doi: 10.18720/MCE.78.9

Influence of heat conducting inclusions on reliability of the system “sandwich panel – metal frame”

Влияние теплопроводных включений на надежность системы «сэндвич-панель – каркас здания»

I.S. Vedishcheva,
M.Y. Ananin,
Ural Federal University named after first president of Russia B.N. Yeltsin, Ekaterinburg, Russia
M. Al Ali,
Technical University in Košice, Košice, Slovak Republic
N.I. Vatin,
Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia

Старший преподаватель Ю.С. Ведищева, канд. техн. наук, доцент, заведующий кафедрой М.Ю. Ананьин,
Уральский федеральный университет им. первого Президента России Б.Н.Ельцина, Екатеринбург, Россия
М. Ал Али,
Технический университет г. Кошице, г. Кошице, Словакия
д-р техн. наук, профессор Н.И. Ватин,
Санкт-Петербургский политехнический университет Петра Великого, г. Санкт-Петербург, Россия

Key words: sandwich panel; temperature field; energy efficiently; thermal bridges; enclosing structures; throat forming screws; heat conduction inclusions

Ключевые слова: сэндвич-панель; температурное поле; энергоэффективность; мостики холода; ограждающая конструкция; самонарезающие винты; теплопроводные включения

Abstract. The paper presents results of numerical research oriented to the influence of heat conducting inclusions on thermo-technical properties of vertical and horizontal sandwich panels. Sandwich panels consist of flat steel sheets and thermal insulation core (from foam polystyrene, foam polyurethane and rock wool). Thread forming screws, which cross the sandwich panel through its depth, and connect the sandwich panel to frame, creates the heat conducting inclusions. The numerical analysis is carried out using software ANSYS. Based on the numerical analysis results, the regression equations for calculation of minimal values of temperature on an internal surface of a vertical sandwich panel are easy to obtain. The analysis of thermal field of the “sandwich panel – metal frame” system shown that the hygiene requirements are not complied. Proposed solution allows the reduction of the influence of heat conducting inclusions on thermo-technical properties.

Аннотация. Представлены результаты численного исследования влияния теплопроводных включений, на теплотехнические свойства стеновых сэндвич-панелей вертикальной и горизонтальной разрезки с плоскими металлическими обшивками и эффективным утеплителем (пенополистирольным, пенополиуретановыми, минераловатным). В качестве теплопроводных включений рассматриваются самонарезающие винты, прорезающие тело панели, с помощью которых панель крепится к каркасу здания – ветровым ригелями или колоннам. Исследование выполняется в программном комплексе ANSYS путем моделирования сэндвич-панели с теплопроводными включениями и, действующего на нее теплового поля, вызванного разностями температур внутреннего и наружного воздуха. По результатам проведения многофакторного численного эксперимента решены уравнения регрессии для вычисления минимального значения температуры на внутренней поверхности ограждающей конструкции, состоящей из панелей вертикальной и горизонтальной разрезки. На основе данных численного эксперимента проводится анализ температурного поля системы «сэндвич-панель – каркас здания». Показано, что при существующей системе крепления сэндвич-панели к каркасу здания не соблюдаются гигиенические требования, регламентирующие температурный перепад между внутренней поверхностью ограждающей конструкции и температурой внутреннего воздуха в помещении.

Ведищева Ю.С., Ананьин М.Ю., Ал Али М., Ватин Н.И. Влияние теплопроводных включений на надежность системы «сэндвич-панель – каркас здания» // Инженерно-строительный журнал. 2018. № 2(78). С. 116–127.

Сделаны выводы о возможности выпадения конденсата водяного пара на внутренней поверхности ограждающих конструкций общественных зданий и промышленных зданий с сухим и нормальным влажностным режимом и внутри сэндвич-панели. Предложен вариант утепления мест крепления сэндвич-панели к каркасу здания.

1. Introduction

Energy saving is the most important task for all industries, including the construction sector. Energy saving in the construction sector is a complex of measures aimed at reducing heat losses during a building life cycle. Design of energy efficient and energy saving structures is the priority area of modern science and technology. It is general knowledge, that the building loses most quantity of heat energy through windows and a ventilation system. However, the building loses more heat energy through a solid wall and roof than considered in the thermo-technical calculation.

Energy efficiency of buildings is a very topical task, so many researches and studies focus on this issue. Some authors compared the different types of external wall insulation in the context of their influence on energy saving and environmental pollution [1]. Other authors describe the tools used to analyze economic life cycle and different facade systems of the building model with the point of energy efficiently and life cycle optimization [2].

The improvement of building economic efficiency is possible by reducing the cost of heating and ventilation process by increasing resistance to heat transfer of building enclosing structures. Reducing the influence of possible “thermal bridges” on the overall resistance to heat transfer achieves these goals. Analysis and studies for the improvement of enclosing structures of buildings are presented in many researches and papers. The possibility of wetting the core of the sandwich panels due to the “thermal bridges” existing is shown in paper [3, 4]. “Thermal bridges” influence can be estimated through the thermotechnical uniformity coefficient. In paper [5] the method of thermotechnical uniformity coefficient evaluation by analyzing thermo grams are accounted. In other way this influence can be estimated through the reduced total thermal resistance [6, 7]. Evaluation of thermal performance of building envelope using the thermo vision control was carried out in papers [8–10]. In [11] non-stationary heat transfer through exterior building envelope was described. Evaluation of efficient of an energy-saving measures complex was carried out in [12–14].

Generally, the cause of heat loss and humidification of wall elements is due to the presence of heat conducting inclusions, which are inevitable for some types of wall. Sandwich panels are in active use as enclosing constructions for different types of buildings [15]. The sandwich panel is a multi-layer structural element consisting of thermal insulation located between flat or profiled metal sheets and fixed to the buildings bearing structure by means of threaded screws. These screws often create “thermal bridges” cross the sandwich panel system.

Thermo-technical properties of sandwich panels are a subject of researches carried out by many authors [13, 16–19]. Mentioned researches focus on the thermo-technical bending analysis of sandwich panels, their non-linear thermal behavior and temperature-bending dependence, using various methods and mathematical equations.

Action of external load together with temperature changes of the surrounding environment affect the global bearing capacity of the structure, so the thermo-technical properties of individual structural elements, including enclosing constructions, can also influence this bearing capacity. The research of some authors was oriented to polymer foam core exposed to elevated temperature and possible changes of sandwich structures behavior, other authors dealt with sandwich panels subjected to compression and/or bending load from the stability and serviceability point of view [20–23]. Therefore, loads and temperature changes are essential in the analysis of sandwich panels’ behavior.

