show comparison with steady state calculation, it is possible to analyze stability of calculation also and see in witch phase thermophysical processes are and how they are evolving in time.

In figure 4 is shown model variant with glass wool inside and brick outside of the wall construction. Total time for analyze here is 30h, in graph transient calculations' room temperature is with small fluctuations, which can be explained as air flow caused temperature changes. For steady state calculation, room temperature is shown as average in all space.

By analyzing steady state and transient calculation results the good match can be seen and it approve that these results can be find as trustful. Calculation of total thermal balance in constructions is accurate as well.

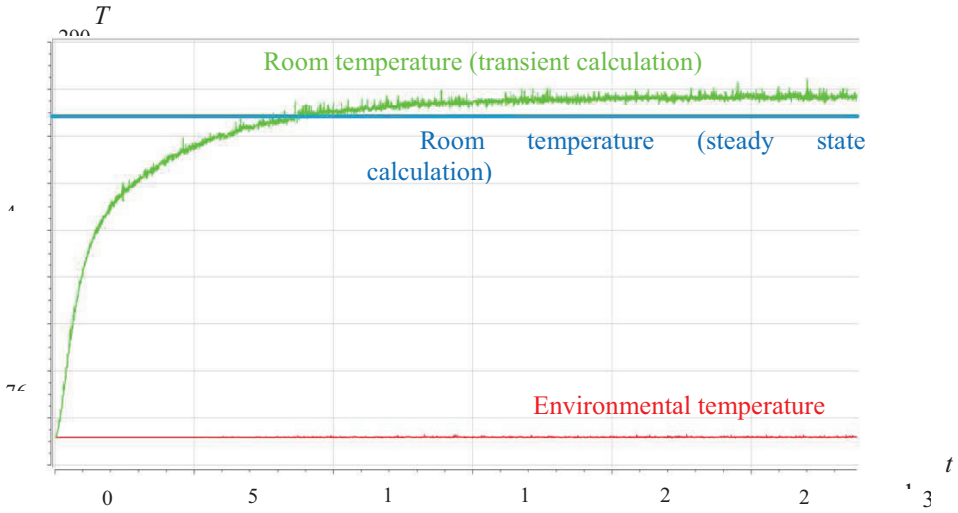

Figure 4. Transient calculations' temperature monitoring points and corresponding steady state calculations' average temperature in room, glass wool inside

Other way to ensure precise results is Courant number analysis in computer simulation. Courant number, $C = \frac{u\,\Delta t}{\Delta x}$ (ANSYS, 2011) where u – flow velocity, Δt – time step and Δx – mesh element characteristic size, is important parameter for time dependent flows. Calculating courant numbers in plane or volume after first iteration of transient calculation helps to effectively find out if the time step is suitable for flow in each place, so in this way it is easy to discover eventual points or areas with large Courant number and analyze critical places in mesh and improve it if necessary.

RESULTS AND DISCUSSION

After training models, first 3D calculations were done for steady state mode with both model wall construction variants. While floor heating is set to constant,+25°C temperature field distribution is shown in figure 5 and 6 where average room temperature difference is ΔT =4.5°C, which shows that corner effects in constructions is very important. Not as expected, higher room temperature is in simulation with glass wool material inside. But total thermal energy balance shows that there are different emitted power from floor heating in simulation 1 (figure 5) and simulation 2 (figure 6). That can be explained as boundary condition specifics, because constant plane temperature on the floor was set.

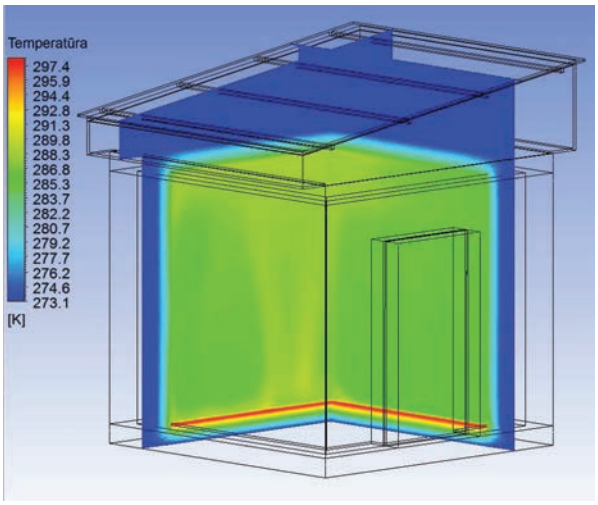

Figure 5. Steady state temperature distribution, glass wool material inside

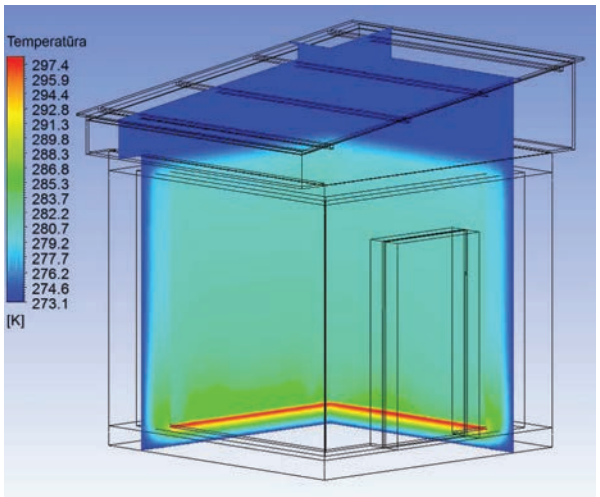

Figure 6. Steady state temperature distribution, brick material inside

For model with glass wool inside, average temperature in the room using steady state calculation is +13.4°C, with brick material inside it is +8.9°C. For calculated temperatures if we take 60% characteristic air humidity in heating season, dew points in constructions are reached at temperatures: glass wool inside:T_{dp}=+5.8°C; brick material inside: T_{dp}=+1.6°C. In figure 7 with thin red line are shown dew point temperatures in constructions.

Figure 7 demonstrates, that in simulation variant with glass wool inside, dew point is reached in porous layer, so in this case it is possible to accumulate water in wall structure if the inside of composite material is not hermetic. In case if brick is inside, all material is in relatively warm zone and works as steam barrier, that is why dew points' isotherm located in glass wool layer is not critical in this situation.

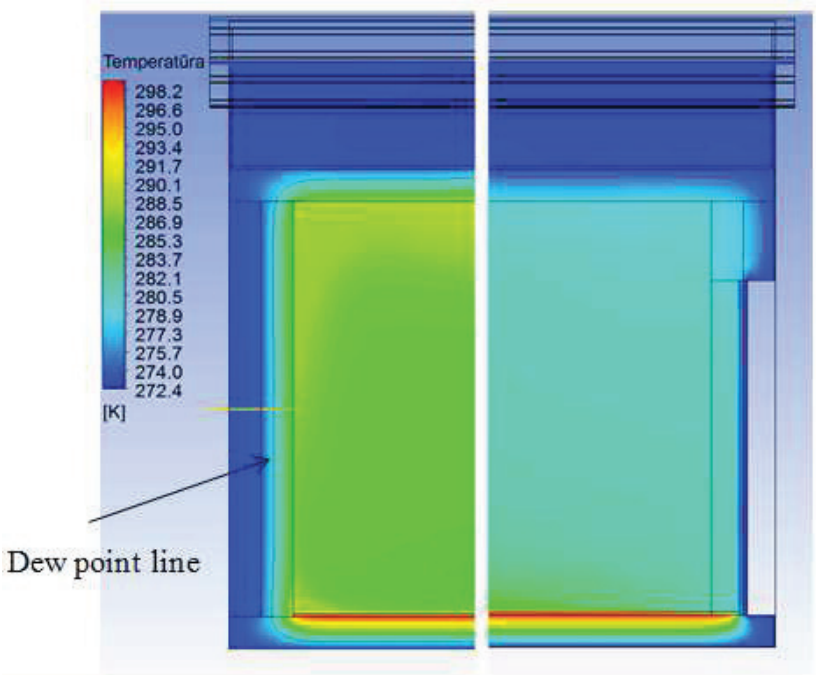

Figure 7. Dew points in constructions – 3D geometry sliced in the middle with plane (on the left glass wool is inside, on the right brick material is inside)

Temperature distribution in the wall shows that isotherms more densely are collected in glass wool (figure 8), so in the insulation material temperature gradient is larger, as expected before. Corner effects and difference in total emitted power for floor heating are main reasons for different inside temperatures in two analyzed models.

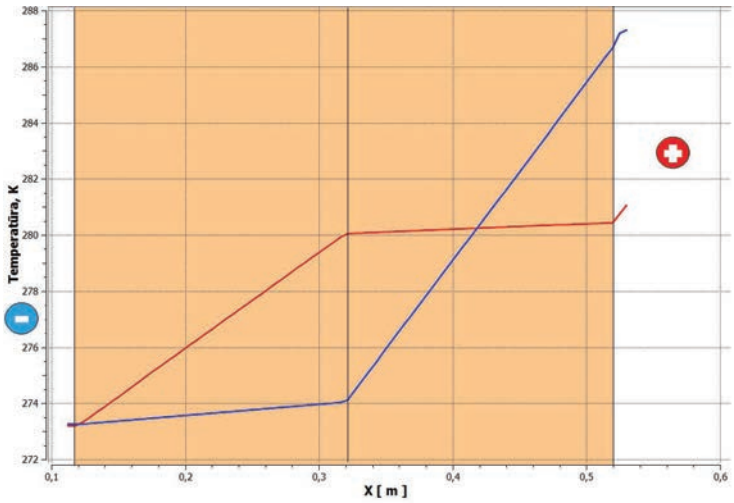

Figure 8. Temperature distribution in the wall for both constructions (red line–glass wool inside, blue line-brick material inside)

When starting transient calculations it is important to analyze with extra high precision the beginning of run, while process dynamics and gradients are high. So small time step and smooth mesh are necessary for good results. Later those parameters can increase for little, to save up resources but still ensure the quality of numerical simulation.

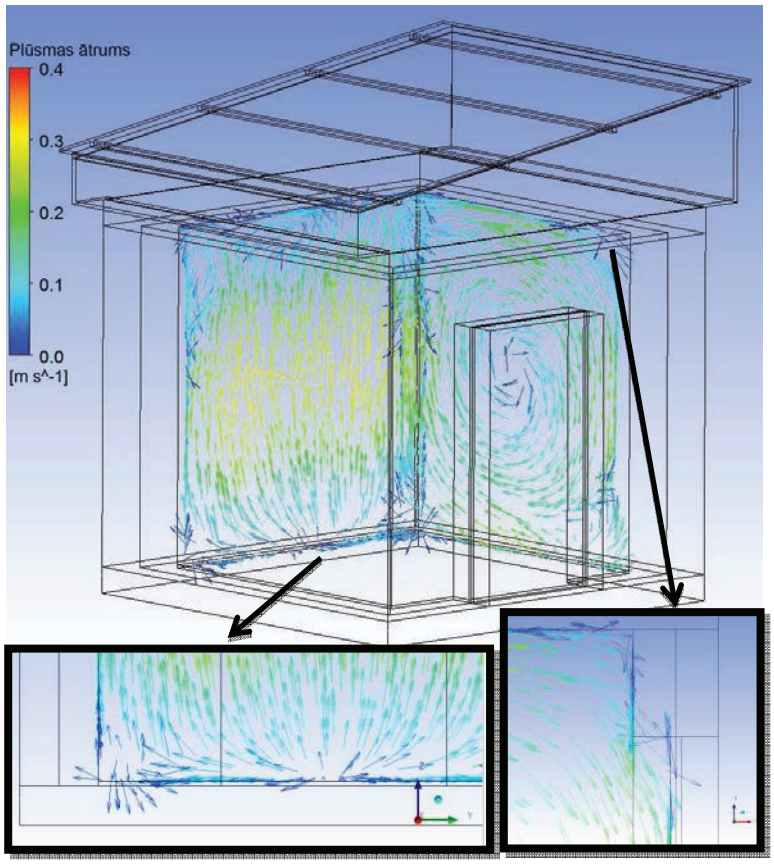

Figure 9. Velocity vector field plotted on two perpendicular planes close to the wall (in figure vectors are with same size, but color represents the value)

Velocity field analyze shows that larger flow speed are in close to wall regions, but on the wall there are no-slip condition, so the velocity decreases to 0. Because of asymmetrical geometry, flow creates vortex oriented in the room center, vortex axis is horizontal and parallel the door plane. Small additional or secondary vortexes with lower velocity are formed in the corners. In figure 9 in perspective view can see the complete structure of velocity vector field, which is plotted on two perpendicular planes close to the wall. In more details different frontal views are shown additionally. Few not-physical effects appear in this case, so it means that mesh resolution is not sufficient.

Analyzing steady state and transient state identical models with glass wool inside of the wall constructions, temperature distribution plotted on same plane shows visually good match. See figure 10.

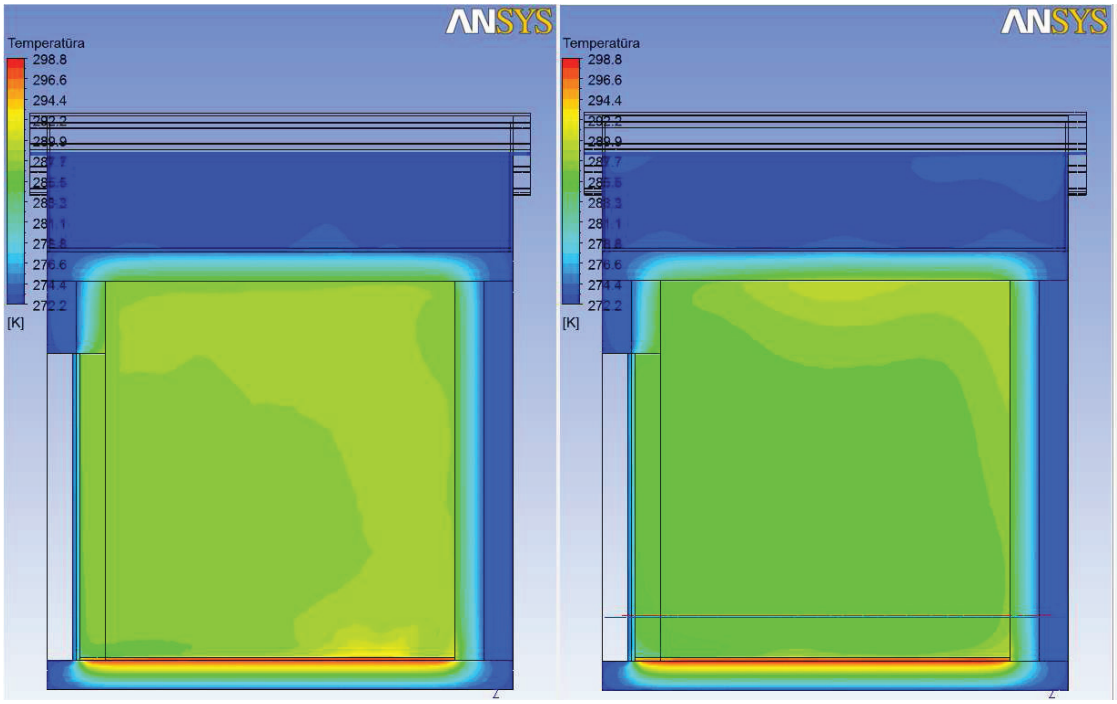

Figure 10. Model variant with glass wool inside: on the right is steady state computation; on the left is transient computation after 34 simulation hours.

