Translucent Coatings of Modern Construction Systems

Abramyan S.G.

Abstract— **It is impossible to imagine modern-time cities without construction systems with translucent insulation coatings. Translucent-coated structures not only ornate any building, but also serve as a life-supporting element. Considering this, the author, based on the review of foreign and national publications, describes the main trends in the application of translucent coatings for engineering and construction of long-span, high-rise and unique buildings. Over the past ten or twelve years, the preference in the global practice of using the above construction systems has been consistently given to polycarbonate and membrane coatings based on ETFE (ethylene tetrafluoroethylene) film. The key reasons for the high popularity of these materials are: blending the boundary between the ambient environment and the inner space of a building; utmost utilization of natural light and solar energy to ensure energy efficiency of a building and maximum comfort during its operation; creation of facilities embodying a new architectural idea involving the most recent engineering achievements; ensuring multi-functionality of a building while preserving traditions and national flavor. Following the analysis of a number of studies, the paper compares the characteristics of glass units filled with aerogel with the characteristics of conventional double and triple-pane glass units, describing their benefits and drawbacks as applied to specific climatic conditions. It is noted that some studies insufficiently explore the safety of spider systems for glazing high-rise and unique buildings in seismically active regions or exposed to hurricane winds.**

Index Terms— **energy efficiency, sports facilities, translucent roofs, unique buildings.**

I. INTRODUCTION

Heightened interest to translucent coatings of construction systems and especially to translucent roofs is witnessed by the plethora of scientific publications featuring the development of materials and technologies. Thus, according to the works of the foreign scientists [1-7], upper horizontal coatings of construction systems are preferably made of polycarbonate [1-4] while membrane cushions are better formed of ETFE film [5-7]. The film made its way to the market in 1975 and, thanks to its excellent performance, has gained popularity in space science, aviation, medicine, electronics etc. In the construction sector, ETFE was first used in the late 1970s for building a zoological garden (Germany) and green houses (Japan). It is worth noting that these facilities still remain operative. However, as a protecting material for roofs and façades, ETFE film has not been widely used until recently and is a relatively new development that has become common during the last ten or twelve years. Its undeniable advantage is that membrane cushions or transparent ETFE film, when combined with reinforced concrete or steel, allows creating curvilinear and other «exclusive» shapes when engineering and creating unique, long-span and high-rise architectural projects distinguished by artistic expression and free layout. Vivid examples proving the success of ETFE are the numerous objects around the world, such as: Allianz Arena football stadium in Munich, Bird's Nest national stadium and Water Cube national aqua park in Beijing, energy-efficient inflated house in Barcelona, National Space Center in Great Britain, Han Shatyr shopping and recreation center in Astana, Fisht Olympic stadium in Sochi, national stadium in Singapore, Corinthians national stadium and Pernambuco arena in Brazil built for the 2014 Football Championship etc.

Abramyan S.G. (Abramyan Susanna Grantovna) Professor of the Department of Construction Production Technology at Volgograd State Technical University, Russia

II. MEIN TEXT

The contemporary experience of engineering and construction of unique buildings reveals the architects' aspiration for forming a comprehensive approach ensuring multi-functionality while preserving the national flavor, respecting the local specifics and complying with the environmental requirements, including environmental safety of materials. These trends were followed during the construction of the stadiums in France for the 2016 European Football Championship and are currently seen in the construction and reconstruction of the sports facilities for the forthcoming Football Championships in Russia in 2018 and in Qatar in 2022.

Notably, the construction and reconstruction of the sports facilities is nearly everywhere performed with the use of ETFE (known in Russia under the fluoroplastic 40 brand), which is an environmentally friendly and energy-efficient material.

For example, the article [8] describes the technical solutions used for the construction of a new façade for the Cuauhtemoc football stadium in Pueblo (Mexico). The brand-new ETFE façade combining three tints of blue and semitransparent white became a real decoration for the city as a whole. During the reconstruction, the stadium was expanded to host approximately 10,000 more people.