The development of computer technologies and software environments allow the researchers for more sophisticated and effective approaches for the solving of challenge tasks and simulations using different FEM based mathematical models and numerical analysis. Researchers, using the mentioned possibilities, can create 3D models of composite structures consisting of materials with different properties in various directions and investigate the behavior of individual layers and elements from the thermal, deflection, stiffness point of view and so on [24–31].

The purpose of this research is the numerical study of thermo-technical behavior of sandwich panels consisting of two flat steel sheets and core from different materials, such as polystyrene foam, polyurethane foam and rock wool and the investigation of the sandwich panels and frame elements humidity due to the external and internal temperature differences. The thermo-technical behavior is undergoing investigation using CAE-software with thermal field simulation.

The objective of this study is to investigate the influence of fasteners on the thermal behavior of the wall of the sandwich panels.

2. Methods

2.1. Types of sandwich panels

The numerical analysis of this study covered two types of sandwich panels: the first type named vertical sandwich panel has vertical size more than horizontal size (Figure 1) and the second type named horizontal sandwich panel has vertical size less than horizontal size (Figure 2).

The two types of sandwich panels mounting are existed: with use of vapor and vibration barrier films and without it. For this research we considered the variant without vapor and vibration barrier films.

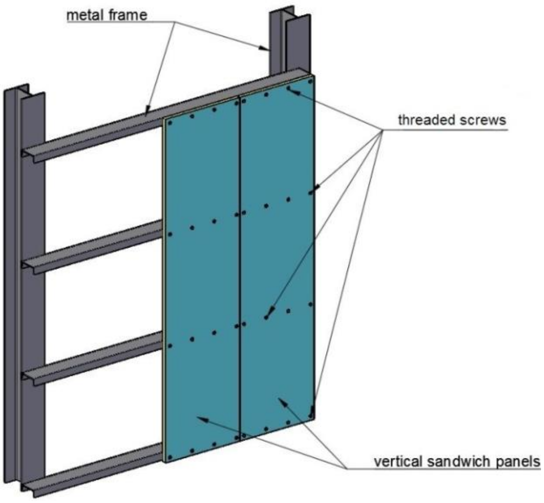

Figure 1. Vertical sandwich panels

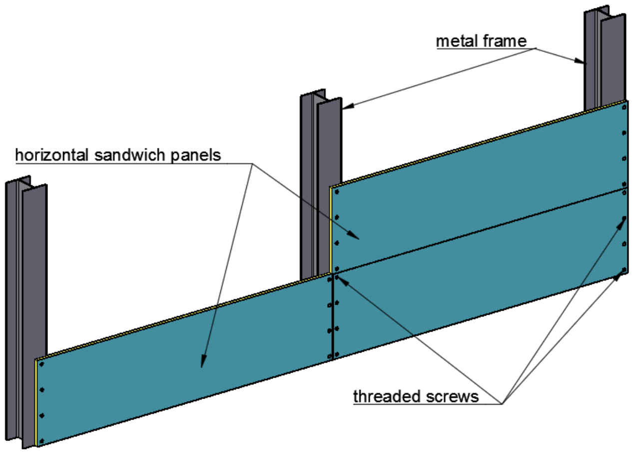

Figure 2. Horizontal sandwich panels

2.2. The determination of the temperature values and humidity near fastening elements

Sandwich panels were: width 1.2 m; length 6.0 m; steel sheet's thickness 0.5 mm; core thickness 100 mm. Next analysis covers a part of sandwich wall structure at the connection of the four sandwich panels. Dimensions of considered part were 1.2 x 6.0 m (Figure 3).

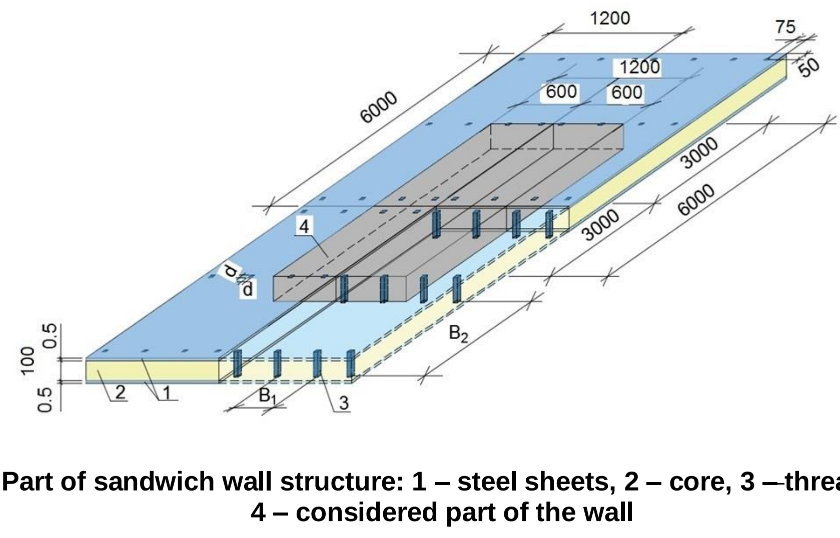

Figure 3. Part of sandwich wall structure: 1 – steel sheets, 2 – core, 3 –threaded screws, 4 – considered part of the wall

Ведищева Ю.С., Ананьин М.Ю., Ал Али М., Ватин Н.И. Влияние теплопроводных включений на надежность системы «сэндвич-панель – каркас здания» // Инженерно-строительный журнал. 2018. № 2(78). С. 116–127.

The transverse spacing of the screws (B_1) was 350 mm for both types of the sandwich panels (vertical and horizontal sandwich panels). The longitudinal spacing of the screws (B_2) for vertical sandwich panels was 1475 mm, for horizontal sandwich panels as 6000 mm.

The joint profile between panels wasn't included in this numerical model because its thermal losses are less then thermal losses through screws.

Presented values of different coefficients in this paper are actual for the time of numerical analysis and modeling realization. The model of sandwich panel core was isotropic material. This materials' characteristics are: heat transfer coefficient (λ_c); 0.05 W/(m·°C); specific heat 0.84 J/(kg·°C); density 110 kg/m^3. For the purpose of finite element mesh simplification, the connecting screws had square cross-sections without threads. This solution does not affect the target or expected results of the thermo-technical analysis. Screws had dimension 6.3 mm and density 7871 kg/m^3 for steel [32] in the model. The heat transfer coefficient of the screws was 44.5 W/(m·°C). Material of steel sheets had the following characteristics: heat transfer coefficient 58 W/(m·°C); specific heat 482 J/(kg·°C); density 7871 kg/m^3.

ANSYS 3D finite elements model consisted of 8-nodes thermal solid elements (SOLID 70). Temperature was the only element's degree of freedom in each node. The Boolean operations had allowed creating the correct model. The model's finite hexagon sweep-elements mesh size was 0.014 m.