Using 3 seconds time step in transient calculation, after 34 hours of simulation time thermal energy balance difference is 9%, average temperature in the room is 13.7°C, but calculation for the same steady state has T_{room}=13.4°C and thermal energy balance with 1% difference. Match between two types of calculations is high and it allows to conclude that description of mathematical methods and physical processes are quite precise and reasonable in simplified models like this.

CONCLUSIONS

To precisely evaluate composite wall constructions' impact on the energy efficiency of buildings and indoor thermal comfort conditions for the human living, main task is to reduce impact of buildings' covering, grounds, doors and windows, what is important both in construction work and numerical calculation.

Highly qualified transient calculations results are time and resources very demanding processes, therefore real 3D object modelling is reduced to small test building analyze with relatively small flow velocities.

It is not rational to realize 3D transient calculations with currently available resources. Further research now is based on 2D transient calculations analyze and 3D steady state calculations analyze, using experience gained since now.

Because of mismatches in research interests and differences in climatic conditions is not desirable to use experimental data for numerical model validation from others as it was meant in the beginning. Supporting by ERAF project in the Botanical garden of University of Latvia is happening five different test building construction for obtaining the monitoring data for climatic conditions in Latvia. Therefore following research with mathematical modelling will involve possibilities to qualitatively compare results with experimental data.

Material arrangement in composite construction and dynamical temperature change effects can make a significant impact on the total thermal energy balance for sure, but this research direction need to be analyze and study in more details.

ACKNOWLEDGEMENT

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REFERENCES

J. Vinha**.** Hygrothermal Performance of Timper-Framed External Walls in Finnish Climatic Conditions. Doctoral Thesis, Tampere University of Technology, Tampere, 2007.

ANSYS® Academic Research, Release 14.0, Help System, Coupled Field Analysis Guide, ANSYS, Inc. ,2011.

Menter, F. R Two-equation eddy-viscosity turbulence models for engineering applications. AIAA-Journal, 32(8), pp. 1598–1605, 1994.

J. Tu, G. Heng Yeoh, C. Liu**.** Computational Fluid Dynamics. Burlinghton, USA. Elsevier Inc., 2008.

S. Gendelis, A. Jakovics. Mathematical Modelling of a Living Room with Solar Radiation Source. WSEAS Int. Conf. on Waste Management, Water Pollution, Air Pollution, Indoor Climate, October 14-16,France, 2007.

X.Shen, G.Zhang, B. Bjern. Investigation of response surface methodology for modelling ventilation rate of a naturally ventilated building. Building and Environment. 54:178-178, 2012.

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Heat Insulation Panels with Multilayer, Low-Emissivity Aluminum-Polyethylene Sheets

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Abstract. Buildings are large consumers of energy in all countries. The proper use of thermal insulation in buildings does not only contribute in reducing the required air-conditioning or heating size, reducing the thickness of walls but also in reducing the annual energy cost. As the heat flows through the building envelope (walls, roofs, floors) in the way of radiation, conduction and convection, there are buildings in which the radiation is the dominant method of heat transmission. Reflective Insulation System is formed by a combination of low emittance surfaces and air spaces that provide reflective cavities which have low levels of radiant energy transmission. In this research insulation panels with multilayer, low-emissivity aluminum-polyethylene sheets were prepared and investigated with a thermal box. The investigation includes the analysis of the effects of changing the number of reflecting layers, ranging from zero to seven, as well as the number and thickness of air spaces, within the same total insulation thickness (40 mm). This study showed that surface emissivity and convection have important influence on heat flow. The aluminum-polyethylene sheets were effective in reflecting heat and reducing heat transfer by radiation.

Keywords: thermal insulation, reflective insulation system, insulation panels

INTRODUCTION

One of the most important research areas today is energy-efficient technologies such as heat insulation in buildings. Heat transfer in walls, windows, roofs and floors of both residential and nonresidential buildings such as shopping centers, supermarkets and factories have been investigated intensively since the first oil crisis (de Brito Filho *et al.* 2011). The investigations deal with the different concepts of external walls (Lindberg *et al.* 2004), double glass windows (Yang *et al.* 2006), ground heat exchangers (Kyriakis *et al.* 2006), building's orientation (Mingfangm, 2002), green roofs (Lazzarin *et al.* 2005), thermal-insulation thickness (Comahli *et al.* 2004), and other aspects.

Heat transfer occurs in three different ways: conduction, convection and radiation. Heat conduction is the transfer of heat due to molecular collisions. In solid materials, the molecules are nearly in contact with each other. This close proximity results in an easy transfer of thermal energy. Convection is the process whereby heat is transferred by the mass movement of molecules from one place to another. In free convection, the formation of convection currents depends on the property of the gas, the temperature difference, and the size of the air cavity. Radiation is heat transfer involving the change in energy form from internal energy at the source to electromagnetic energy for transmission then back to internal energy at the receiver. It plays a very important role in the heat transfer process both in gases and in vacuum (Incropera *et al.* 2007). Heat flow by radiation is commonly used with the term "Low E". The "E" stands for emittance and the values range from 0 to 1, with 0 being no radiation and 1 is the highest measure of emittance or radiation RIMA-I (2002). Mass insulation such as fiberglass, rock wool, and polystyrene foam use the high insulation capacity of air by segmenting it into small compartments. The heat conductivity of air is 0.025W/mK at 20ºC if the air molecules are not moving in the same direction (the convection effect is zero), and if the size or thickness of the air layer is more than 1mm (Zhang *et al.* 2009). Despite the relatively high insulation value of air, the above-mentioned insulation materials have heat conductivity value of around 0.04W/mK. The difference between the insulation values of air and of the insulation materials comes from the higher heat conductivity of the solid component (filament of fiber glass, rock wool, and polystyrene) of the insulation materials acting as heat bridges. Thus, one possible solution to decreasing the heat conductivity of an insulation material is to decrease the effect of heat bridges (Pasztory *et al.* 2011). Standard types of insulation, such as fiberglass, foam, and cellulose primarily reduce heat transfer by trapping air or some type of a gas. Thus, these products or technologies reduce convection as a primary method of reducing heat transfer. They are not as effective in reducing radiant heat transfer, which is often a primary mode of heat transfer in a building envelope, in fact, these products, like most building materials, have very high radiant transfer rates. In other words the surfaces of standard types of insulation are good radiators of heat.

Most building materials, including fiberglass, foam and cellulose have surface emittances or "E" values in excess of 0.70. Reflective insulations typically have "E" values of 0.03. Therefore, reflective insulation is superior to other types of insulating materials in reducing radiant heat. The term reflective, in reflective insulation, is in some ways a misnomer, because aluminum either works by reflecting heat (reflectance of ~ 0.97) or by not radiating heat (emittance of ~ 0.03). Whether stated as reflectivity or emissivity, the performance is the same RIMA-I (2002).When reflective insulation is installed in building cavities, it traps air (like other insulation materials) and therefore reduces heat flow by convection, thus addressing all three modes of heat transfer.

Reflective insulation is a thermal insulation with low levels of radiant energy transmission and consists of one or more low emittance surfaces, bounding one or more enclosed air spaces. In all cases, the reflective material must be adjacent to an air space. Aluminum, when sandwiched between two pieces of plywood for example, will conduct heat at a high rate. In fact, the metalized and foil materials commonly used in reflective insulation will reduce radiant heat transfer by as much as 97% RIMA-I (2002). Layers of aluminum or a low emittance material and enclosed air spaces, which in turn provide highly reflective or low emittance cavities adjacent to a heated region, typically form a reflective insulation system. Some reflective insulation systems also use other layers of materials such as paper or plastic to form additional enclosed air spaces. The performance of the system is determined by the emittance of the material, the lower the better, and the size of the enclosed air spaces. The smaller the air space, the less heat will transfer by convection. Therefore, to lessen heat flow by convection, a reflective insulation, with its multiple layers of aluminum and enclosed air space, is positioned in a building cavity (stud wall, furred-out masonry wall, floor joist, ceiling joist, etc.) to divide the larger cavity into smaller air spaces. These smaller trapped air spaces reduce convective heat flow RIMA-I (2002).The resistance of air space is a function of its thickness. Thinner air spaces have less resistance due to greater conduction. Thicker air spaces, on the other hand, have less resistance due to heat transfer from convection currents. Therefore, the optimum air space thickness in reflective insulation system should be used $\approx 20mm$ (Nisson *et al.* 1985).

Reflective insulation products incorporate trapped air spaces as part of the system. These air spaces, which may be layered or closed-cell, can be included in the system either when the product is manufactured or while it is being installed. In either case, the advertised performance of the insulation requires that these air spaces be present after the product is installed. The labeled resistance to heat flow (R-value) will not be achieved if the product is not installed correctly.

The thermal performance of the reflective system varies with the size and number of enclosed reflective spaces within the building cavity. Most reflective systems range from one to five enclosed air spaces. There are other beneficial considerations for using reflective insulation. Generally, these products have a very low water vapor and air permeance. When installed properly, with joints taped securely, reflective insulation materials are efficient vapor retarders and an effective barrier to air and radon gas RIMA-I (2002).

Most insulating materials work by creating miniature air spaces. Reflective insulation, on the other hand, uses larger air spaces faced with foil on one or both sides. The performance of reflective insulation depends on a number of factors (Budaiwi *et al.* 2002):

- The radiation angle of incidence on the reflective surface. The best performance of reflective insulation is achieved when radiation falls at a right angle of incidence on the reflective surface (perpendicular to the surface).
- The temperature difference between the spaces on both sides of the reflective material. The greater the temperature difference, the greater the benefits of the reflective insulation.
- The emissivity of the material. The lower the emissivity (the higher the reflectance) the better.
- The thickness of the air space facing the reflective material. Air space must exist on at least one side of the reflective insulation.
- The orientation of the air space.
- The direction of heat flow.

In addition to the reflective performance characteristics of reflective materials, other characteristics such as strength, flammability, availability, and oxidation should be considered (Dr. Al-Homoud, 2005). Aluminum is the material of choice to produce low-emittance facings with the emittance as low as 0.03, but as with many metals, oxidation can occur. (Budaiwi *et al.* 2002) Aluminum oxidation is a chemical reaction between oxygen and aluminum. If bare aluminum is exposed to an oxygen-rich environment, then a process called passivation will occur. Passivation is the spontaneous formation of a thin, protective oxide film which limits the potential for further corrosion. The rate at which aluminum-oxide forms, depends upon a number of factors including: metal purity, atmospheric conditions, and the presence of an existing oxide film. A low-emittance surface is the key component in any reflective insulation system; as such, the preservation of a facing's emittance value is essential in maintaining optimal thermal performance RIMA-I (2002).

Reflective insulation materials are designed for installation between, over, or under framing members, used together with or without mass insulation and as a result, are applicable to:

- Residential construction, new and retrofit – walls, basements, floors, ceilings, roofs, and crawl spaces;
- Commercial construction, new and retrofit – walls, floors, basements, ceilings, roofs, and crawl spaces;
- Manufactured housing construction, new and retrofit – walls, floors, roofs, and crawl spaces;
- Other uses in new and retrofit – water heater covers, cold storage units, poultry, and livestock buildings, equipment sheds, pipe insulation and recreational vehicles RIMA-I (2002).

The use of low-emissivity surfaces for reducing heat radiation has been well known for decades. This technology has been developed for space applications, like the heat insulation of spacecrafts. Heat reflection is important in space: there is no air pocket that is used in traditional heat insulation materials and radiation energy is higher than on Earth. Alifanov et al. (2009) investigated the modeling and other technical issues related to multilayer insulation systems. The multilayer reflecting foil as core material was used in vacuum insulation technology and it was found that when using multilayer reflecting foils, the radiation heat transfer decreased significantly (Known *et al.* 2009). The effect of radiant barriers with the combination of different insulation materials was investigated both theoretically and experimentally in hot climates and it was found that the foils could reflect a high percentage of heat energy and the effectiveness of foils at higher temperature was higher (Suehrcke *et al.* 2008). The reflected energy ratio can be increased on a light color roofing membrane after cleaning its soiled surface (Levinson *et al.* 2005). In addition, increasing the number of air cavities in a hollow block (building unit) increased the thermal resistance. However, the number of air cavities used did not increase the thermal resistance linearly (Antar *et al.* 2009).

In this study insulation panels with multilayer, low-emissivity aluminum-polyethylene sheets were prepared and investigated. The overall objective of this research is the development of an economical, high-efficiency heat insulation system for residential and public buildings by using different reflecting materials. The investigation includes the analysis of the effects of changing the number of reflecting layers, ranging from zero to seven, within the same total insulation thickness.

METHODS

Reflective insulation reduces heat transfer by radiation. Materials react to radiant energy falling on them through the following ASHARE (2001):

- Absorptance (α): fraction of incident radiation absorbed through the material.
- Transmittance (τ): fraction of incident radiation transmitted through the material.
- Reflectance (ρ): fraction of incident radiation reflected by the material.

Therefore,

$$\alpha + \tau + \rho = 1 \tag{1}$$

For opaque surfaces: $\tau = 0$ and $\alpha + \rho = 1$; for a black surface $\tau = 0$; $\rho = 1$ and $\alpha = 1$. Reflective (polished) surfaces are characterized by high reflectance and, therefore, low emittance (ε); material's ability to diffuse radiant energy ($\varepsilon = \alpha$, for gray surfaces), which makes them effective in reducing radiant heat transfer in buildings. The emittance is a function of the material, and the condition and temperature of its surface.

The reflective insulation works as follows (Lechner, 2001):

- Heat from hot surfaces radiates in a straight line to other cooler surfaces surrounding them. The reflective insulation (radiant barrier) reduces radiant heat transfer from such hot surfaces (e.g., roof or wall) to cooler spaces (e.g., attic or living space).
- The reflective insulation must be both a poor emitter (≤ 0.1 emittance) and a poor absorber (good reflector, ≥ 0.9 reflectance) of thermal radiation.
- The first layer of reflective insulation is the most effective (stops about 95% of radiant heat flow). Additional layers of reflective insulation create additional air spaces that reduce convection heat flow.
- Although radiation is independent of orientation, convective heat flow depends greatly on both the orientation of the air space and the direction of heat flow.
- The resistance of air spaces and reflective insulation varies with their location in the structure and the time of the year (direction of heat flow).