In Qatar, one of the world's richest states, the preparation for the 2022 Football Championship includes the construction of architecturally unique sports facilities with the use of innovative materials. With this in view, specialists suggest that ETFE membrane cushions will undergo major alteration and upgrading [9]. The characteristics of translucent materials and products are also reviewed by the author in [10, 11], and the innovative sliding roof design engaging membrane cushions – in [12].

The comparative analysis of various modern construction projects featuring sports facilities – both completed (over the past ten years) and current or pending – leads to the conclusion that architects see it not only as a pragmatic task of building a facility for sports competition, but also as a conceptual challenge of creating a place that will embody a new architectural idea involving the most recent engineering achievements.

This way, it becomes perfectly clear that new modified structural elements – transparent coatings based on fluoroplastic 40 – will enable a step-change in the global economy in the nearest future and will help in reaching a fundamentally new stage of technical development.

For illustration purposes, the distinctive characteristics of film made on the basis of fluoroplastic 40 (ETFE) and glass are provided in Fig. 1.

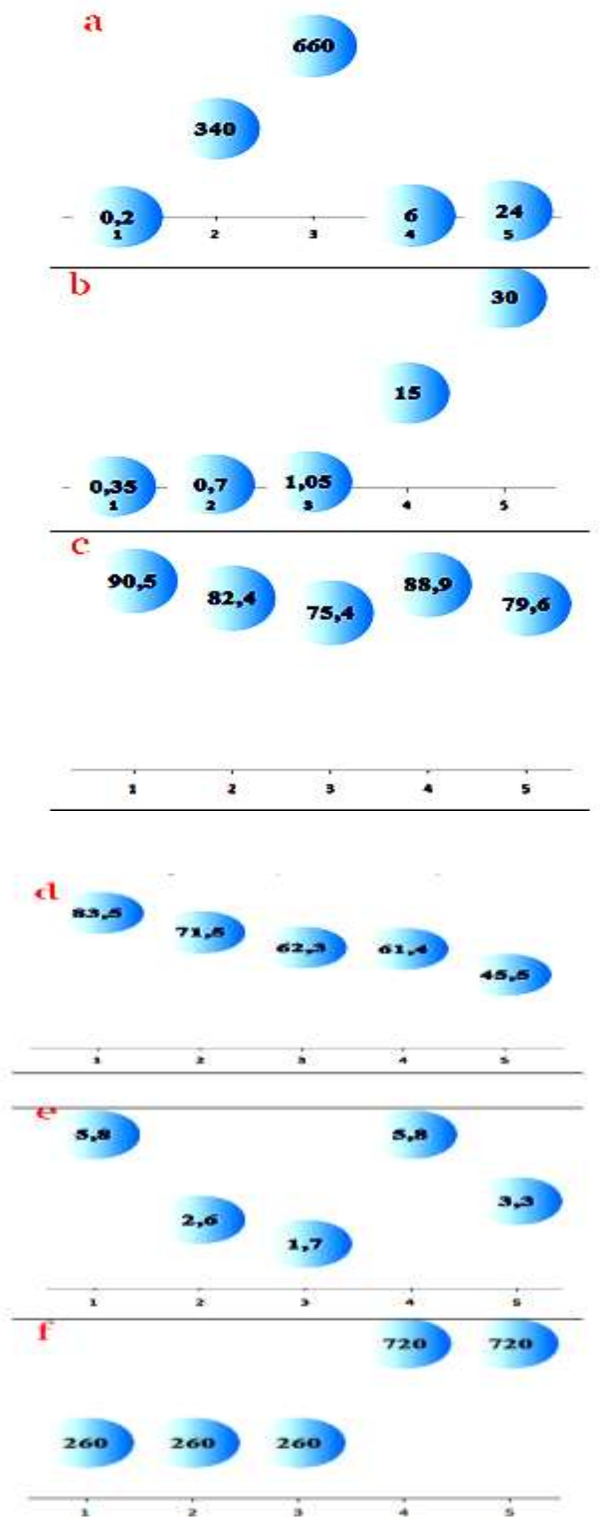

Fig. 1. – Comparative characteristics of ETFE film (1 – single-layer, 2 – double-layer, 3 – triple-layer) and glass (4 – monoglass, 5 – glass unit): a) – thickness, mm; b) – weight, kg//m^2; c) – visible light transmission capacity, %; d) – ultra-light transmission capacity, %; e) – thermal conductivity

It should be noted that the modern trends in the development of architectural solutions for buildings and structures are focused on blending the boundary between the ambient environment and the inner space of a building, which requires continuous expansion of transparent and translucent surfaces letting in the sun's light not only through façades of buildings, but also through their structural elements. Translucent vertical structures in modern buildings are no longer just a decorative element and simple filling of apertures permitting solar beams into enclosed space and protecting it against the weather. According to the foreign scientists M. Kozlovskiy, M. Kadely, Ya. Khulimki, apart from the traditional tasks, modern translucent structures are set to bear and transmit certain loads to other structural elements of construction systems. The scientific work [13] offers to replace conventional reinforced concrete and steel load beams with beams made of composite fiberglass, and cites the result of the numerical study as part of simulating brittle crushing (cracking) of glass. The study allowed developing the optimal parameters for the final fiberglass load beams.