Convection on areas is the boundary condition. The external sheet had following parameters: film coefficient 23 W/(m^3·°C), bulk temperature -35 °C. The internal sheet parameters were: film coefficient 8.7 W/(m^3·°C), bulk temperature 20 °C.

The ANSYS temperature field calculation gave node temperature volumes on the external surface (τ_{ext}) and internal surface (τ_{int}) of the structure and gave possibility do determine the average value of the temperatures for both of them.

In addition, temperature data processing included comparison of the:

- minimal values of temperatures on the internal surface of sandwich panel ($\tau_{\text{int}}^{\min}$) and the dew point temperatures for two types of buildings: industrial buildings and public places;
- the indoor temperature and temperature of the internal surface of enclosing structure with the temperature gradient, given by Russian national standard [33].

The temperature field near the lengthwise connecting screws also underwent investigation.

2.3. The numerical complete multivariable analysis

Complete multivariable analysis resulted in the equations for calculation of minimal values of temperature on the internal surface of vertical and horizontal sandwich panels. Sandwich panels had: flat steel sheets of thickness 0.5 mm; varied core thickness from 50 mm to 150 mm; heat transfer coefficient from 0.03 W/(m·°C) to 0.05 W/(m·°C). The transverse spacing between screws (B_1) varied from 300 to 500 mm and the longitudinal spacing between screws (B_2) varied from 1500 to 6000 mm. Because the diameter of screws (*d*) may be also varied according to environment conditions, their diameters in the analysis varied from 5 to 8 mm.

3. Results and Discussion

The numerical analysis results gave the regression equations for the calculation of minimal values of temperature on the internal surfaces of vertical and horizontal sandwich panels:

$$\tau_{\text{int},vert}^{\min} = 21.372 - 1.527 \cdot d - 24.812 \cdot \lambda_c \qquad (1)$$

$$\tau_{\text{int},hor}^{\min} = 21.36 - 1.522 \cdot d - 25.125 \cdot \lambda_c \qquad (2)$$

Differences between calculation results according to equations 1 and 2 are minimal from the accuracy point of view, so the both equations are applicable.

Figures 4, 5 illustrate the area near fitting location of the sandwich panel to metal frame for analysis of the temperature values on the internal surface of panel (Figures 4, 5).

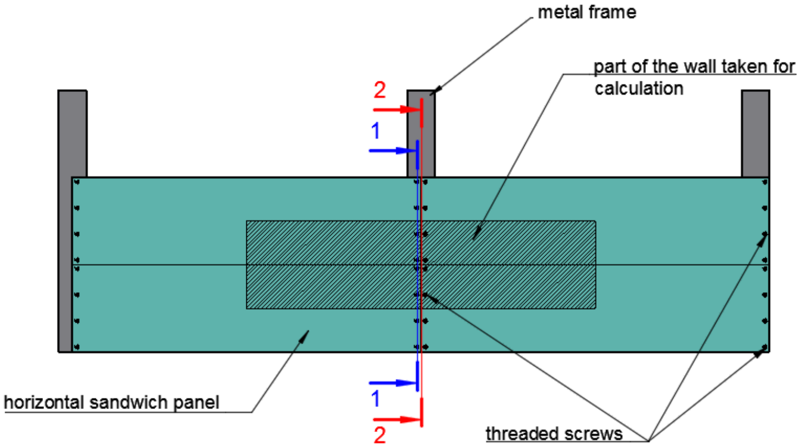

Figure 4. The cross sections of the horizontal sandwich panels with the area for analysis

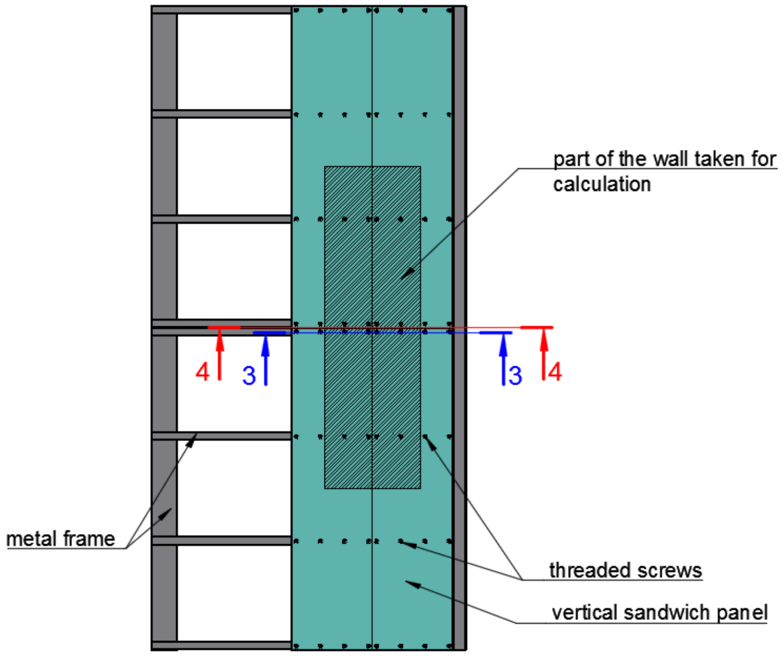

Figure 5. The cross sections of the vertical sandwich panels adopted for analysis

The diagrams (Figures 6–9) show temperature distribution (t, °C) by panel length direction (L, meters). The diagrams demonstrate that the thermal gradient exceeds the requirements values for some types of buildings:

- the green lines ($\Delta t_n(1)$) in the diagrams show the lower limit of standard temperature gradient between internal surface of enclosing structure and indoor temperature for public buildings;
- the red lines ($\Delta t_n(2)$) show the lower limit of standard temperature gradient between internal surface of enclosing and indoor temperature for industrial buildings of dry and normal humidity conditions;
- the violet lines represent the dew point temperature (t_d) for values of relative humidity (φ) 60 %;
- the blue lines represent the dew point temperature (t_d) for values of relative humidity (φ) 55 %;
- the orange lines represent the dew point temperature (t_d) for values of relative humidity (φ) 50 %.