White color is also effective in minimizing heat transfer into buildings because it is not only a poor absorber of energy but also a good emitter.

To increase heat resistance, it is better to use a surface with a very low emissivity (e.g. aluminum). A thin aluminum foil has a higher reflecting property than that of an aluminum plate (Kostic *et al.* 2010), but the foil has a very low tensile strength. An aluminum foil reinforced with polyethylene is commercially available and was used in this study. The aluminum–polyethylene sheet has the mechanical integrity to withstand rough

handling during manufacture and construction, while retaining low emissivity. The aluminum side of the sheet has a surface emissivity of 0.05 while the polyethylene side has a surface emissivity of 0.5.

For Latvia's climate conditions multi-layer structure with n layers of the resulting thermal resistance can be calculated as the sum of the individual layers of thermal resistance and adding to the resulting value also the thermal resistances of outdoor R_a and indoor R_i thermal boundary layers.

$$R = R_a + R_1 + R_2 + ... + R_n + R_i (m^2 K / W) \tag{2}$$

The resistances of thermal boundaries are determined by standard LVS ISO EN 6946. Their values depend on whether the heat flow direction is directed horizontally or vertically, upward or downward. Vertical heat flow (upward), for example, R_i=0,10 m^2K/W and R_a=0,04 m^2K/W.

Homogeneous k-layer thermal resistance is calculated using the thickness d_k (m) and the heat conduction λ_k (W/mK), according to the formula:

$$R_k = \frac{d_k}{\lambda_k} \tag{3}$$

If the layer is not homogeneous, for example, hollow bricks, frame construction, Keraterm blocks etc., then an effective thermal conductivity is used in calculation, which is determined by measurements or calculations:

$$R_k = \frac{d_k}{\lambda_{ef.k}} \tag{4}$$

Thus, opaque structures, through which is no air flow and where there are no microscopic air inclusions, the resulting heat resistance can be calculated relatively easily.

If constructions single k-layer is made of air gap or with any other gas-filled gap, then the layer's thermal transmittance U_k (W/m^2K) and it's correspond thermal resistance $R_k=1/U_k$ are determined by three physical mechanisms of heat transfer:

- gas convective movement in a gap, which intensity depends on the properties of gas thermal expansion and temperature differences;
- infrared radiation from surfaces, which are in contact with the transparent medium (gas);
- gas thermal conductivity.

The gas thermal conductivity usually has a minor role in the heat transfer of these layers, for example, air's thermal conductivity is 0.027 (W/mK). Generally, if the materials' surface emission coefficient ε values are greater than 0.9 (concrete, bricks, plasterboard), the most important is the heat transfer through radiation. If the material's, which is facing the gas gap, surface emission coefficient value decreases (for polished aluminum surface $\varepsilon \leq 0.1$), it also reduces the radiant heat exchange intensity. The convective heat exchange can be reduced using gas with a low thermal expansion coefficient for gap filling. This method is used in glass packets, which are hermetically sealed. However, in practice, in lamellar constructions (except the mentioned glass packages) the filling gas is air LU FMF (2005).

Thus, practically the only way how to reduce heat exchange between these layers is the use of surface coatings or materials with low heat emission factor. Since the radiation intensity varies in proportion to the absolute temperature's fourth grade (T^4), then the heat resistance of these layers is a nonlinear function of surface temperature and convective flow, as already mentioned above:

$$R = \left(E \cdot h_r + h_c\right)^{-1} = \frac{\Delta T}{Q} \tag{5}$$

where h_r and h_c (W/m^2K) are during the heat exchange (permeability) of radiation and convection towards characterized parameters. [Reflective Insulation Manufacturers Association International]

Convective heat transfer coefficient is determined through experimental measurements and tabulated as a two-argument (surface temperatures' difference and mutual surfaces' distance) function: $h_c = h_c\left(T_2 - T_1, d\right)$.

Radiation heat transmission parameter h_r is calculated according to the formula:

$$h_r = 0{,}5 \cdot \sigma \cdot E\left(T_1 + T_2\right)^3 \tag{6}$$

where $\sigma = 5{,}67032 \cdot 10^{-8} (W / m^2 \cdot K^4)$ - radiation characterizing Stephan-Bolcman constant LU FMF (2005).

According to Reflective Insulation Manufacturers Association the mutual radiation factor E of two parallel surfaces is calculated from the opposite surface emission factors ε_1 and ε_2 RIMA-I (2002):

$$E = \left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1 \right)^{-1} \tag{7}$$

Thus, to determine such multi-layered constructions the resulting thermal resistance has to be tasked with the air temperature on both sides of the buildings (T_i- inside and T_a – outside) and then the nonlinear equation systems, that are showed above, have to be solved, assuming that the parameters, which are characterizing the construction's layers: d_k, λ_k, R_i, R_a and ε_i are given LU FMF (2005).

To investigate the effect of the number of reflecting aluminum–polyethylene sheets within the same insulation thickness, a series of experiments has to be conducted using a panel with the same shape and size. The size of the panel is limited to 300mm×300mm for it to accommodate the heat conductivity measuring device. Each panel contains three parts: the bottom plate, the top plate, and the space between the two plates (which henceforth will be referred to as the air field). The bottom and top plates of the panel are made from 3.2 mm thick pressed cardboard. The side elements are made from 15mm×40mm pine lumber. Thus, the distance between the bottom and top plates is 40mm and has to be kept constant throughout the series of experiments.

The temperatures of:

- heating plate (lower plate) + 20 ºC;
- cooling plate (upper plate) 0 ºC.

The heat transfer through each of the panels was modeled using Hot Box FOX600, the experimental duration for one panel was 2 to 3 hours.

The heat flow was organized in normal direction from lower plate to upper plate, one – dimensional.

For the investigation 6 different panel types were made, respectively:

Panel 1: The 40-mm air field is bordered by pressed cardboard surfaces with 0.9 emissivity.

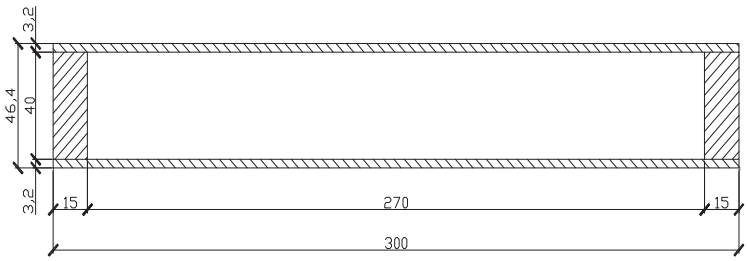

Figure 1. Panel №1

Panel 2: The inner surfaces of the bottom and top plates are lined with a 0.05 emissivity aluminum foil. In comparison to the previous panel, only the surface emissivity property is changed.

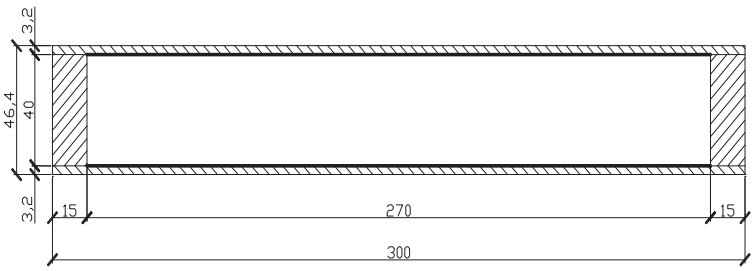

Figure 2. Panel №2

Panel 3: The side elements of Panel 2 are cut into two parts and an aluminum–polyethylene sheet (2mm thick) is fastened in between. Thus, the sheet divides the 40 mm distance between the top and bottom plates into two equal air cavities that are parallel with the plates. Henceforth, the terms "air cavity" and "air space" will be used interchangeably to refer to the space between a sheet and a plate, or the space between sheets (see description for Panels 4–6). This is different from the term "air field", which as mentioned earlier is the whole space between the top and bottom plates. Aluminium foil is with 0.05 emissivity; polyethylene – with 0.5 emissivity.

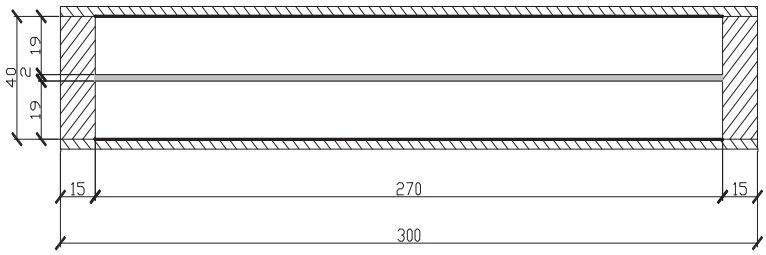

Figure 3. Panel Nº3

Panel 4: The air field is divided into four equal cavities using three aluminum–polyethylene sheets. Thus, the panel consists of three stretched sheets and four air cavities.

Panel 5: The air field is divided into six equal air cavities using five aluminum–polyethylene sheets.

Panel 6: The air field is divided into 8 equal air cavities using seven aluminum–polyethylene sheets.

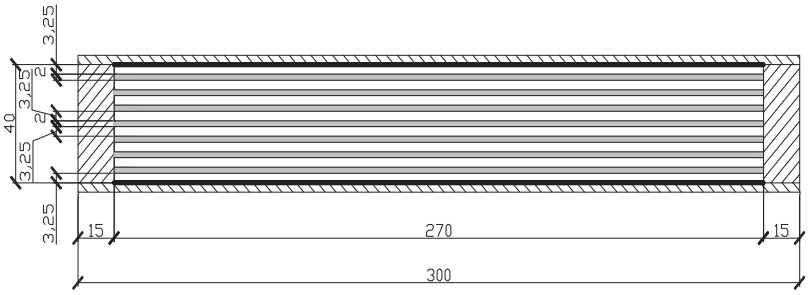

Figure 4. Panel Nº6

RESULTS

In this research insulation panels with multilayer, low-emissivity aluminum-polyethylene sheets were prepared and investigated with a thermal box. This study was intended to determine the effect of radiation in a heat insulating system that uses multiple thermal reflection sheets to divide the cavity within the wall. The investigation includes the analysis of the effects of changing the number of reflecting layers, ranging from zero to seven, as well as the number and thickness of air spaces, within the same total insulation thickness (40 mm). Also this study showed that surface emissivity and convection have important influence on heat flow. The aluminum-polyethylene sheets were effective in reflecting heat and reducing heat transfer by radiation.

Table 1. Experimental and calculated R-Values

Panel Type	Inside surface of bottom & top plates	Number of AL-PE sheet	Number of air cavities in the air field	Thickness of each sample (mm)	Thickness of each air cavity (mm)	R – Value, m^2K/W		
						Experimental R - Value; AL sheet facing lower plate	Experimental R - Value; AL sheet facing upper plate	Calculated R-Value
1	Pressed card board	0	1	45.54	40	0,3677	0,3677	0,3449
2	Aluminium foil	0	1	45.21	40	0,6057	0,6057	0,6766
3	Aluminium foil	1	2	46.73	19	0,9144	0,8855	1,3577
4	Aluminium foil	3	4	46.22	8.5	1,3194	1,4250	1,3863
5	Aluminium foil	5	6	46.12	5	1,3129	1,2893	1,4141
6	Aluminium foil	7	8	46.07	3.25	1,3165	1,3153	1,4793

After analyzing the effects of changing the number of reflecting layers within the same insulation thickness, the following results can be summarized:

1. Surfaces with low emission properties (aluminium foil, polyethilene sheets) were found to influence heat flow and heat radiation existing in building construction significantly. As shown in figure 5, more than 50% of heat flow decrease was observed when the inner surfaces of the bottom and top plate were lined with aluminium foils. In European wood frame residential buildings, polyethylene foil is commonly used as vapor barrier with 0.9 to 0.95 surface emissivity. Replacing the polyethylene foil with aluminum foil or aluminum-polyethylene sheet could result in an increase in the thermal resistance of the wall construction.

2. Increasing the number of reflective sheets between the plates resulted in lower effective heat conductivities. By increasing just one sheet, it was possible to obtain a thermal resistance equal to those of commonly used insulation materials. The thermal resistance of insulation system approached that of stagnant air as more sheets were inserted. The relationship between the thermal resistance and the number of sheets is not linear (see figure 5). The first inserted sheet had the highest effect (the result of panel 4 is not taken in account) and each additional sheet had less influence on heat resistance.

3. The relationship between the thermal resistance and the number of air cavities is also not linear.

The number of the air cavities varied from zero to seven, and their thickness according to the amount from 40 mm to 3,25 mm. The optimal number of sheets and the air cavity width should be further investigated for different wall constructions. Finite element modeling (FEM) and experiments should be used.