The issues of improving energy efficiency of construction systems through smart engineering and using translucent structural elements of buildings and structures are reviewed in the works [14-17]. The authors [14] offer new principles of bulk design using translucent elements ensuring energy efficiency of buildings and helping to recover heat that was normally lost. The overview of the publications for 2004 - 2015 focusing on solar façades is provided in the works [15, 16], where the authors infer from the analysis their own classification of solar façades made of non-transparent, translucent and transparent materials. This includes façades which absorb and reflect incident solar energy, but cannot transmit «direct solar radiation into the building» [15].

In [17], the stress is laid on the fact that translucent glazing consisting of a «glass unit with aerogel» holds bright promise from the standpoint of energy efficiency. An experimental study was carried out on building façades, which showed that for the climatic conditions of Tokyo and Singapore panels consisting of a glass unit with granulated aerogel provide the «lowest energy demand» as compared with double-pane façades. On the other hand, if used with three-pane glazing, aerogel may ensure energy efficiency of buildings for the cold climate (Oslo). The authors note that the study may facilitate the development of new architectural solutions for buildings with translucent outer coatings, with a further opportunity to improve the energy efficiency by regulating the daylight.

The work [18] considers other opportunities to prevent overheating of a well-insulated building in summer. For example, with the use of adjustable façade elements where «convection around a translucent insulating panel is controlled by the vertical movement of this panel inside a double-pane glass unit». According to the experiments, the use of such façade elements may reduce the energy demand for cooling buildings in summer by up to 29.6%.

Energy efficiency of translucent façades with spider glazing was analyzed in the works [19-22]. The authors of the work [19] consider the multi-optional design of façade glazing using low-emission hardened glass and compare it with structural glazing from the inner part of façade. To determine the energy efficiency of a façade, the system was considered as a «complex thermodynamic system where, depending on the climatic and ambient conditions and indoor temperature, an efficient design was made possible with the help of various ventilation modes». The safety of spider glazing systems in high-rise and unique buildings in seismically active regions or exposed to hurricane winds is studied in the work [18], although it is fair to say that such studies are scarce. The authors [23] explored the effects of hurricane winds on silicon glues which are used in translucent façades.

Despite the fact that glass as a material is found to be quite environmentally safe, the effects of glass glare on people's health are unfortunately underexplored. The works [24-27] are focused specifically on these aspects, as well as on solutions to problems and drawbacks [27] of translucent façade systems.