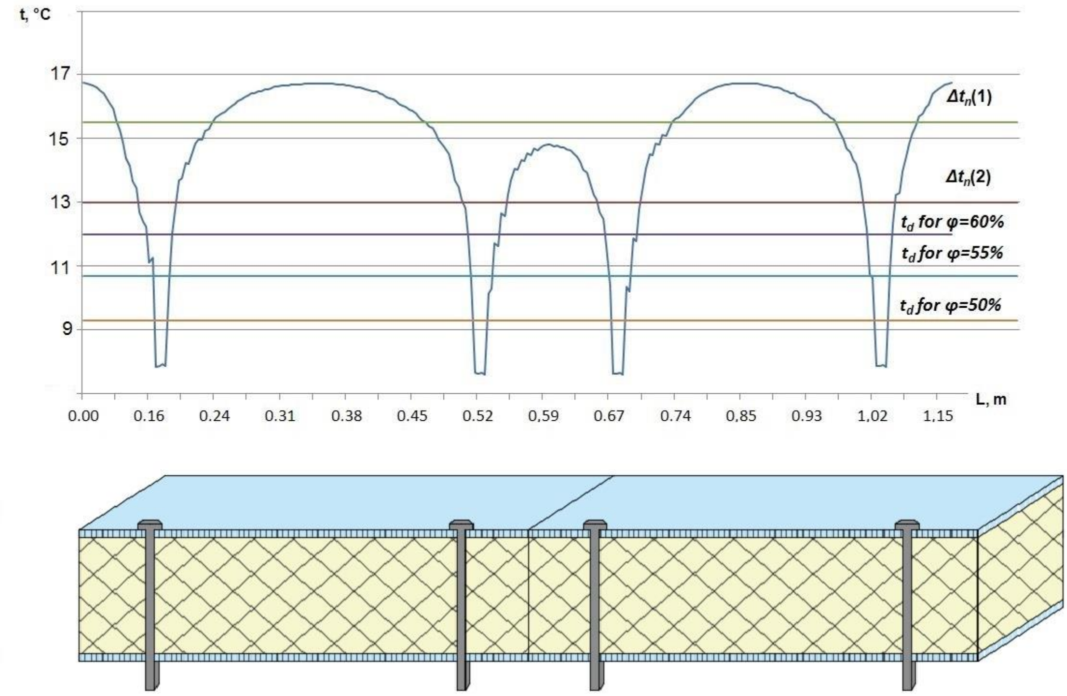

Figure 6. Diagram of temperature distribution along the internal surface of the horizontal sandwich panel. The cross section passes through the screws (section 1-1 Figure 4)

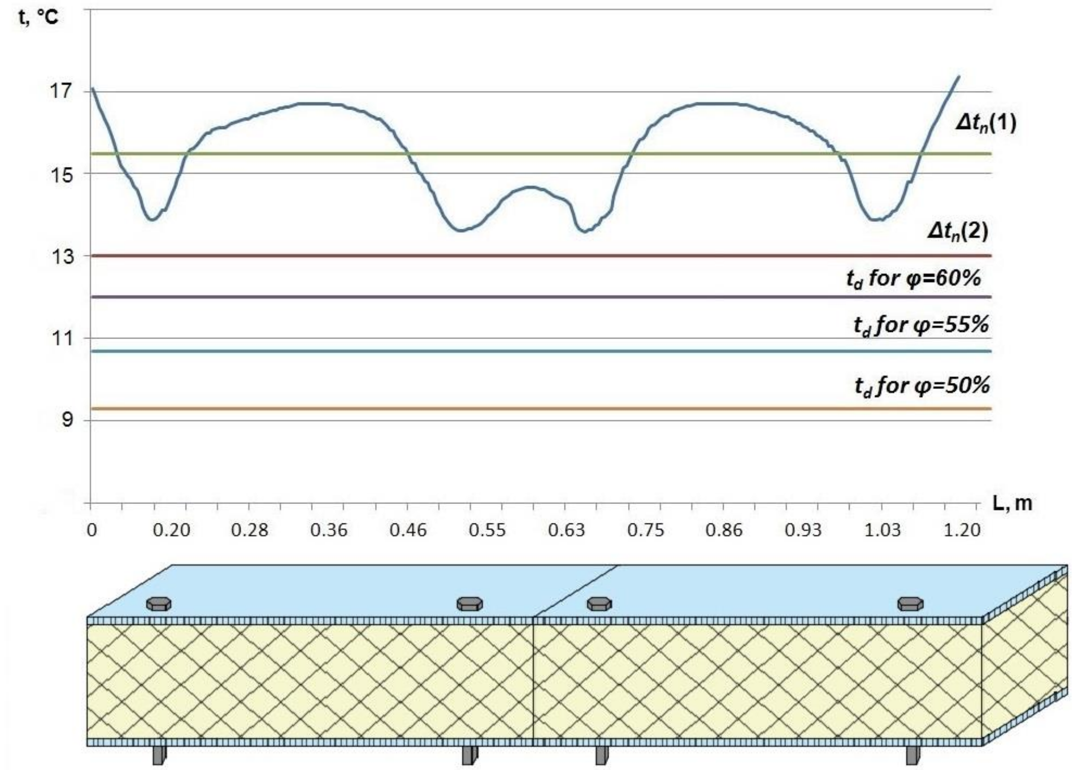

Figure 7. Diagram of temperature distribution along the internal surface of the horizontal sandwich panel. The cross section is at the junction of sandwich panels (section 2-2 Figure 4)

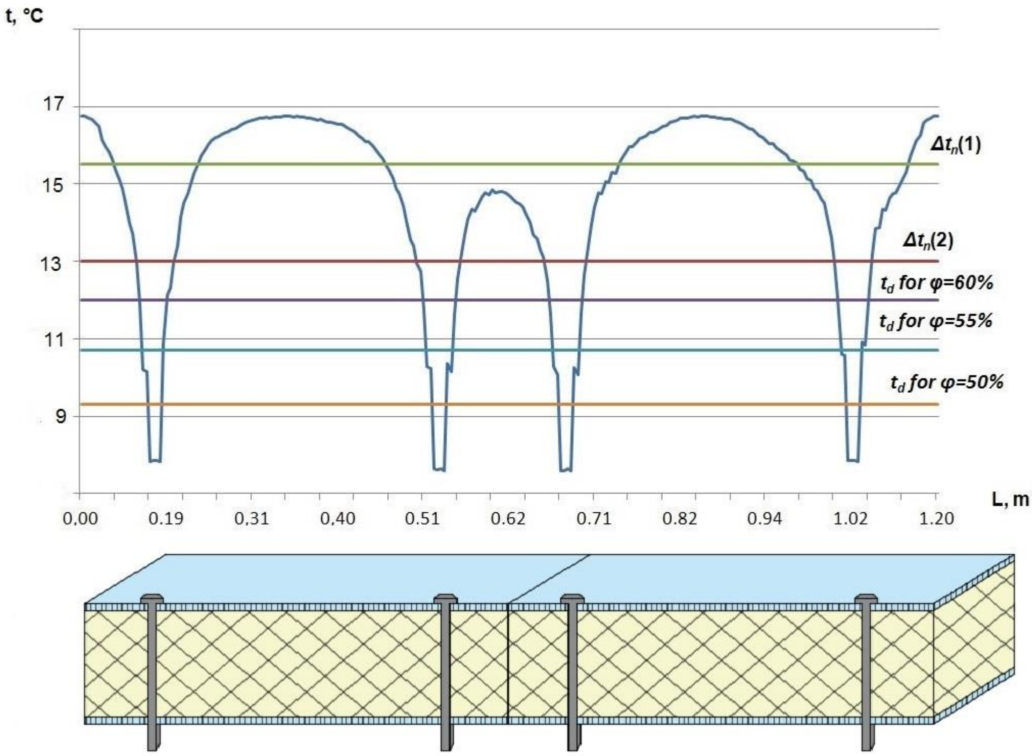

Figure 8. Diagram of temperature distribution along the internal surface of the vertical sandwich panel. The cross section passes through the screws (section 3-3 Figure 5)