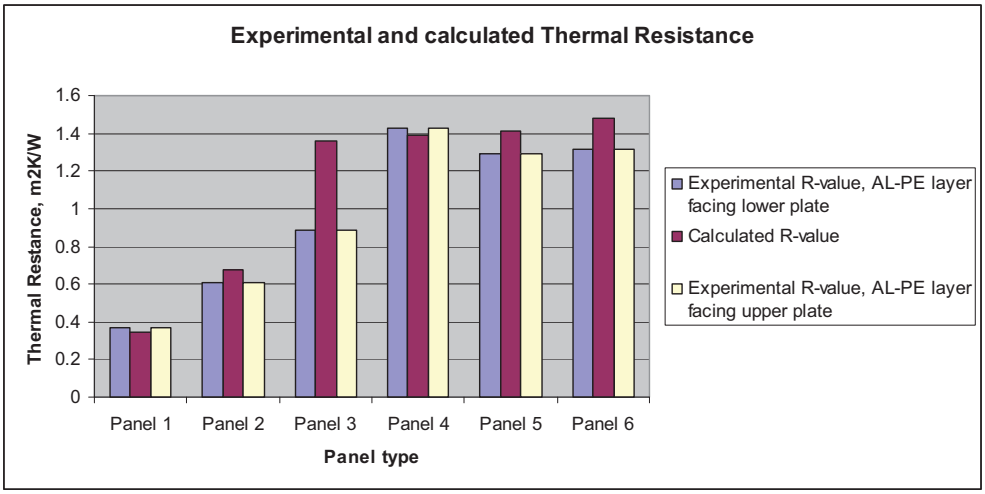

Figure 5. Experimental and calculated thermal resistance

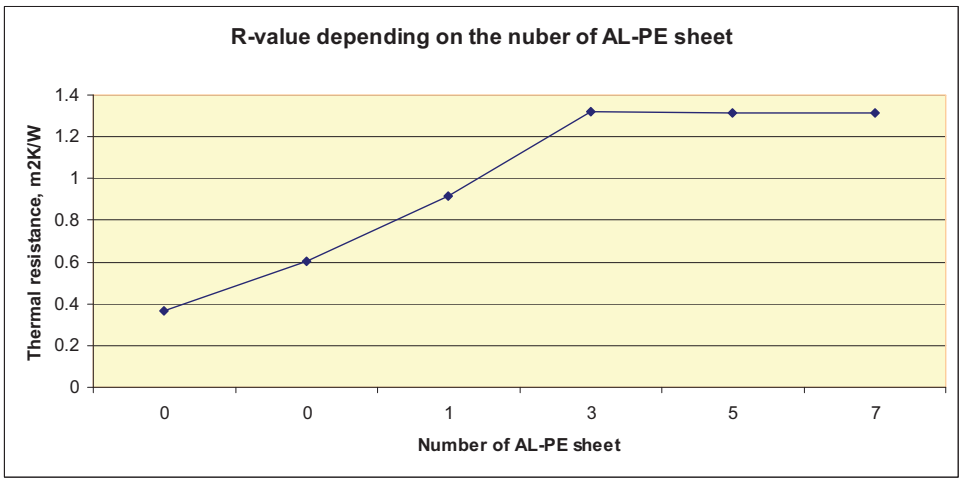

Figure 6. R-values depending on the number of AL-PE sheet

4. The material reflectivity has influence on thermal resistance. Aluminium foil has a lower emmitance 0.05 than polyethylene sheet 0.5, that's why the thermal resistance for AL-PE sheet facing lower plate is higher than

the resistance, where AL-PE sheets are facing upper plate (except Panel 4). So as the heat is moving from warmer surface to a colder surface, a higher reflective surface has to face the side, where the temperature is higher.

DISCUSSION

According to the results, Panel 4 has the highest R-value. Theoretically it's not right because as more aluminum polyethylene sheets are used in panel construction as higher is the thermal resistance. Also looking at the results of Panel 4, the thermal resistance for AL-PE sheet facing upper plate is higher than the resistance, where AL-PE sheets are facing lower plate, but it should be opposite. Aluminum foil has a lower emmitance 0,05 than polyethylene sheet 0,5. So as the heat is moving from warmer surface to a colder surface, a higher reflective surface has to face the side, where the temperature is higher. The incorrect results for the panel 4 can be explained with the aluminum foil unstick from pressed cardboard plates during the experiment. Additional air gaps were created and this could cause the false measurements.

As shown in figure 4, Panel 3 has the highest difference between theoretical and experimental values. This can be explained that the aluminum sheets that were glued to the cardboard plates hadn't the emmitance of aluminum surface 0.05. Also heat flow leakages could have occurred during the experiment.

The amount of formulas that were used for the theoretical calculation, doesn't give exact results and precise description of the material workability. Because the mathematical calculations in multilayer insulation don't involve surface changes according to heat flow direction, that's why the theoretical results for aluminum-polyethylene sheet facing lower plate and upper plate are the same. Here a Finite element modeling (FEM) should be used to get appropriate results; it would also show the working properties of a multilayer insulation by changing the reflective material sheet amount and direction.

CONCLUSIONS

This study has resulted in the development of an efficient heat insulation system by simply using aluminum-polyethylene sheets to divide the air field within a residential and public building envelope. This approach proved effective in reducing heat transfer by radiation, convection and conduction by decreasing surface emissivity, minimizing convection currents, and eliminating micro heat bridges, respectively. Full size heat insulation panel systems with multilayer-aluminum sheets need to be built in order to analyze the feasibility of production, to determine the heat resistance of this system in practice, and to compare the results with other insulation systems. Also FEM modeling should be used to get better view of reflective insulation material working properties.

REFERENCES

American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHARE) 2001, Handbook of Fundamentals, Atlanta GA, USA.

Dr. Al-Homoud, M.S. 2005. Performance characteristics and practical applications of common building thermal insulation materials, Building and Environment 40 (2005) 353-366.

Incropera, F.P., de Witt, D.P., Bergman, T.L., Lavine, A.S. 2007. Fundamentals of Heat and Mass Transfare, sixth eddition

Suehrcke, H., Peterson, E.L., Selby, N. 2008. Effect of roof solar reflectance on the building heat gain in a hot climate, Energy and Buildings 40 (2008) 2224-2235.

Budaiwi, I.M., Abdou, A.A., Al-Homoud, M.S. 2002. Variations of thermal conductivity of insulation materiāls under different operating temperatures: impact on envelope induced cooling load, Journal of Architectural Engineering 2002; 8(4):125-32.

Nisson, J.D., Dutt, G. 1985. The super insulated home book, New York: Wiley.

De Brito Filho, J.P., Henriquez, J.R., Dutra J.C.C. 2011. Effects of coefficients of solar reflectivity and infrared emissivity on the temperature and heat flux of horizontal flat roofs of artificially conditioned nonresidential buildings; Energy and Buildings 43 (2011) 440-445.

Known, J.S., Jang, C.H., Jung, H. et al. 2009. Effective thermal conductivity of various filling materials for vacuum insulation panels, International Journal of Heat and Mass Transfer 52 (2009) 5525-5532.

Comahli, K., Yuksel, B. 2004. Environmental impact of thermal insulation thickness in buildings, Applied Thermal engineering 24 (5-6) (2004) 933-940.

Latvijas Universitāte Fizikas un Matemātikas fakultāte (LU FMF), Vides un Tehnoloģisko Procesu Matemātikās Modelēšanas Laboratorija 2005. Daudzslāņu būvkonstrukciju ar gaisa starpslāņiem un zemas emisijas virsmām siltuma pretestības aprēķins [Latvian University, Faculty of Physics and Mathematics, Laboratory of Environment's and Technologies Process Mathematical Modeling 2005. Heat resistance calculation for multilayer construction with packed air layers and low emission surfaces].

Kostic,.L.T., Pavlovic, T.M., Pavlovic, ZT. 2010. Influence of reflectance from flat aluminum concentrators on energy efficiency of PV/Thermal collector, Applied Energy 87 (2010) 410-416.

Antar, M.A., Baig, H. 2009. Conjugate conduction-natural convection heat transfer in a hollow building block, Applied Thermal engineering 29 (2009) 3716-3720.

Kyriakis, N., Michopoulos, A., Pattas, K. 2006. On the maximum thermal load of heat exchangers, Energy and Buildings 38 (1) (2006) 25-29.
Lechner, N. 2001. Heating, cooling, lighting design methods for architects, 2nd edition New York: Wiley.
Alifanov, O.M., Nenarokomow, A.V., Gonzalez, V.M. 2009. Study of multilayer thermal insulation by inverse problems method, Acta Astronautica 65 (2009) 1284-1291.
Reflective Insulation Manufacturers Association International (RIMA-I) 2002. Understanding and using Reflective Insulation, Radiand Barriers and Radiation Control coatings, Second edition, 26 p.
RIMA-I 2008. Technical Bulletin 105 "Oxidation of Aluminum Foil Facings in Reflective Insulation", 2 p.
Levinson, R., Berdahl, P., Berhe, A.A., Akbari, H. 2005. Effects of soiling and cleaning on the reflectance and solar heat gain of a light-colored roofing membrane, Atmospheric Environment 39 (2005) 7907-7824.
Lindberg, R., Binamu, A., Teikari, M., 2004. Five-year data of measured weather, energy consumption, and time-dependent temperature variations within different exterior wall surfaces, Energy and Buildings 36 (6) (2004) 495-501.
Lazzarin, R.M., Castellotti, F., Busato, F. 2005. Experimental measurements and numerical modeling of green roof, Energy and Buildings 37 (12) (2005) 1260-1267.
Mingfangm, T. 2002. Solar control for buildings, Building and Environment 37 (7) (2002) 659-664
Zhang, Y.Z., Zhao, B., Huang, G.Y., Yang, Z., Zhang, Y.F. 2009. Heat conduction of air in nano spacing, Nanoscale Research Letters 4 (2009) 850-853.
Pasztory, Z., Peralta, P.N., Peszle, I. 2011. Multi-layer heat insulation system for frame construction buildings, Energy and Buildings 43 (2011) 713-717.
Yang, Z., Li, X.H., Hu, Y.F. 2006. Study on solar radiation and energy efficiency of building glass system, Applied Thermal Engineering 26 (8-9) (2006) 956-961.

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Microclimate in Premises of Buildings Heated by Air

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Abstract. Good indoor thermal comfort is one of the main factors affecting good human health. A mechanical ventilation system (MVS) is necessary in low thermal energy buildings because of a high level of thermal insulation and air tightness. MVS can be used as air-heating systems (AHS) too. This system will work effectively only if the building heat losses will be compensated by supplying of not higher than 50 °C air temperature and not more than the minimum amount of required fresh air for building ventilation. The other issue is to maintain the indoor comfort by ensuring the correct air velocity and supplied air temperature differences in working zone of premises. This paper presents the theoretical studies and experimental results of indoor thermal climate parameters by supplying the heated air in premises using AHS.

Keywords: ventilation system, air-heating system, indoor comfort, microclimate, supply air.

INTRODUCTION

People spend 80% of their lifetime indoors (Shengxian W. *et. al.* 2010; Zhao R. *et.al*. 2004). In order to avoid good people's health, comfort, satisfaction and productivity it is necessary to maintain the microclimate parameters in it. (Atthajariyakul S. *et.al*. 2004; Shengxian W. *et. al.* 2010; Zhiqiang W. *et. al.* 2011). Residential buildings indoor microclimate in Lithuania is defined as combination of these parameters: air temperature, the temperature differences between the surroundings and operating area, air velocity and relative air humidity (HN 42:2009). According to HN 42:2009 cold season limit indoor parameters are: air temperature 18 – 22 °C, temperature differences between the surroundings and operating area 3 °C, air velocity 0.05 – 0.15 m/s, relative air humidity 35 – 60 %. The combination of these parameters influences indoor thermal comfort, but air quality is no less important factor affecting people well-being. Chemical compounds, odors, combustion products and other harmful products continuously releases in premises as a result indoor air can be more polluted then outdoor (Matuliauskaitė A. 2009). Indoor air quality can be improved by supplying fresh air to the premises, the supplying air amount is regulated by STR 2.09.02:2005 "Heating, ventilation and air conditioning" in Lithuania. According it the least amount of supplying air is 14.4 m³/h for 1 person or 1.8-2.5 m³/h 1 m² floor area, depending on room use.

The air change rate in building is ensuring by ventilation system which can be natural or mechanical. Uncontrolled air flow enters to the premises through the building envelope leaks in buildings with natural ventilation systems. The high level of thermal insulation and air tightness is a solution to reduce heating energy consumption in buildings, but in such buildings the natural air changes are decreasing or absolutely disappearing, consequently the natural ventilation system should be change to the mechanical ventilation system (Smeds J. *et. al.* 2007). This system maintain supplying and exhausting air amount, controlling supplying air temperature and level of air purification. This system can be effectively used as air heating system in this way eliminating the need for other sources of heating (Krajčik M. *et. al.* 2011; Feist W. *et. al.* 2005). The pre-heated outdoor air necessary for ventilation are supplied to the premises. To compensate for the most part of heat losses of the building, the temperature of air must be higher than of the premises in buildings heated by air. However, the temperature of air cannot exceed 50°C (Feist W. *et. al.* 2005), because in such case, dust combustion process begins in the air ducts and the supplied air no longer satisfies the hygiene requirements (Venckus N. *et. al.* 2010). To reduce the amount of energy used to heat the supplied air, heat recovery units are installed. Systems with such units pre-heat the fresh air supplied from the outside using thermal energy of the indoor air that is exhausted from the premises (Fernandez-Seara J. *et. al.* 2011). The amount of recovered heat depends on the efficiency of the heat recovery unit.

When the premises are air-heated, the amount and temperature of the supplied air have to be balanced to cover the heat losses of the building and ensure the microclimate requirements. In previous research was

analyzed groups of buildings with different thermal properties and the results shown that under the Lithuanian climatic conditions, the air heating system will operate efficiently if the heat transmission coefficient does not exceed 0.12 W/m²K and 0.85 W/m²K for non-transparent and transparent envelopes respectively, air exchange in the building is within the limit of 0.05 1/h, linear thermal bridges are allowed only through window and door reveals and do not exceed 0,05 W/mK, and finally, the heat recovery efficiency of the mechanical ventilation equipment is no less than 80%.

METHODS

The theoretical and experimental studies were made to set the parameters of indoor thermal climate in premises heated by air.

The main purpose of theoretical studies, were to calculate parameters: air speed and temperature of supplying air jet in operating area, then the least amount of 50 °C air necessary for ventilation are supplied to the premises. These studies were made in a modeled residential building. The total area equaled to 179.90 m² and volume to 719.47 m³. It had two floors: the ground floor included a utility room, toilet, staircase, kitchen, sitting room, workroom, and tambour, while a hallway, two living rooms, bedroom and bathroom. In the modeled building, air is supplied to the sitting room, workroom and bedrooms and is exhausted into the sanitary room and kitchen. The location of supply air outlet was modeled in two different variants by changing the distance from the ventilation grill to the operating area. The first variant of air supply was across and the second along the premises (Fig. 1).

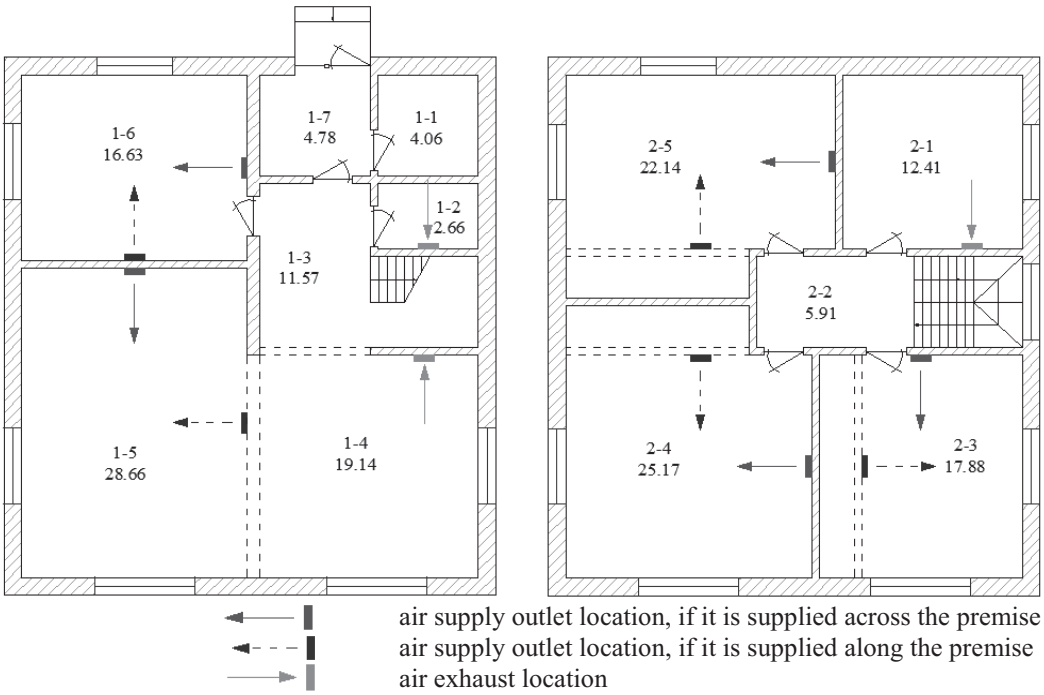


Figure 1. Principal scheme of air supply and exhaust outlet location

Dimension of the premises with supplying air system shown in Table 1. Air is supplied through the ventilation grilles, mounted in the wall above the operating area (Fig. 2).