III. Conclusion

The use of glass and other translucent materials for external enclosing structures in designing high-rise and unique buildings can well be recognized as a breakthrough in architecture. First, they allow creating construction systems with distinct and unique shapes, often beyond the boundaries of human imagination. Second, the utmost utilization of natural daylight and solar energy ensures the optimal energy efficiency of buildings and maximum comfort of their operation.

References

[1] Stach, E., Synthesis of form, structure and material - Design for a formoptimized lightweight membrane construction. 1st International Conference on Design and Nature, Udine, Italy. Design and Nature: Comparing Design in Nature With Science and Engineering (2002); Volume: 3; pp. 245-256.

[2] Rudorf-Witrin, W., ETFE - FOIL: a New Material for "Textile Architecture". Tensinet Symposium 2007: Ephemeral Architecture Time and Textiles. Politecnico Milano, ITALY, pp. 329-337.

[3] Reid, RL. Transparent Roof, Operable Walls Highlight Minnesota Multipurpose Stadium. Civil Engineering (2015); Volume: 85 (Iss.9); pp. 20-24.

[4] Dome concept of weather protection system for northern cities. URL: http://usirf.ru/news/12108/koncepciya-kupolnoi-sistemiklimaticheskoi-zashiti-dlya-severnix-gorodov. html

[5] Ye, XW., Luo, YW., Gao, X., Zhu, SP. Design and evaluation of a thermochromic roof system for energy saving based on poly (Nisopropylacrylamide) aqueous solution. Energy and Buildings (2012); Volume: 48; pp. 175-179. DOI: 10.1016/j.enbuild.2012.01.024

[6] Nijsse, R.: Special steel and adhesively bonded connections for glass structures. Struct. Eng. Int. 2, pp. 104–106 (2004). doi:10.2749/101686604777964125.

[7] Glass roofs. Part 1: Special glass types. URL: krovlirussia.ru/rubriki/materialy-i-texnologii/steklyannye-krovli-chast-1-specialnye-vidy-stekla.

[8] Llinares, MA., Schone, L., Weininger, F. A new ETFE facade creates a landmark for Puebla F.C. Steel Construction-Design and Research (2016); Volume: 9 (Iss 2); pp. 151-155. DOI: 10.1002/stco.201610018.

[9] Abramyan S.G., Oganesyan O.V., Farniev D.K. Translucent coatings of unique buildings and structures. «European research», 2016. № 6 (17), pp.: 29-31.

[10] Abramyan S.G., Farniev D.K. Characteristic Features of Transparent Roofing Materials. Internet-journal "NAUKOVODENIE" Vol: 8, №2 (2016) http://naukovedenie.ru/PDF/58TVN216.pdf. DOI: 10.15862/58TVN216.

[11] Abramyan S.G., Farniev D.K., Oganesyan O.V. Construction of translucent roofs. Part 1. Traditional materials and products. Inženernyj vestnik Dona, 2016, №2. URL: ivdon.ru/uploads/article/pdf/IVD_188_Abramyan.pdf_abbad35813.pdf

[12] Abramyan S.G., Farniev D.K., Oganesyan O.V. Construction of translucent roofs. Part 2. Innovative technologies and materials. Inženernyj vestnik Dona, 2017, №1. URL: http://www.ivdon.ru/uploads/article/pdf/IVD_37_Abramian.pdf_d56f40c303.pdf

[13] Kozlowski, M., Kadela, M., Hulimka, J. Numerical Investigation of Structural Behaviour of Timber-Glass Composite Beams. Procedia Engineering. 2016. Vol: 161, pp.: 990-1000. DOI: 10.1016/j.procng.2013.08.838.

[14] Akhmyarov, TA., Spiridonov, AV., Shubin, IL. New Solutions for Translucent Structures. LIGHT & ENGINEERING (2016) Vol:24 (Iss. 1), pp.: 66-72.