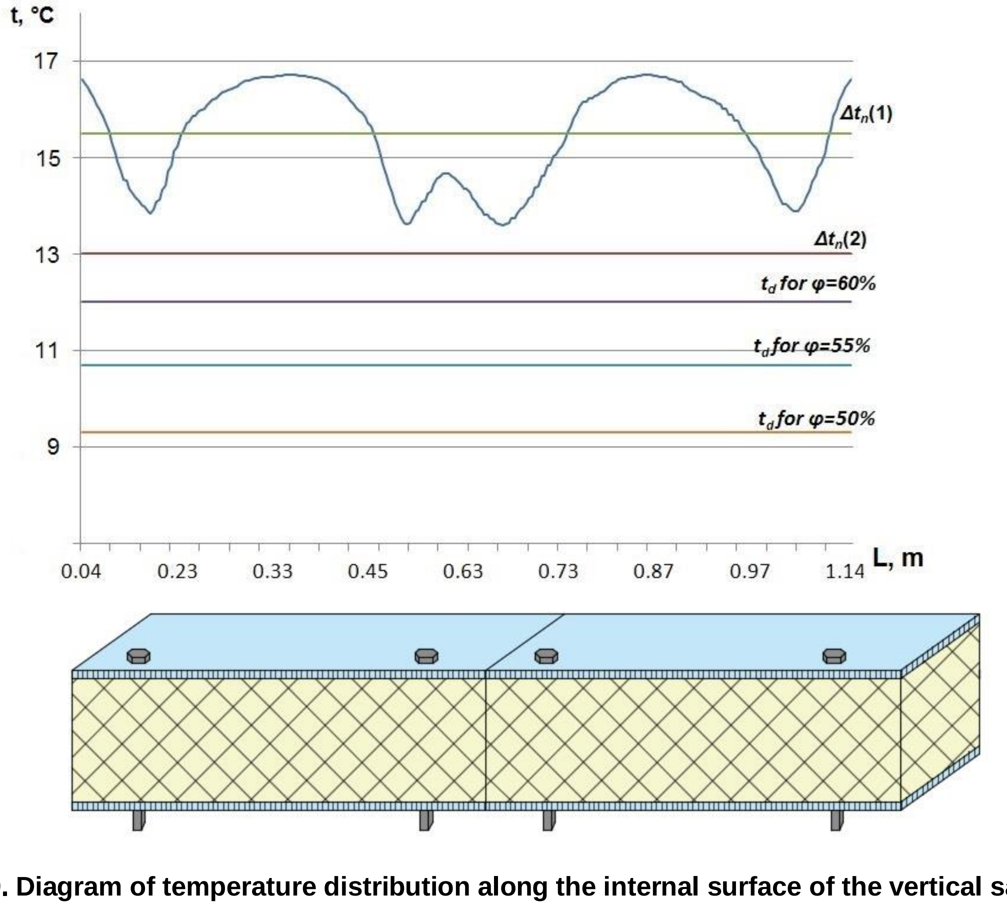

Figure 9. Diagram of temperature distribution along the internal surface of the vertical sandwich panel. The cross section is at the junction of sandwich panels (section 4-4 Figure 5)

The analysis of the thermal field on the internal surface of sandwich panels showed that the thermal gradient between internal surface of enclosing structure, in the case of both horizontal and vertical sandwich panels, and indoor temperatures exceed the nominal values [33] at the bonding locations of panels to frame for public buildings and for industrial buildings of dry and normal humidity conditions.

Obtained results show that temperature on an internal surface of an enclosure structure is less than the dew point temperature for considered parameters – the indoor temperature (t_{int} = 20 °C) and for the relative humidity is φ = 50 %, φ = 55 % and φ = 60 %. If the value of element temperature less than dew point temperature on the surface of the element than condensation of water vapor is possible. So, condensate formation is possible on an internal surface of enclosure structures.

Based on the results obtained by numerical simulations, following facts became clear: condensate formation is possible on the internal surface of sandwich panels bonded to the frame due to existence of thermally conductive elements. Areas with temperatures less than the rated temperature tend to appear on sandwich panel surface. The width of these areas was 62 mm for industrial buildings of dry and normal humidity indoor conditions, and the width of these areas can achieve 200 mm for public buildings with indoor temperature less than the rated.

In order to eliminate the negative influence of possible condensation on the internal surface of enclosure structure we should use the corrosion protection of fitting locations of sandwich panels to metal frame.

Diagrams for analyzing the humidity conditions of the area near the screws, distribution of temperature values along the screw for places on the surface of screw and near it (Figures 10, 11).

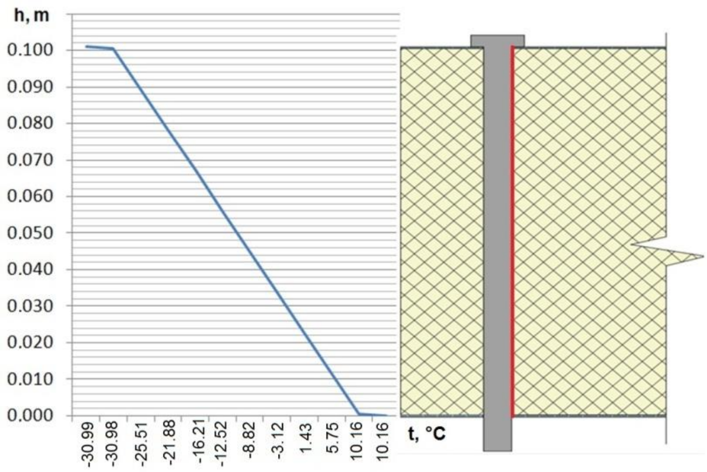

Figure 10. The distribution diagram of temperature values along the screw on surface of screw