Table 1. Dimension of the premises with supplying air systems

Counting No.	Premise No. in the plan	The purpose of premises	Supplying air amount, m³/h	Width of premises, m	Length of premises, m	Surface area, m²	Distance from the ventilation grille to the operating area, m	
							If air supplied across the premise	If air supplied along the premise
1	1-5	Sitting room	51.59	4.40	4.60	20.24	4.90	5.10
2	1-6	Workroom	29.93	4.50	6.13	27.59	5.00	6.63

3	2-3	Bedroom	44.70	4.05	4.40	17.82	4.55	4.90
4	2-4	Bedroom	62.93	4.40	4.90	21.56	4.90	5.40
5	2-5	Bedroom	55.35	3.45	5.37	18.53	3.95	3.95

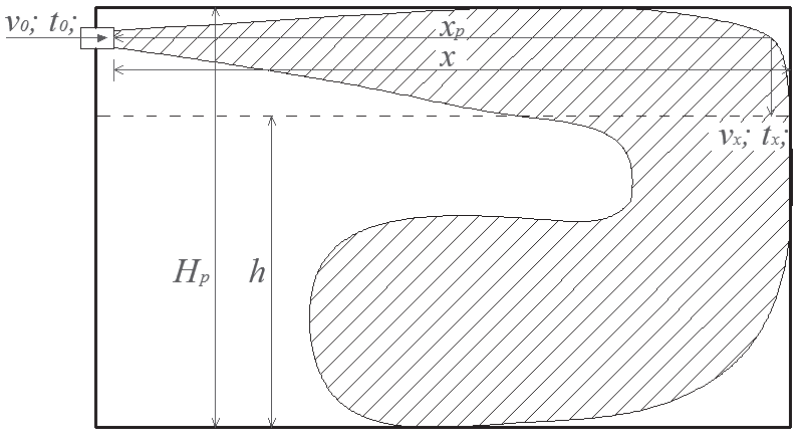


Figure 2. Air flow pattern in the premise

The microclimate parameters in operating area (v_x, Δt_x) of modeled building were calculated using 1 and 2 formulas (Juodis 2008).

$$v_x = v_0 \cdot \frac{m_2 \cdot K_v \cdot \sqrt{A_0}}{x_p} \tag{1}$$

$$\Delta t_x = \Delta t_0 \cdot \frac{n_2 \cdot K_v \cdot \sqrt{A_0}}{x_p} \tag{2}$$

where: v_x - air flow speed in the operating area [m/s]; v_0 – air flow speed near the ventilation grille [m/s]; m_2, n_2 – the damping coefficients of air flow $m_2=m_1 \cdot K_2$, $n_2=n_1 \cdot K_2$, where: $m_1=4.5$, $n_1=3.2$, $K_2=1,35$; K_v – correction factor of influence between equal parallel flows, if it is just one flow $K_v=1$; A_0 – area of ventilation grilles [m^2]; Δt_x – temperature difference between the operating area and the inflow air in it [$^\circ$C]; Δt_0 – temperature difference between operating area and the supplying air [$^\circ$C]. ko

The calculation method was set after the estimating an air jet flowing in the premise. An air jet is called a free jet if it is not affected by walls, ceiling, or other surface, confined jet is affected by surfaces (Juodis 2008) . The confining by walls of air jet was calculated by Formula 3.

$$\frac{x_p}{\sqrt{A_p}} \leq 2.1 \tag{3}$$

where: x_p – distance from the ventilation grilles to the operating area [m]; A_p – croos-sectional area of confined space normal jet [m²].

If the proportion of distance from the ventilation grilles to the operating area (x_p) and the croos-sectional area of confines space normal jet (A_p) is less than 2.1 – the air jet is free, if no – confines jet.

Input parameters of supplying air (v_o, t_0) were assessing from the literature review. The amount of fresh supplying air was calculated by STR 2.09.02:2005 ensuring the minimum ventilation requirement of 1 m² room floor area. The supplying air temperature set equal to the maximum allowable rate 50 °C. The initial air speed adjusted by changing grille area from 0.010 till 0.035 m².

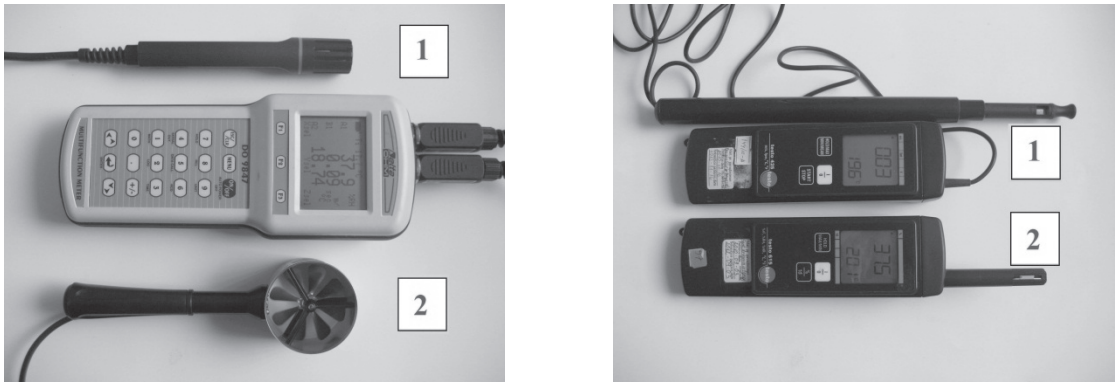
Experimental research was carried out in order to verify the accuracy of the methodology presented previously. The experimental research was made in the experimental room 2.99 m wide, 5.56 m long and 3.16 m

high. A heating-ventilation system consisting of air heater, ventilator, smoke machine, air duct and air supply grille was installed in the experimental room (Fig. 3.). The amount of air supplied into the room was regulated using a hand-controlled closing device. Changing supplying air amount from 0.016 till 0.031 m/h, five experiments were made. The effective area of the grille amounted to 0.01 m² and the distance from it to the operating area was 4.31 m.

a. 1) ventilator, 2) air heater, 3) smoke machine; b. 4) ventilation grille, 5) air duct.

Figure 3. The elements of the model of air heating system

During the experiment the speed of the supplied air and temperature were measured next to the grille and in the operating area. Equipment used during the measurements presented in Fig. 4.



a. Multifunctional meter „Delta OHM DO 9847“ 1. Combined relative humidity and temperature probe; 2. Air velocity probe.

b. 1. Thermal anemometer „Testo 425“; 2. Humidity measuring instrument „Testo 615“

Figure 4. Equipment used during the measurements

RESULTS

Results of theoretical research on microclimate parameters of the premises

To ensure microclimate parameters by supplying warm air into the premises, it is necessary to consider the hygiene requirements. The proportion of distance from the ventilation grilles to the operating area (x_p) and the croos-sectional area of confines space normal jet (A_p) was less than 2.1– the air jet is free in all premises According to the calculation methods the parameters v_x and Δt_x were estimated. Two versions of calculations were performed by changing the distance from the ventilation grill to the operating area. The first version of calculation was made if air is supplied across, and the second - along the premise. The results of the experiment are presented in Table 2 and Table 3.

Table 2. The parameters of supply air flow in the operating area, if it is supplied across the premise

Premises No. in the plan	Supplying air amount, m^3/s	Distance from the ventilation grille to the operating area, m	The area of ventilation grilles, m^2									
			0.010		0.015		0.021		0.022		0.035	
			v_{x1}	Δt_{x1}	v_{x2}	Δt_{x2}	v_{x3}	Δt_{x3}	v_{x4}	Δt_{x4}	v_{x5}	Δt_{x5}
1-5	0.014	4.90	0.18	3	0.15	3	0.12	4	0.12	4	0.09	5
1-6	0.008	5.00	0.10	3	0.08	3	0.07	4	0.07	4	0.05	5
2-3	0.012	4.55	0.17	3	0.14	3	0.11	4	0.11	4	0.09	5
2-4	0.017	4.90	0.22	3	0.18	3	0.15	4	0.15	4	0.12	5
2-5	0.015	3.95	0.24	3	0.19	4	0.16	5	0.16	5	0.13	6

Table 3. The parameters of supply air flow in the operating area, if it is supplied along the premise

Premises No. in the plan	Supplying air volume, m^3/s	Distance from the ventilation grille to the operating area, m	The area of ventilation grilles, m^2									
			0.010		0.015		0.021		0.022		0.035	
			v_{x1}	Δt_{x1}	v_{x2}	Δt_{x2}	v_{x3}	Δt_{x3}	v_{x4}	Δt_{x4}	v_{x5}	Δt_{x5}
1-5	0.014	5.10	0.17	3	0.14	3	0.12	4	0.12	4	0.09	5
1-6	0.008	6.63	0.08	2	0.06	2	0.05	3	0.05	3	0.04	4
2-3	0.012	4.90	0.15	3	0.13	3	0.11	4	0.11	4	0.08	5
2-4	0.017	5.40	0.20	2	0.16	3	0.14	3	0.14	4	0.11	4
2-5	0.015	3.95	0.16	2	0.13	3	0.11	3	0.11	3	0.09	4

The obtained results demonstrated that to ensure microclimate parameters of the premises, it is relevant to select a suitable area of the grilles and the distance from the ventilation grille to the operating area. This is because the increasing area of the grilles reduces the air speed and increases the temperature difference between the ambient air and air flowing into the operating area. However, it is not always possible to combine the parameters of air speed and temperature differences by changing the area of the grilles to meet the hygiene requirements: in such case the shape and dimensions of the premises should be altered.

Results of experimental research on microclimate parameters of the premises

The parameters of microclimate were measured near the ventilation grille (Table 4) and in the operating area. After evaluation the initial data and the confinement of the air jet the parameters in operating area were calculated (Fig. 5 and Fig. 6).

Table 4. Experimental results of indoor climate parameters by supplying the heated air in premises

Exp. No.	Air temperature in premises. °C	Supplying air amount, m^3/s	The measured parameters near the ventilation grille	
			v, m/s	T, °C
1	19.80	0.016	1.57	39.60
2	19.90	0.022	2.20	43.16
3	19.90	0.027	2.72	44.50
4	20.40	0.030	2.95	44.90
5	20.60	0.031	3.06	46.90

Note: v – air velocity, m/s; T – air temperature, °C.

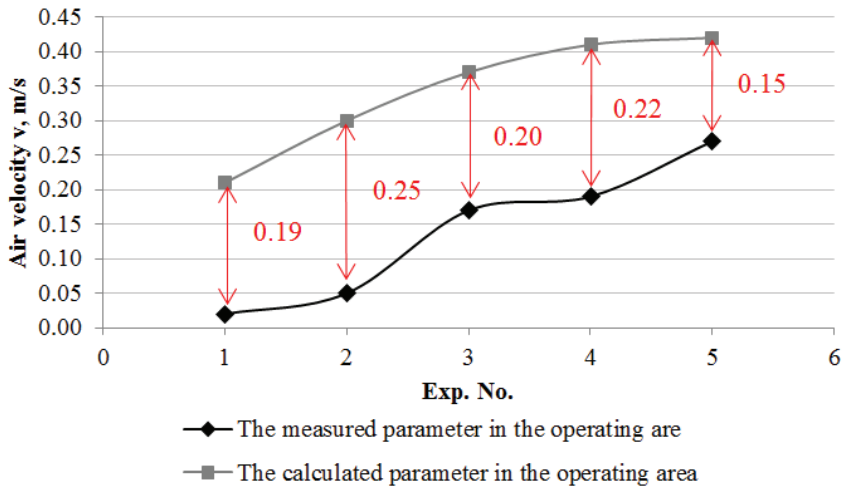


Figure 5. The difference between calculated and measured parameters in operating area of air velocity

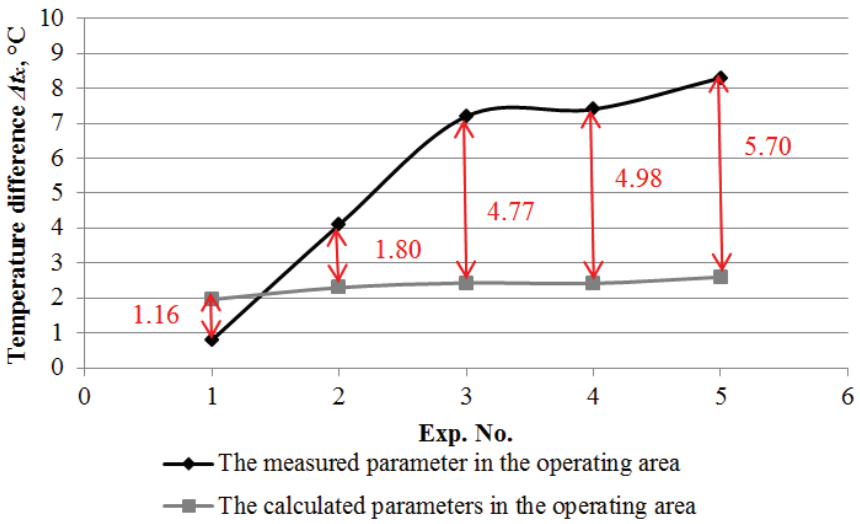


Figure 6. The difference between calculated and measured parameters in operating area of temperature

The comparison of the estimated values and the results obtained during the experimental research demonstrated that measured air velocity is less 0.15m/s just in 1 and in 2 experiments and the calculation results are exceed this limit in all experiments. The measured temperature differences between operating area and air inflowing in this area not exceed the limit of 3°C just in first experiment, the calculated temperature differences is less 3°C in all the experiments. The analysis of the results of experimental research and calculation demonstrated that air velocity difference between calculation and measurements values gets lower and temperature difference – higher while the amount of supply air was increased.