[15] Quesada, G., Rousse, D., Dutil, Y., Badache, M., Halle, S. A Comprehensive Review Of Solar Facades. Transparent and Translucent Solar Facades. RENEWABLE & SUSTAINABLE ENERGY REVIEWS (2012). Vol: 16 (Iss. 5), pp.: 2643-2651. DOI: 10.1016/j.rser.2012.02.059/

[16] Lai, CM., Hokoi, S. Solar Facades: A Review. BUILDING AND ENVIRONMENT (2015). Vol: 91, pp.: 152-165. DOI: 10.1016/j.buildenv.2015.01.007.

[17] Ihara, T., Gao, T., Grynning, S., Jelle, BP., Gustavsen, A. Aerogel Granulate Glazing Facades and Their Application Potential From an Energy Saving Perspective. APPLIED ENERGY (2015). Vol: 142, pp.: 179- 191. DOI: 10.1016/j.apenergy.2014.12.053.

[18] Pflug, T., Kuhn, TE., Norenberg, R., Gluck, A., Nestle, N., Maurer, C. Closed Translucent Facade Elements with Switchable U-Value-A Novel Option for Energy Management via the Facade. ENERGY AND BUILDINGS (2015). Vol: 86, pp.: 66- 73. DOI: 10.1016/j.enbuild.2014.09.082.

[19] Bugarin, M., Domazet, Z. Development of Interactive Double Skin Glass Facade with External Structural Envelope. MID-TERM CONFERENCE ON STRUCTURAL GLASS (2013). Pp. 103-112.

[20] Amadio, C., Bedon, C. Viscoelastic Spider Connectors for the Mitigation of Cable-Supported Facades Subjected to Air Blast Loading. ENGINEERING STRUCTURES (2012). Vol: 42, pp.: 190 - 200. DOI: 10.1016/j.engstruct.2012.04.023.

[21] Martins, L., Delgado, R., Camposinhos, R., Silva, T. Seismic Behaviour of Point Supported Glass Panels. CHALLENGING GLASS 3 (2012), pp.: 281 - 292. DOI: 10.3233/978-1-61499-061-1-281.

[22] Nizovtsev M.I., Terekhov V.I. Translucent structures with regulated thermal characteristics// PROBLEMELE EENRGGETICII REGIONALE 1(15) 2011. URL: https://www.allbeton.ru/upload/mediawiki/1ce/svetoprozrachnyie_konstruktsii_s_reguliruemyimi_teplovyimi_harakteristikami_nizovtsev_.pdf.

[23] Clift, CD., Hutley, P., Montes, V. Optimization Study of Advanced Structural Silicone Glazing. AEI 2017: RESILIENCE OF THE INTEGRATED BUILDING (2017). Pp: 279-284.

[24] Sun, YY., Wu, YP., Wilson, R .Analysis of the Daylight Performance of a Glazing System with Parallel Slat Transparent Insulation Material (PS-TIM). ENERGY AND BUILDINGS (2017). Volume: 139; pp. 616 - 633. DOI: 10.1016/j.enbuild.2017.01.001.

[25] Solovyov, AK., Reflective Facades and Their Influence on Illumination of Nearby Buildings. LIGHT & ENGINEERING (2017). Vol: 25 (Iss. 2), pp.: 88 - 93.

[26] Matusiak, BS.Glare from a Translucent Facade, Evaluation with an Experimental Method. SOLAR ENERGY (2013). Vol: 97, pp. 230-237. DOI: 10.1016/j.solener.2013.08.009.

[27] Chesnokov A.G. Professional approach to spider glazing. URL: http://www.glassinfo.ru/articles/2015_03_Professionalnyj_podhod_k_spajdernomu_ostekleniju.pdf

Abramyan S.G. (Abramyan Susanna Grantovna) Professor of the Department of Construction Production Technology at Volgograd State Technical University, Russia. Research Interests: technology of construction production, reconstruction of main pipelines, environmental problems in construction