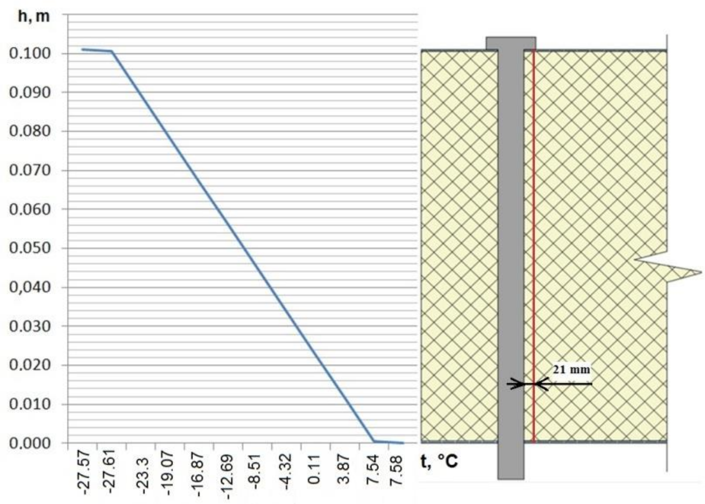

Figure 11. The distribution diagram of temperature values along the screw near screw

The diagrams show that the temperature values at areas located near the screw are less than the dew point temperatures. Therefore, the humidification process at areas located near the screws can be monitored. It follows that besides the internal surfaces, insulation cores of the sandwich panels can be exposed to humidification process. This process results in the reduction of thermal insulation and also in the reduction of sandwich panel life-cycle, because the insulation core is moisture-laden and the steel sheets are exposed to the corrosion process. In addition screws and frame are also exposed to the corrosion process.

Therefore, reduction of thermal insulation properties of sandwich panels, corrosion process of screws, sandwich panel steel sheets and frame, as well as the exceeding of temperature gradient result in the reduction of the construction life-cycle and comfort of people living in the building. Usage of additional thermal insulation at connection locations of sandwich panels to frame by mounting of panel strips with an additional thermal insulation layer may solve the above-mentioned problem. The new type of joint thermal insulation is necessary. One possibility is that we can use a thermal insulation tube when we screw fasteners into sandwich panel (Figure 12).

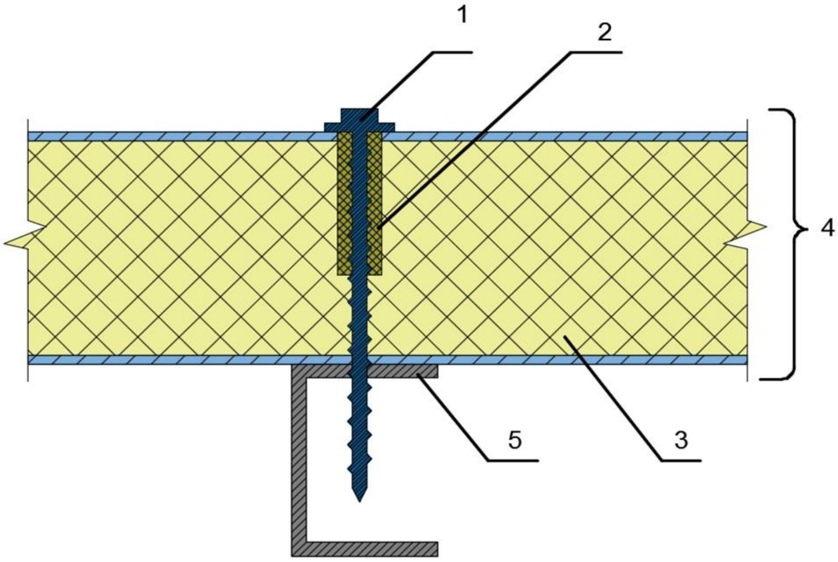

Figure 12. The alternative to thermal insulation at connection location of a sandwich panel to frame: 1 – screw, 2 – thermal insulation tube, 3 – sandwich panel core, 4 – sandwich panel, 5 – frame element

Nylon and plastic expansion bolt shield can work like a thermal insulation tube. According to thermo-technical analysis of sandwich panel with plastic expansion bolt shield thermal insulation tube the temperature gradient between the internal surface of the enclosing structure (the sandwich panel) and the indoor temperature does not exceed the standard temperature gradient near the bolt. In this case, the temperature values near the screw are less than the dew point temperature. This solution is useful to prevent condensate formation in the core near the screw.

Influence of the influence of heat conducting inclusions on thermal properties of sandwich panels can estimate with use reduced total thermal resistance. Author of follow papers [7, 30] had simulated sandwich panel thermo behavior with use other software and obtained thermal fields of roof sandwich panels with screw connections. The results shown that thread forming screws reduce the overall thermal resistance of sandwich panel. Influence of heat conducting inclusions was estimate through the reduced total thermal resistance without temperature values on constructions. This method is useful for practical evaluation by designers and engineers. Both of these methods should be considered together for different engineers tasks.

4. Conclusions

Following the above presented results and analysis, gave possibility to make following conclusions:

1. The equation for calculation of minimal values of temperature on an internal surface of a vertical sandwich panel was obtained.

2. The thermal field of a blank wall from vertical and horizontal sandwich panels was analyzed.
3. For affixing sandwich panels to a frame with thread forming screws with diameter 6.3 mm, the Russian building code hygiene requirements are not complied:
   3.1. The temperature gradient between an internal surface of an enclosure structure on affixing locations of a sandwich panel to a frame and the indoor temperature are more than requirements for public buildings and for industrial buildings with dry and normal humidity conditions.
   3.2. The temperature on internal surfaces of an enclosure structure is less than the dew point temperature in the fastening points of the sandwich panel to the frame.
4. Thermal insulating effectiveness of sandwich panels is less than designed and sandwich panel steel sheets and thread forming screws and frame elements are in danger of corrosion process. These facts reduce the life cycle of these constructions.
5. Proposed to use nylon and plastic expansion bolt shield like a thermal insulation tube, which makes it possible to reduce the influence of heat conducting inclusions on thermal technical properties.

5. Acknowledgement

This paper is supported by the project ITMS "26220220124": "Research into Filler-Beam Deck Bridges with Encased Beams of Modified Sections".