To determine the directions of air flow and the limits of coverage, an experiment with smoke machine and thermography research were made. Firstly it was made the experiment with smoke machine, the smokes were allowing into the premise through the ventilation system, supplying the maximum passible amount (0.031 m³/s) and temperature (46.90 °C) air to the premise. Level of sinking smoke was observational near the wall ahead the ventilation grille (Fig. 7). The supplied warm air heats the ceiling and the wall of premise. The level of air jet sinking (Fig. 8) and the direction of air jet on the ceiling (Fig. 9 and Fig. 10) is clearly visible in thermography photos.

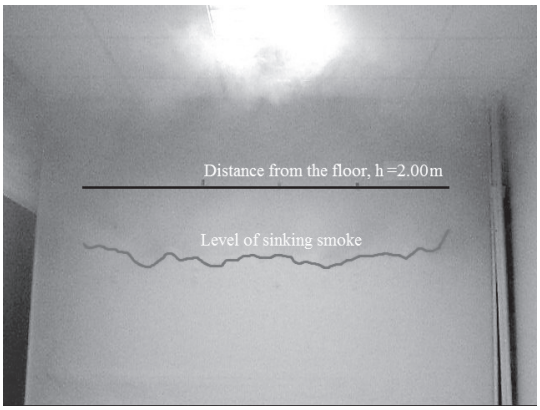


Figure 7. The experiment with the smoke

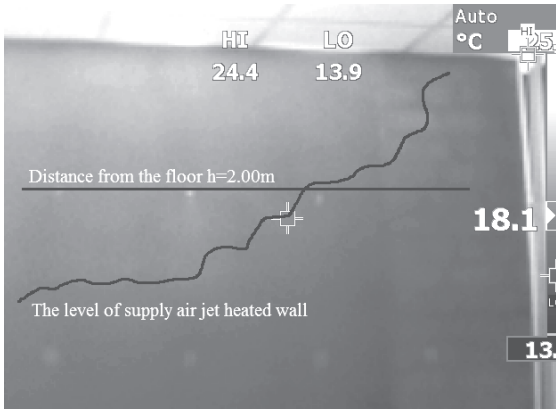


Figure 8. The level of supplying air jet sinking

The lowermost level of sinking smoke was stated 1.5 m distance from the floor. The same result of air jet sinking was obtained in thermography research.. Hot air jet heated the wall ahead the ventilation grille about 1.5 m from the floor. The direction of air flow is clearly visible in Fig. 9 and Fig. 10, the supplied air jet is not affected by walls – the air jet is free.

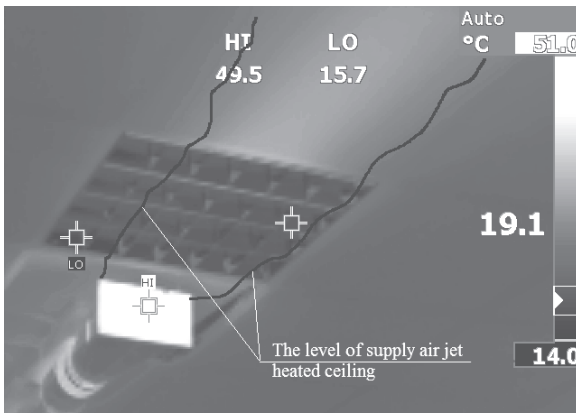


Figure 9. Supplying air jet expansion angle near the grille

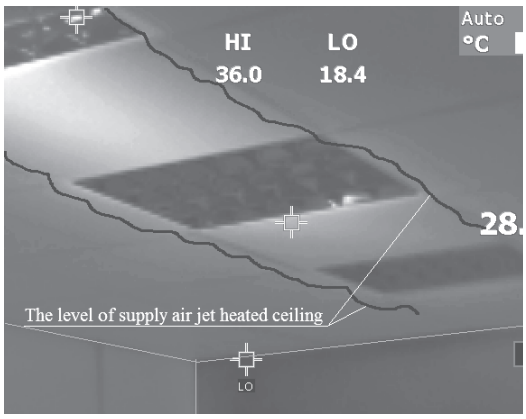


Figure 10. Supplying air jet expansion angle

After the experiment with smoke machine and thermography research it was found out that the air jet rests near the ceiling and not goes down to the operating area as it should be when the warm air is supplied to the premise. For this reason, the air speed is very low in the operating area.

CONCLUSIONS

1. According to results of calculation methodology the air speed and temperature difference between the surroundings and operating area satisfy the hygiene requirements if air is supplied along the premise.

2. To determine the directions of air flow in premise an experiment by allowing smokes into the premise and thermography research were made, it was observed that the hot air jet did not move down to the operating area as it is refer in calculation methodology. For this reason air velocity difference between calculation and measurements values gets lower and temperature difference –higher while the amount of supply air was increased.

3. The analysis of experimental data shown that the supply air temperature is too high and the air jet did not become colder till the operating area, because of too short distance from the ventilation grilles to the operating area. Also the supply air amount is to low and the air jet dissipated till the operating area. For these reasons the calculation method of microclimate parameters of the premises used for the theoretical research has to be revised.

REFERENCES

Atthajariyakul S., Leephakpreeda T. 2004. Real – time determination of optimal indoor – air condition for thermal comfort, air quality and efficient energy usage. Energy and Buildings 36 (2004), 720 - 733.

Feist W., Schnieders J., Dorer V., Haas A. Re – inventing air heating: Convenient and comfortable within the frame of the Passive House concept. Energy and buildings, 2005, Vol. 37, p. 1185 – 1203.

Fernandez-Seara J., Diz R., Uhia F. J., Topazo A., Ferro J. M. Experimental anglysis of an air-to-air heat recovery unit for balanced ventilation systems in residential buildings. Energy Conversion and Management , 2011, Vol. 52, p. 635-640.

Juodis E. „Vėdinimas“. Vilnius, „Technika“ 2008, 80 p.

HN 42:2009 „Gyvenamųjų ir visuomeninių pastatų patalpų mikroklimatas“ [Microclimate in dwellings and public buildings]. Vilnius.

Krajčik M., Simone A., Olesen B. W., Petraš D. Experimental evaluation of thermal environmemt and ventilation effectiveness in a room heated by warm air, Indoor Air 2011, Austin: Austin Convention Center. 2011 June 5 - 10.Zhao R., Sun S., Ding R. 2004. Conditioning strategies of indoor thermal environment in warm climates, Energy and Buildings 36 (2004), 1281 – 1286.

Matuliauskaitė A. 2009. Oro tarša kietosiomis dalelėmis, jos įtaka gyvenimo kokybei ir taršos mažinimo patalpose priemonės. Sience – future of Lithuania, 2009, 1 tomas, Nr. 5, 114 – 117.

Shengxian W., Ming L., Wenxian L., Yanlin S. 2010. Parametric studies and evaluations of indoor thermal environment in wet season using a field survey and PMV - PPD metfod. Energy and Buildings 42 (2010), 799 - 806.

Smeds J., Wall M. Enhanced energy conservation in houses through high performance design. Energy and Buildings, 2007, Vol. 39, p. 273 – 278.

STR 2.09.02:2005 “Šildymas vėdinimas ir oro kondicionavimas” [Heating ventilation and air conditioning]. Vilnius: Ministry of Environment of the Republic of Lithuania.

Venckus N., Bliūdžius R., Endriukaitytė A., Parasonis J. 2010. Research of low energy house design and construction opportunities in Lithuania, Technological and Economic Development of Economy, 2011, 16:3, 541-554.

Zhiqiang Wang, Jensen S. Zhang 2011. Characterization and performance evaluation of a full - -scale activated carbon – based dynamic botanical air filtration system for improving indoor air quality. Building and Environment 46 (2011) 758 – 768.

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Diagnostics and Problems Analysis of Buildings Air Tightness

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EXTENDED ABSTRACT

Constantly increasing prices of energy and rising heating costs are forcing inhabitants of multifamily apartment houses and individual houses to think about savings of heating costs and improvement of living conditions as well. Air tightness is one of the most important factors influencing comfortable, energy efficient living environment. During winter time, air movement forms because of the pressure difference between outside and inside air. Air moves from the higher to the lower pressure zone, i. e. cold outside air penetrates to the room through the lower parts of the walls, and finally when it warms up, it goes out of the premises through the upper parts of the construction. The higher of uncontrolled air circulation is present in the premises, i. e. the more of cold air penetrates into the room, the higher energy consumption is required for heating. These energy losses can be reduced by increasing air tightness of the buildings.

The aim of this research is to investigate the most common places of the buildings' leakage and the causes of it. For this study, different types of newly constructed or renovated buildings were selected. Thermographic survey was performed in order to identify defective parts of the investigated buildings. Qualitative detection of thermal irregularities in building envelopes (LST EN 13187) based on Infrared method was used for this purpose. In order to investigate air leakages places, thermographic investigations were carried out twice. First, to determine the normal situation, the surface temperature measurements were performed without any additional pressure difference. Next, to determine the main air leakage places, the 50 Pa negative pressure under the envelope was set with fan pressurization equipment. After the infiltration airflow the surface temperatures were measured with the infrared camera from the inside of the building.

This survey revealed the typical leaky places of all types of buildings: junction of the ceiling/floor with the external wall; junction of the partitions with the external wall and roof; penetrations of the electrical and plumbing installations through the air barrier membranes; penetrations of the chimney and ventilation ducts through the air barrier; leakage around and through electrical sockets and switches; leakage around and through windows and doors.

The investigated cases show, that on the statistical assessment of walls, windows and roof with more than 80 % relative humidity of indoor air, condensation is possible near the cool surfaces of the envelope (the RH may be lower). The investigation and calculation results show, that the highest probability of occurrence of condensation is on the window glazing, frame and its mounting perimeter; the lowest probability for condensation is for roof enclosure.

Keywords: Infiltration, Blower Door, Ventilation, Air Leakage, Energy

REFERENCES

Becker, R. 2010. Air Leakage of Curtain Walls – Diagnostics and Remediation, Journal of Building Physics, 34(1), 57-75.

LST EN 13187:2000 Thermal performance of buildings - Qualitative detection of thermal irregularities in building envelopes - Infrared method (ISO 6781:1983 modified). Brussels. 16 p.

Nielsen, K., F., Holm, G., Uttrup, L., P., Nielsen, P., A. 2004. Mould growth on building materials under low water actinities. Influence of humidity and temperature on fungal growth and secondary metabolism, International Biodeterioration & Biodegradation, 54, 325-336.

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Analysis of Slope Stability Under Cyclic Load

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Abstract. Several important concepts should be kept in mind while analysis slope stability problem because slopes may be natural, due to erosion by rivers, or man-made by excavation or fill. These concepts include safety factors, limit states, loads combinations. Generally the limiting height and angle of a slope depend on the strength of the soil and there are a number of different soil strengths. The most important distinctions are between undrained strength and drained or effective stress strength and between peak, critical state and residual strengths. The main object of this paper the review and the task formulation of the analysis of the slope response to cyclic load.

Keywords: slope stability, response, cyclic load.

INTRODUCTION

The analysis of dynamic impact acting on a structure is a complicated task. This is because it is necessary to study how vibrations, caused by cyclic or complex loading, affect the strength and stability of the structural members. Generally, there is a great number of researches, related to structures and its elements response to the acting force or dynamic loading. For instance, researchers have tried to monitor the footing when it is affected by vibration (Novak, 1970). In addition to this, scientists performed similar experiments with fixed foundation (Gazetas *et al*. 1991). These studies were not sufficient so researchers became interested in how vibrations, induced by moving objects, affect the soil. The ring – shear apparatus were designed and improved in order to determine the strength properties of soil. Already in 1939 the shear rings were applied for the determination of shear strength (Hvorslev, 1939). This method is being improved up to now. At present the shear apparatus allows to determine more parameters and apply more conditions that facilitate to find out how soil response to influencing load. As the device options were improved there is a possibility to monitor and control the entire process of the experiment (Kyoji Sassa e*t al*. 2004). Researchers determined the dynamic characteristics of soil that is affected by different loads and oscillations, induced by a rigid body. However, results and conclusions of all these studies were not considered while dealing with the problem of the slope stability. New factors and conditions must be taken into an account while analyzing this problem. For example, the blast loading was applied to rock slopes in order to find out how they respond to such impact (Lu Wenbo *et al*. 1996). Moreover, scientists analyzed the man - made embankment response to train - induced vibration (Xian-zhang LING *et al*. 2011). Nevertheless, the slope stability under cyclic and dynamic loading was not analyzed. This issue is quite broad because there is a wide variety of slopes and each one of them has different properties. There is a need to analyze the relationships and conclusions, which are already determined, and apply this information for further investigations. The main purpose of this paper is to formulate the questions and tasks for subsequent researches.

Review analysis of problem

In general there are various types of slopes and each one of them has different properties. Slopes can be natural or man - made. Also they can be composed of different soil types. It can be clay, sand or combination of these two elements. The main hazard causing landslides is the deformation of soil. Landslide is a relatively fast downward movement of (natural or man - made) soil slopes when gravity force, hydrodynamic pressure and other forces are affecting unstable slopes. Therefore, the stability of slope, in terms of landslide formation, depends on the inclination and height of the slope and arrangement of soil layers within the slope. It is also important to pay attention to physical parameters of soil, including degrees of consolidation and saturation, meteorological conditions and dynamic impacts (for instance, earthquake). Despite the fact that, many soil properties are already established while applying different conditions, there still are outstanding questions about the stability of slope. For example, slope response to cyclic loading or permanent vibration. This is an insufficiently analyzed, but undoubtedly significant, problem. What is more, slopes can be drained or undrained.

Practically all these features can be combined together in many different ways and it is a challenging task to analyze stability of such slopes, especially, when it comes to the impact of cycling loading or vibrations.

Researches that were discussed in the introduction presented significant results that may be used for further analysis. It should be noted that all investigations were done using special experiment methods. First of all, (Xian-zhang LING *et al*. 2010) established the relationships between train-induced vibrations and different parameters that describe the dynamic properties of soil and man-made embankment. The influence of temperature was also taken into an account. It is significant that researchers investigated how train-induced vibrations affected the stability of the embankment. The relationships between parameters, influencing the embankment response to oscillation, were also explained. These experiments were carried out with the embankment that was composed of four layers, respectively arranged from bottom to top: silty clay, compacted soil of silty clay, compacted soil of silty clay and gravel, ballast. The influencing parameters such as distance from the rail, speed and load of the train were analyzed. Furthermore, investigations were carried out in summer and winter, to be precise, frozen and unfrozen conditions of soil layers were taken into an account. That means that influence of temperature changes has not been omitted. The movements of embankment were analyzed by applying three types of trains: fast and slow passenger trains and freight train. It was discovered that, despite the higher speed of passenger train, vibration caused by freight train was more intensive. Considering all results, it is the load of the train rather than its speed that influences vertical vibrations of the embankment. There is no doubt that these significant results will be taken into an account while designing embankments of the rails. The similar technology of investigations can be used to analyze and monitor the roads, located near the slopes. The changing flow of vehicles induces the dynamic loading that may affect the stability of the particular slope. It is especially important to analyze the stability of natural slopes as their interaction with the dynamic load is predictable even harder.

The second, equally important, factor while analyzing the motion of man - made embankment is temperature. In order to learn about influence of this parameter, experiments were carried out at different temperatures in summer and winter, precisely, under frozen and unfrozen soil conditions. It was found that during the cold period of the year frozen layers of soil get stiffer. For this reason, man – made embankment is more resistant to longitudinal vibrations when soil is tightly frozen. Also, deeply frozen layers of soil restrict lateral oscillation of embankment. Due to the fact that layers of soil freeze seasonally, vertical vibration in summer was higher, comparing to the same results in winter. To be added, vertical vibration in unfrozen layers attenuates more rapidly than longitudinal vibration in frozen soil. It is because the elastic modulus of frozen layers is greater, comparing to unfrozen soil. These results demonstrate how the change of temperature affects characteristics of soil and man-made embankment. This is external factor that has to be taken into an account while analyzing the stability of slopes. These experiments were carried out using man-made embankment mostly consisting of silty clay. These results are suitable for analysis of man - made slope when it is affected by cyclic loading. Further researches may be performed with natural slopes. Drained or undrained soil conditions can also be evaluated while analyzing the stability of slopes under cycling or dynamic loading.

The third factor, influencing the stability of slope, is the distance from the slope to the vibration source. (Xian-zhang LING *et al.* 2010) measured this distance from the rail to the particular point. It is evident that acceleration of embankment oscillation decreases when moving further from the railway. However, it should be emphasized that, as distance from the rail increases, the frequencies of soil vibration move towards a low frequencies zone. It is significant, as the low - frequency vibration is reduced much slower than high- or medium- frequency oscillation. Furthermore, the factors that induce vibrations of the points, situated in different spaces from the rail, are not exactly the same. The area that is closer to the track is mostly affected by these factors: train speed, gaps between adjacent ties and slope conditions. Meanwhile, points, located further from the railway, are more responsive to train speed, rigid wheelbase of the suspension, etc. The important relationships between the motion of the embankment and the distance from the vibration source were established. This relationship is given using the predominant frequency f_1 and f_2 that depends on the train speed and the tie spacing.

$$f_1 = \frac{v}{d_1} \tag{1}$$

where

v – train speed,
d_1 – tie spacing.

$$f_2 = \frac{v}{d_2} \tag{2}$$

where

d_2 – rigid wheelbase.

It is significant information because, besides the investigation of slope stability under dynamic loadings, it is critical to pay attention to structures located nearby the slope. The transmitted vibration, displacements or landslides can be extremely dangerous for adjacent objects.

As it was mentioned earlier, there is a variety of parameters affecting the slope stability and dynamic properties of soil. All these parameters cannot be analyzed by performing one type of investigations. In the research work (Yoon- Sang Kim *et al*. 2007) applied four different methods in order to find out the soil response to the vibration of rigid body that was placed on the top of the soil layer. To be precise, researchers performed cycling triaxial tests and three types of model vibration tests. All experiments were carried out using siliceous sand and applying consolidated and undrain conditions. In other words, sand was saturated and made into a solid compact mass. The method introduced by (Yoon-Sang Kim *et al*. 2001) was used because neither dynamic properties of vibration nor the function of shear strength are linear. Experiments were performed using rigid objects with particular size, weight, inertial moment and different forms of basis (round, square and rectangular). Rigid body was forced to fluctuate cyclically at different frequencies. However, despite different forms of the rigid body and soil density the graph shape of the vibration period is the same. The applied mechanical oscillation is graphically depicted as the sinusoidal wave. It was found that the period of soil vibration depends on the weight of the rigid body and size of the base area. The period increases with the increase of the body weight. Also, the decrease of the basis size (it is especially apparent if the form of the basis is round) amplify the value of vibration period. It was noticed that, the soil density influences the period of oscillation, because the higher the density the smaller the period. This relationship may be related to the shear strength dependence on the density index. The density index is defined as

$$I_D = \frac{e_{\max} - e}{e_{\max} - e_{\min}} \tag{3}$$

where

e - void ratio.

As known, the density index of a soil in its densest possible state ($e = e_{\min}$) is 1 (or 100%) and the density index in its loosest possible state ($e = e_{\max}$) is 0. For example, in the case of sands, the maximum density is determined by compacting a sample underwater in a 1-1 mould, using a circular steel tamper attached to a vibrating hammer. The sand from the mould is then dried in an oven, enabling the dry density to be determined. The minimum dry density for sands can be determined, then a 1-1 measuring cylinder is partially filled with a dry sample of mass 1000 g and the top of the cylinder closed with a rubber stopper. The minimum density is achieved by shaking and inverting the cylinder several times, the resulting volume being read from the graduations on the cylinder (British Standard 1377, 1990). We did the analysis of experimental data and determined that this parameter is very important because there is a linear correlation between shear wave velocity and density index of soil. We also did the regression analysis of investigation and got that correlation can be expressed as empirical equation:

$$c_\tau = a_0 + aI_D \tag{4}$$

where

c_τ - shear wave velocity

a_0 - initial shear wave velocity

a – coefficient of shear wave velocity

For instance, after performing regression analysis of investigation data we established the following parameters of particular sand, which the distribution of sand particles is shown in Fig. 1.

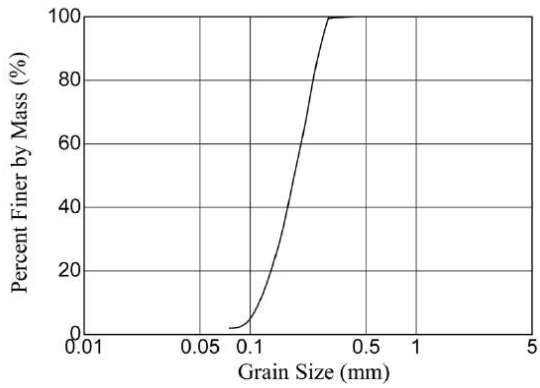

Figure 1. Grain size distribution

The established parameters are $a_0 = 41.46$ m/s, a=0.64 m/s and equation:

$$c_\tau = 41.46 + 0.64 I_D \tag{5}$$

This relationship is shown in Fig. 2.

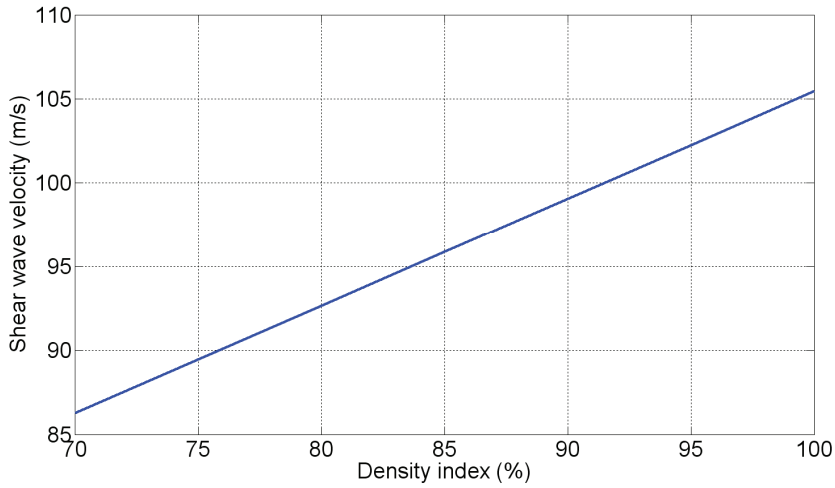

Figure 2. Relationship between density index of soil and shear wave velocity

These relationships can be established for different soils and applied for the solution of slope stability problem.

In the research work (LU Xiaobing, 2004) investigated the conditions that induce the liquefaction of saturated sand. The layer of experimental sand was affected by vertical vibration in order to determine how different parameters influence the liquefaction zone. The bottom of saturated specimen was fixed while vibration was induced through water on the top of the sand. The liquefaction zone forms as soon as the load is applied and develops quickly when the permeability of sand is high. When the permeability is lower the liquefaction primarily forms the initial zone that gradually expands along the depth of the specimen. It is important to emphasize that, if the permeability in some particular points is 10% or even 5% smaller comparing to other points the pore pressure and deformation will increase quickly and concentrate at those particular points. What is more, the expansion of liquefaction area is fast when initial tangent modulus is small. On the other hand, when this parameter is greater the liquefaction zone develops towards the depth of the sand. The influence of initial limit strain is also significant. As this parameter is big the liquefaction region forms instantaneously just in the beginning of the loading. When initial limit strain is smaller the liquefaction area turns up quite quickly as soon as the loading is applied. Afterwards it develops in time downwards the sand. The speeds of water and sand particles change significantly near the surface where the loading is applied and afterwards taper along the depth. Sometimes the direction of vectors of these two velocities can be different. Hence it can affect the soil structure. The rapid expansion of the liquefaction region is also influenced by increscent frequency and amplitude of the

vibration. These investigations demonstrated that vertical vibration can induce the liquefaction of saturated sand and established the influence of different parameters. These significant conclusions enable to predict the slope response to water impact while considering the slope characteristics more easily.

Formulation of the main task

The performed analysis of researches, related to the slope stability and interaction between soil and cyclic loading, allows formulating the main tasks for further investigations:

1. To investigate the temperature change influence on the stability of natural slope that is affected by cyclic loading.
2. To investigate the correlation between dynamic characteristics of cyclic loading and physical parameters of natural slope.
3. To investigate the groundwater influence on the stability of natural slope that is affected by cyclic loading.

It is necessary to emphasize that further analysis should appeal the already obtained results that were discussed in the previous chapter.

CONCLUSIONS

Considering the performed review and analysis of the slope response under cyclic load the following conclusions can be made:

1. the stability of slope under cyclic loading is insufficiently analyzed field and it is promising problem for further investigations;
2. while performing further analyzes it is necessary to consider that:
   - 2.1. the dominant frequency range of embankment with frozen and unfrozen soils all shift to low frequency band with the increase of distance from the source of vibrations.
   - 2.2. embankment vibration increases with the increase of train speed and train load, and the train load has more effects on embankment vibration than the train speed. Moreover, dynamic magnification factors are the greatest for the freight train and the least for the high-speed passenger train;
   - 2.3. the relationship between the vibration characteristics of a rigid body on a soil surface and the dynamic properties of the soil are important and can be will find.
   - 2.4. the saturated sand may liquefy under the vibration loading. The dropping rate of the effective stress increases with the decrease of the permeability or the initial tangent modulus or with the increase of the amplitude or frequency of the loading or the initial porosity;
3. We determined that there is a linear correlation between shear wave velocity and density index of soil and it can be expressed as empirical equation (4).

REFERENCES

Novak M., “Prediction of footing vibration”. Journal of Geotechnical Engineering Division, ASCE, 1970. Vol. 96, No. 3, 837-861.

Gazetas G., Stokoe K.H., “Free vibration of embedded foundation; theory versus experiment.” Journal of Geotechnical Engineering Division, ASCE, 1991. Vol. 117, No. 9, 1382-1401.

Hvorslev MJ, “Torsion shear tests and their place in the determination of the shearing resistance of soils”, 1939. Proc Am Soc Test Mater 39:999–1022

Sassa K., Fukuoka H., Wang G., Ishikawa N., “Undrained dynamic-loading ring-shear apparatus and its application to landslide dynamics”. Landslides 2004 1:7–19.

Wenbo L., Shixiang L., Chuangyun Z., “Analysis of the dynamic stability of rock slopes under blasting vibration conditions”. Mining and Metallurgical Engineering, 1996.

Kim, Y.S., Ha T.G., Choi J. J., Chung C.K., “The Influence of Dynamic Properties of Ground Soil on Vibration Characteristics of Rigid Body on Sand Ground”. KSCE Journal of Civil Engineering, 2007. Vol. 11, No 2, 81-91.

Kim Y.S., Miura K., Miura S., Nishimura M., “Vibration characteristics of rigid body on sand ground.” Journal of Soil Dynamics and Earthquake Engineering, 2001. Vol. 21, No. 1, pp. 19-37.

Ling X. Z., Wang L.N., Zhang F., Chen S.J., Zhu Z.Y., “Field experiment on train-induced embankment vibration responses in seasonally-frozen regions of Daqing, China”. Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering) 2010 11(8):596-605.

British Standard 1377 (1990) Methods of Test for Soils for Civil Engineering Purposes, British Standards Institution, London, 1990.

Xiaobing L., Qingming T., Cheng C.M., Shanbing Y., Peng C., “Liquefaction and displacement of saturated sand under vertical vibration loading”. Acta Mechanica Sinica, Vol.20, No.1, 2004, 96-105.

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Aspects of Aseismic Building on the Territory of the Republic of Belarus

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Abstract. The basic results of researches, principles of normalization and designing of buildings affected by natural and technogenic geodynamic influences on the territory of Belarus are considered in this article.

Keywords: foundations of buildings and structures, geodynamic influence, geodynamic-resistant designing and building, limiting acceleration, methods of protection

INTRODUCTION

For Belarus and it is capital - Minsk, the problems of seismic stability of constructions and methods of their designing and protection are also actually, in connection with planning of tall buildings' construction. According to the general map of seismic zoning of North Eurasia, Minsk is located in a seven-point zone of possible concussions under the scale of seismic intensity MSK-64 (Aizberg *et al.* 2007) on the western part of an ancient East-European platform.

Sources of earth-waves on territory of Belarus are earthquakes with focus in a zone of Vrancha and local potential earthquake zones. That's why development of methods of seismic designing is producing in Belarus for short and long periods of vibrations of ground, common for Romanian earthquakes.

It is necessary to note, that sources of seismic loads can be not only earthquakes, but also technogenic factors: commercially-technologic and terroristic (transport, equipment, explosions and other), geoterritorial (earth slides, collapses, subsidence in karstic and undermine cavities), appeared because of human activity or seismic load.

International building experience in seismic regions shows for providing seismic stability of buildings, reducing harmful seismic loads, it is necessary to realize special measures, like: increasing the rigidity of the bases, using active and passive vibration insulation, dynamic shock damper and other, but it significantly increases the cost and construction time (Polyakov V.S. 1988).

The Eurocode 8 contains requirements on harmonization the national standard documents in considered area with the account of accumulated experience in conditions of the concrete countries.