References

1. Vilcekova S., Sedlakova A., Kridlova Burdova E., Vojtus Ja. Comparison of environmental and energy performance of exterior walls. *Energy Procedia: 6th International Building Physics Conference, IBPC 2015*. 2015. Vol. 78. Pp. 231–236.
2. Kovacic I., Waltenbereger L., Gourlis G. Tool for life cycle analysis of facade-systems for industrial buildings. *Journal of Cleaner Production.* 2016. Vol. 130. Pp. 260–272.
3. Ananin M.Yu., Vedishcheva I.S.. Chislennyye issledovaniya teplotekhnicheskikh svoystv sendvich-paneley [The numerical study of teplotechnical properties of sandwich panels]. *Stroitelstvo i obrazovaniye*. 2011. No. 14. Pp. 34–39. (rus)
4. Ananin M.Yu., Vedishcheva I.S. Mnogofaktornoye chislennoye issledovaniye teplotekhnicheskikh svoystv sendvich-paneley vertikalnoy razrezki [Multiply-factor numerical research of heat engineering properties sandwich panels of vertical position]. *Akademicheskiy vestnik UralNIIproyekt RAASN.* 2012. No. 2. Pp. 80–84. (rus)
5. Vasilyev G.P., Lichman V.A., Yurchenko I.A., Kolesova M.V. Method of evaluation of thermotechnical uniformity coefficient by analyzing thermograms. *Magazine of Civil Engineering.* 2016. No. 6. Pp. 60–67.
6. Gaysin A.M., Samokhodova S.Yu., Paymetkina A.Yu., Nedoseko I.V. Cravnitelnaya otsenka udelnykh teplopoter cherez elementy naruzhnykh sten zhilykh zdaniy, opredelyayemykh po razlichnym metodikam [Comparative assessment of specific heat losses through elements of external wallsof residential buildings determined by different methods]. *Zhilishchnoye stroitelstvo.* 2016. No. 5. Pp. 36–39. (rus)
7. Tusnina O.A. Otsenka teplozashchitnykh svoystv pokrytiy iz sendvich-paneley [Assessing the heat-shielding properties of sandwich panel surfaces]. *Science Review.* 2013. No. 9. Pp. 269–274.
8. Korniyenko S.V., Vatin N.I., Gorshkov A.S. Thermophysical field testing of residential buildings made of autoclaved aerated concrete blocks. *Magazine of Civil Engineering*. 2016. No. 4. Pp. 10–25.
9. Korniyenko S.V. Mnogofaktornaya otsenka teplovogo rezhima v elementakh obolochki zdaniya [Multifactorial forecast of thermal behavior in building envelope elements]. *Magazine of Civil Engineering.* 2014. No. 8(52). Pp. 25–37. (rus)
10. Korniyenko S. Evaluation of thermal performance of residential building envelope. *Procedia Engineering.* 2015.

Литература

1. Vilcekova S., Sedlakova A., Kridlova Burdova E., Vojtus Ja. Comparison of environmental and energy performance of exterior walls // Energy Procedia: 6th International Building Physics Conference, IBPC 2015. 2015. Vol. 78. Pp. 231–236. https://doi.org/10.1016/j.egypro.2015.11.617
2. Kovacic, I., Waltenbereger, L., Gourlis, G. Tool for life cycle analysis of facade-systems for industrial buildings // Journal of Cleaner Production. 2016. Vol. 130. Pp. 260–272. https://doi.org/10.1016/j.jclepro.2015.10.063
3. Ананьин М.Ю., Ведищева Ю.С.. Численные исследования теплотехнических свойств сэндвич-панелей // Строительство и образование. 2011. № 14. С. 34–39.
4. Ананьин М.Ю., Ведищева Ю.С.. Многофакторное численное исследование теплотехнических свойств сэндвич-панелей вертикальной разрезки. // Академический вестник УралНИИпроект РААСН. 2012. №2. С. 80–84.
5. Васильев Г.П., Личман В.А., Юрченко И.А., Колесова М.В. Метод оценки коэффициента теплотехнической однородности из анализа термограмм // Инженерно-строительный журнал. 2016. № 6(66). С. 60–67. DOI: 10.5862/MCE.66.6
6. Гайсин А.М., Самоходова С.Ю., Пайметькина А.Ю., Недосеко И.В. Сравнительная оценка удельных теплопотерь через элементы наружных стен жилых зданий, определяемых по различным методикам // Жилищное строительство. 2016. № 5. С. 36–39.
7. Туснина О.А. Оценка теплозащитных свойств покрытий из сэндвич-панелей // Научное обозрение. 2013. № 9. С. 269–274.
8. Корниенко С.В., Ватин Н.И., Горшков А.С. Натурные теплофизические испытания жилых зданий из газобетонных блоков // Инженерно-строительный журнал. 2016. № 4(64). С. 10–25. DOI: 10.5862/MCE.64.2
9. Корниенко С.В. Многофакторная оценка теплового режима в элементах оболочки здания // Инженерно-строительный журнал. 2014. № 8(52). С. 25–37.
10. Korniyenko S. Evaluation of thermal performance of residential building envelope // Procedia Engineering. 2015. № 117(1). Pp. 191–196.
11. Korniyenko S.V. The experimental analysis and calculative assessment of building energy efficiency // Applied Mechanics and Materials. 2014. № 618. Pp. 509–513.
12. Vatin N., Gorshkov A., Nemova D., Tarasova D. Energy efficiency of facades at major repairs of buildings // Applied

No. 117(1). Pp. 191–196.

11. Gorshkov A.S., Rymkevich P.P. Diagrammnyy metod opisaniya protsessa nestatsionarnoy teploperedachi [A diagram method of describing the process of non-stationary heat transfer]. *Magazine of Civil Engineering.* 2015. No. 8. Pp. 68–82. (rus)
12. Vatin N., Gorshkov A., Nemova D., Tarasova D. Energy efficiency of facades at major repairs of buildings. *Applied Mechanics and Materials.* 2014. No. 633-634. Pp. 991–996.
13. Korniyenko S.V. The experimental analysis and calculative assessment of building energy efficiency. *Applied Mechanics and Materials.* 2014. No. 618. Pp. 509–513.
14. Meyntser S.V. Bystrovozvodimyye zdaniya promyshlennogo naznacheniya [Prefabricated building of industrial purpose]. *Magazine of Civil Engineering.* 2009. No. 6. Pp. 9–11. (rus)
15. Li D., Deng Z., Chen G., Xiao H., Zhu L. Thermomechanical bending analysis of sandwich plates with both functionally graded face sheets and functionally graded core. *Composite Structures.* 2017. No. 1692017. Pp. 29–41.
16. Frostig Y., Thomsen O.T. Non-linear thermal response of sandwich panels with a flexible core and temperature dependent mechanical properties. *Composites: Part B.* 2008. Vol. 39. Pp. 165–184.
17. Frostig Y, Thomsen O.T. Non-linear behaviour of foam cored curved sandwich panels subjected to thermo-mechanical loading. *ICCM-17.* Edinburgh, Scotland. 2009.
18. Frostig Y., Thomsen O.T. Non-linear thermo-mechanical behaviour of delaminated curved sandwich panels with a compliant core. *International Journal of Solids and Structures.* 2011. Vol. 48. Pp. 2218–2237.
19. Zhang S. *Thermomechanical interaction effects in polymer foam cored sandwich structures*: PhD Thesis, University of Southampton, name of the University School or Department, 2013.
20. Al Ali M., Tomko M., Demjan I. Experimental investigation and theoretical analysis of polystyrene panels with load bearing thin-walled cold-formed elements. *Applied Mechanics and Materials: Trends in Statics and Dynamics of Constructions.* Pfaffikon: Trans Tech Publications Ltd. 2015. Vol. 769. Pp. 145–152.
21. Sedláková A., et al. Optimal construction solutions of the external wall structures. *Interdisciplinarity in Theory and Practice.* 2015. No. 8. Pp. 157–163.
22. Lobanov D.S., Vildeman V.E., Babin A.D., Grinev M.A. Experimental research into the effect of external actions and polluting environments on the serviceablity of fiber-reinforced polymer composite materials. *Mechanics of Composite Materials.* 2015. No. 1(51). Pp. 69–76.
23. Ćetković M., Vuksanovic G. Thermal analysis of laminated composite and sandwich plate using layer wise finite element. *Construction of Unique Buildings and Structures.* 2014. No. 5(20). Pp. 7–14.
24. Petrov S.M. *Nesushchaya sposobnost i deformativnost trekhsloynykh paneley s obshivkami iz metallicheskikh i kompozitsionnykh materialov i legkimi zapolnitelyami* [Bearing capacity and deformation of sandwich panels with skins of metal and composite materials and light fillers]: PhD Thesis. Moscow State University of Civil Engineering. Moscow, 2013. (rus)
25. Seemann R., Krause D. Numerical modelling of nomex honeycomb cores for detailed analyses of sandwich panel joints. *11th World Congress on Computational Mechanics, WCCM 2014, 5th European Conference on Computational Mechanics, ECCM 2014 and 6th European Conference on Computational Fluid Dynamics, ECFD 2014.* 2014. Pp. 2547–2558.