However in active standard documents of the Republic of Belarus there is lack of data on these questions in the necessary volume for estimation the operational reliability of objects, their designing and protection. On this basis RUE "Institute BelNIIS" has executed corresponding in-situ and laboratory researches on studying conditions and degree of probable seismic danger on the territory of the Republic of Belarus were carrying out and working out sound methods of damage and losses minimization from seismic and anthropogenic geodynamic impacts, methods of designing new aseismic constructions and protection of existing objects.

METHODS OF RESEARCHES

Successful solutions of problems of aseismic construction are connecting with:

- getting accurate data of real dynamic loads on buildings and using this material during designing methods of analysis;
- truthful determination estimated data of basement vibration or initial data of the bases features, including dynamic characteristics;
- decreasing the amplitude of oscillation of the bases for the account of vibration reduction.

For tests under laboratory and field conditions seismoreceivers and registration equipment was applied under following schemes of measurements:

- transillumination (sound scanning) in a blanket;
- transillumination the depth with the help of parallel beams;

- seismic profiling;
- seismic transillumination with the help of parallel beams longitudinal and cross-section waves.

Under laboratory conditions methods of research for various grounds and ways of protection were fulfilled on models. For checking the research results the control testing was made on twelve test grounds under field condition using different vibration sources (dieselhammer, tamper) and their gauging both in designs of existing buildings (bricken, panel and framed system) and in the bases sandy, clay, artificial average durability and friable.

Under field conditions the equipment of Danish firm "Bruel and Kjer" was used which consists of: registration and analyzing paths from vibrometer type 2511 with vibrosensor 4370 and the amplifier-formation of signal - type 2635.

The signal from vibrosensor with a preamplifier moves to the four-channel tape recorder of type 7005 with the subsequent decoding of a magnetic recording under laboratory conditions by means of an analyzing path consisting of the filter type 1618, recorder - type 2306 or vibrometer type 2511.

Questions of waves formation and expansion in ground (on depth and on a surface), free from piles and with presence of a pile field, and also the mechanism of their influence on buildings (damage rate) were investigated. Excitation of waves inside and on ground surface of a massif was made by driving piles or tamping under the scheme z-z, x-x, y-y. Experimental data under references and synthesized accelerograms for Belarus from local and distant earthquakes are generalized and analyzed.

RESULTS AND PRACTICAL APPLICATION

Based on researches, technical sources, etc. norms of admissible influences on designs of existing buildings, factors of attenuation and transferring fluctuations on the bases (tables 1- 4) are developed. And methods of their calculation which were included into the developed Technical codes on designing and building of geodynamic-resistant construction.

During researches following basic directions of decreasing the influence of fluctuations on buildings from ground are confirmed: reduction of dynamic tension under the bases; reduction static pressure of buildings on the basis; increasing the rigidity and bearing ability of a ground under the base; insulation against vibration of the bases.

Basing on researches it is possible to ascertain.

The choice of any of above-stated measures should be proved and considering area of its rational application.

The most accessible and approved way of decreasing the level of pulse fluctuations of a ground and quantity of the impulses influenced on buildings, is increasing the rigidity of the basis for the account of making a pile field or geomassif with vertical reinforcement of soil. The ground acceleration in a pile field from a source of vibration, being behind its bounds have appeared on 30% more poorly, than acceleration of the same free piles ground. At the same time when the source of fluctuations is in a pile field the boomerang effect is observed - accelerations of environment displacement increases.

“Hollow screens” filled with air or trenches which reduce amplitude of vertical fluctuations in 2-3 times are effective in this plan.

Realized measurements of seismoisolating features of “hollow screens” depending on its arrangement between source of fluctuations and building have shown that efficiency of the “hollow screens” that above, than further it is from protected object. The area of rigid links breaking out opposite walls of tranches shouldn’t exceed 5 % of the “hollow screens”.

Systems of seismoisolation not less effectively reduce the fluctuations transferred to the bases of buildings from a ground. As shows the experience of experimental designing and building stored in the CIS, such systems provide vibration strength of under construction and reconstructed buildings for the account of reduction geodynamic loadings on a design of an elevated part of buildings on 1-3 points that allows to lower the budget cost of building on 3-6 %, labor intensity on 4-6 % and the expense of materials on 5-10%.

The results comparison of calculation by various existing techniques of forecasting the ground fluctuations from seismic and vibrodynamic sources with received experimental data for soil conditions of the Republic of Belarus has shown that none of them guarantee validity and reliability of estimation level of the ground fluctuations depending on distance to a source of fluctuations “r”. Obviously, it is connected with the applied formulas, which based on admission (models) where all kinds of fluctuations are harmonious, and the ground is replaced with an elastic homogeneous environment with decreasing fluctuations about their source under the law 1/r or $1/\sqrt{r}$. It does not allow to consider the full variety of ground conditions and their properties. By results of the executed researches, it is recommended to apply the formula of academician B.B.Golitsina (1) for a tentative

Table 1. Value factor of transferring fluctuations from the bases on the foundation K depending on type of a ground bearing layer of the basis (Seskov and Krautsou, 2008)

The object characteristic	Factor Kfor the bases of combined grounds		
	Type 3: Friable sands, sandy loams and clays with a fluidity indicator I_L>1,0	Type 2: Sand of average durability, sandy loams and clays with a fluidity indicator 0,5<I_L<1,0	Type 1: Durable sand, sandy loams and clays with a fluidity indicator 0,5<I_L
Intact buildings or constructions of flexible and conditional-flexible systems to: • 2 floors • 5 floors • 9 floors •12 and higher	 0,8 0,7 0,6 0,5	 0,9 0,8 0,7 0,6	 1,0 0,9 0,8 0,7
The equipment established on: •a ground •building or construction overlapping	 0,9 0,85	 0,95 0,9	 1,0 1,0

Table 2. Value factor of seismic attenuation **δ** for different grounds of the Republic of Belarus (Seskov and Krautsou, 2008)

The ground name	The characteristic of the ground basement	Coefficient **δ**, 1/m
Sands	Durable (1 category) Average durability (2 category) Soft (3 category)	0,10 0,15 0,20
Sands(filled-up)	Loose(Kc_{Om}=0,92-1,0)	0,30
Sand clay and loams(moraine)	Durable Average durability Soft	0,10 0,12 0,16
Sand clay and Loams(loess, pulverescent)	Durable Average durability Soft	0,10 0,15 0,22
Quaternary clay	Durable Average durability Soft	0,08 0,15 0,25
Peat	Moisture W=300-1200	1,00
Peated ground	The same, W=50-300	0,50
Sapropels, alluviums	The same, W=40-150,150- 600	0,60
Frozen grounds	-	0,04
Sands (aquic)	Durable Average durability Soft	0,07 0,08 0,10

Table 3. Acceleration limit of displacement of the foundation au at frequency of fluctuations f=2Hz

The name and design features of constructions	Damage degree of constructions	Acceleration a_u, m/s^2, depending on the type of foundation		
		standard	average	soft
1	2	3	4	5
Industrial and civil buildings with a full steel skeleton without filling. Buildings and constructions in which there are no additional efforts from non-uniform settling. High rigid constructions and chimneys.	I (without damage) II (Cracks to 1 mm) III (Cracks more than 1 mm)	2,0 1,5 1,0	1,5 1,0 0,8	1,0 0,7 0,5
Industrial and civil buildings with a full reinforced concrete skeleton without filling and with a steel skeleton with filling. Free skeleton buildings with bearing walls from a brick setting and large-size blocks with reinforcing or bracing booms.	I II III	1,5 1,2 0,8	1,2 0,9 0,6	0,9 0,5 0,2
Industrial and civil buildings with reinforced concrete filling. Free skeleton buildings with bearing walls from large-size blocks and a brick setting without reinforcing and bracing booms.	I II III	1,2 1,0 0,7	1,0 0,8 0,5	0,8 0,3 0,15
Free skeleton large-panel building	I II III	1,0 0,7 0,5	0,8 0,6 0,4	0,6 0,3 0,15
Note - Limiting values a_u at frequencies of fluctuations of the bases f in limits from 2 to 50Hz issupposed to be defined under the formula $a_u = \sqrt{k_d f}$, where k_d factor of vibration for the third level of danger of fluctuation under table 4 taking into account item 3 of its notes.				

Table 4. Danger levels of vibrodynamic fluctuations of the bases at maintenance of dynamic intensity p=95 %

Coefficient of vibration k_d, cm^2/s^3 at f=2-50Hz	Estimation of danger degree of fluctuations for intact civil and industrial constructions on sandy and clay bases.
<0,05	**Level of fluctuations** -1, equivalent seismic grade- 4 on СНиП11-7-81 *. The lowest limit of sensitivity of the vibrations, not causing additional collapses of the bases and damages to overground designs.
from 0,05 to 0,25	**Level of fluctuations - 2,** equivalent seismic grade- 5 Causing weak damping collapses to S<3 mm per year, not dangerous.
from >0,25 to 0,7	**Level of fluctuations - 3,** equivalent seismic grade- 6. The same, S=3-5mm per year and eliminated damages.
from 0,7 to 2	**Level of fluctuations - 4,** equivalent seismic grade- 7. Not damping collapses S> 5 mm per year causing critical damages of the third degree (breakdown point for some kinds of designs, grounds, as a rule, biogenic, weak and soft, a pre emergency)
from 2 to 5	**Level of fluctuations - 5,** equivalent seismic grade- >7. Critical stability of average durability bases. Its excess at constant influence of fluctuations leads to destruction of structures and threatens human life (catastrophic situation)

Note.

1. k_d - Coefficient of vibration defined under the formula $k_d = \frac{a_{max}}{f}$, where a_{max} -maximum from measured values of acceleration of the base, m/s^2; f - frequency of fluctuation, Hz, corresponding to the maximum value of acceleration.

2. The lowest limit of values k_d belongs to constructions with the first degree of damages under the table 3, and top to the third degree (value k_d for constructions with the second degree of damages are defined by interpolation between values of the first and thirds of degrees)

3. Value k_d for constructions of rigid and flexible systems should be multiplied by factor 1.3, for panel buildings - on 0,8, for bases of the second category of complexity under table 2 - on 0,75, for the bases of the third categories - on 0,6 (constructions with damages of the first degree) and 0,3 (constructions with damages second and third degrees under the table 3)

level estimation of ground fluctuations, which with satisfactory accuracy for practice establish ground fluctuation parameters of the real basis depending on damping degree of a wave and distances to its source

$$A = A_0 \sqrt{r_0 / r}\, e^{-\delta(r - r_0)} \quad (1)$$

where A, A_0 - are amplitudes of a wave of vertical ground displacement on distances r and r_0 from a source, mkm;

δ - damping factor of displacement with distance from a source of the fluctuations, m^{-1}, defined by practical consideration, and for predesigning under table 2, made by results of executed researches of the Belarus region.

Calculation of the horizontal seismic loading S_{ki} enclosed to a point k and corresponding to **i** form of own fluctuations of a building or constructions, it is recommended to define under the formula (2):

$$S_{ki} = k_1 \cdot k_2 \cdot k_3 \cdot S_{0ki}, \quad (2)$$

where k_1 - coefficient, considering condition and constructive system of building, accepted at seismicity of a platform - 7 points γ=l (for constructions in which deformations are not supposed) 0,25-0,5(other cases)

k_2- factor of constructions responsibility, k_2= 0,5-1,5;

k_3 - factor considering number of storeys, defined under the formula

$$k_3 = 1 + 0{,}02H, \quad (3)$$

H- building height, m;

S_{oki} - horizontal seismic loading under the **i** form of own fluctuations of constructions.

Maintenance set forth above principles of seismic building in the Republic of Belarus is carried out on the base of developed Technical codes and the normative acts providing scientific and technical support, monitoring and experimental building of objects of the raised responsibility.

CONCLUSION

According to the general map of seismic zoning of North Eurasia GSZ-97-D (Ulomov and Shumilina, 2000) compiled for the territory of Belarus and qualifying detail map (Aizberg *et al.* 2007) maximum credible earthquake for the Republic of Belarus -7 points from the local potential earthquake zones. In this connection in RUE Institute BelNIIs special researchers on studding geodynamic impacts on the buildings were carrying out and working out methods of buildings' designing and construction.

REFERENCES

Айзберг, Р.Е., Аронов, А.Г., Гарецкий, Р.Г., Карабанов, А.К., Сафронов, О.Н., Сероглазов, Р.Р., Аронова, Т.И. 2007. Сейсмотектоническое районирование западной части Восточно-Европейской платформы. В: Землетрясения книга 1, Петрозаводск, 368-381. [Aizberg, R.E., Aronov, A.G., Garetsky, R.G.,Karabanov, A.K, Safronov, O.N., Seroglasov, R.R., Aronova, T.I. 2007. Seismogeotectonics zoning of the East European platform. In: Earthquakes, book 1, Petrozavodsk, 368-381].

Eurocode 8: Design of structures for earthquake resistance. EN 1998-1 and EN 1998-5. General rules, seismic actions, design rules for buildings, foundations and retaining structures. 2005. 197 p.

Медведев, С.В., Шпонкхоир, В., Карник, В. 1965. Шкала сейсмической интенсивности MSK-64. Москва, 1965. 11 с. [Medvedev, S.V., Shponkhoiyer, V., Karnik, V. Seismic activity scale MSK-64. Moscow, 1965. 11 p.].

Поляков, В.С. 1988. Современные методы сейсмозащиты здания. Москва, 1988. 310 с. [Polyakov V.S. 1988. Modern methods of seismic protection of the buildings. Moscow, 1988. 310 p.].

ТКП 45-3.02-108-2008 Высотные здания. Строительные нормы проектирования. Минск, 2008. 85с. [TKP 45-3.02-108-2008 High-rise buildings. Design Building Rules. Minsk, 2008. 85 p.].

ТКП 45-5.01-67-2007 Фундаменты плитные. Нормы проектирования. Минск, 2007. 136с. [TKP 45-5.01-67-2007 Slab foundation. Rules of designing. Minsk, 2007. 136 p.].

Сеськов В.Е., Кравцов В.Н. 2008. О затухании упругих волн в грунтах. В: Будівелні конструкцціі, Киев, вып, 69, 339-346. [Seskov, V.E., Krautsou, V.N. 2008. Damping of the elastic waves in soils. In: Buildings' structures, Kiev, Vol. 69, 339-346.].

Уломов В.И., Шумилина Л.С. 2000. Сейсмогеодинамика и вероятностное сейсмическое районирование Северной Евразии. В: Геофизика на рубеже веков: избр. тр. ученых ОИФЗ РАН, Москва, 2000, 216-252. [Ulomov V.I., Shumilina L.S. 2000. Seismogeodynamics and probable seismic zoning of North Eurasia. In: Geophysics at the Turn of the Century: selected works of scientists, Moscow, 2000, 216-252.].

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