Mechanics and Materials. 2014. № 633-634. Pp. 991–996.

13. Горшков А. С., Рымкевич П. П. Диаграммный метод описания процесса нестационарной теплопередачи // Инженерно-строительный журнал. 2015. № 8(60). С. 68–82. DOI: 10.5862/MCE.60.8
14. Мейнцер С.В. Быстровозводимые здания промышленного назначения. // Инженерно-строительный журнал. 2009. № 6 С. 9–11.
15. Li D., Deng Z., Chen G., Xiao H., Zhu L. Thermomechanical bending analysis of sandwich plates with both functionally graded face sheets and functionally graded core // Composite Structures. 2017. № 1692017. Pp. 29–41.
16. Frostig Y., Thomsen O.T. Non-linear thermal response of sandwich panels with a flexible core and temperature dependent mechanical properties // Composites: Part B. 2008. Vol. 39. Pp. 165–184.
17. Frostig Y., Thomsen O.T. Non-linear behaviour of foam cored curved sandwich panels subjected to thermo-mechanical loading // ICCM-17 Edinburgh, Scotland. 2009.
18. Frostig Y., Thomsen O.T. Non-linear thermo-mechanical behaviour of delaminated curved sandwich panels with a compliant core // International Journal of Solids and Structures. 2011. Vol. 48. Pp. 2218–2237.
19. Zhang S. Thermomechanical interaction effects in polymer foam cored sandwich structures: PhD Thesis, University of Southampton, name of the University School or Department, 2013.
20. Al Ali M., Tomko M., Demjan I. Experimental investigation and theoretical analysis of polystyrene panels with load bearing thin-walled cold-formed elements // Applied Mechanics and Materials: Trends in Statics and Dynamics of Constructions. Pfaffikon: Trans Tech Publications Ltd. 2015. Vol. 769. Pp. 145–152.
21. Sedláková A., et al. Optimal construction solutions of the external wall structures // Interdisciplinarity in Theory and Practice. 2015. № 8. Pp. 157–163.
22. Lobanov D.S., Vildeman V.E., Babin A.D., Grinev M.A. Experimental research into the effect of external actions and polluting environments on the serviceablity of fiber-reinforced polymer composite materials // Mechanics of Composite Materials. 2015. № 1(51). Pp. 69–76.
23. Четкович М., Вуксанович Дж. Термический анализ ламинированных композитных и сэндвич-панелей с применением многослойного конечного элемента // Строительство уникальных зданий и сооружений. 2014. № 5(20). С. 7–14. (англ.)
24. Петров С.М. Несущая способность и деформативность трехслойных панелей с обшивками из металлических и композиционных материалов и легкими заполнителями: дисс. Москва. канд. техн. наук. Московский государственный строительный университет, Москва, 2013.
25. Seemann R., Krause D. Numerical modelling of nomex honeycomb cores for detailed analyses of sandwich panel joints // 11th World Congress on Computational Mechanics, WCCM 2014, 5th European Conference on Computational Mechanics, ECCM 2014 and 6th European Conference on Computational Fluid Dynamics, ECFD 2014. 2014. Pp. 2547–2558.
26. Cernescu A., Romanoff J., Remes H., Faur N., Jelovica J. Equivalent mechanical properties for cylindrical cell honeycomb core structure // Composite Structures. 2014. № 108(1). Pp. 866–875.
27. Горшков А.С., Рымкевич П.П., Ватин Н.И. Моделирование процессов нестационарного переноса тепла в стеновых конструкциях из газобетонных блоков // Инженерно-строительный журнал. 2014. № 8(52). С. 38–48.

Ведищева Ю.С., Ананьин М.Ю., Ал Али М., Ватин Н.И. Влияние теплопроводных включений на надежность системы «сэндвич-панель – каркас здания» // Инженерно-строительный журнал. 2018. № 2(78). С. 116–127.

26. Cernescu A., Romanoff J., Remes H., Faur N., Jelovica J. Equivalent mechanical properties for cylindrical cell honeycomb core structure. *Composite Structures.* 2014. No. 1(108). Pp. 866–875.
27. Gorshkov A.S., Rymkevich P.P., Vatin N.I. Simulation of non-stationary heat transfer processes in autoclaved aerated concrete-walls. *Magazine of Civil Engineering.* 2014. No. 8(52). Pp. 38–48.
28. Tusnina O. A finite element analysis of cold-formed Z-purlins supported by sandwich panels. *Applied Mechanics and Materials.* 2014. Vol. 467. Pp. 398–403.
29. Tusnina O. An influence of the mesh size on the results of finite element analysis of Z-purlins supported by sandwich panels. *Applied Mechanics and Materials.* 2014. Vol. 475–476. Pp. 1483–1486.
30. Tusnina O.A., Tusnin A.R. Programmnyy kompleks dlya teplotekhnicheskogo rascheta stroitelnykh konstruktsiy [A computing program for the thermal analysis of building structures]. *Promyshlennoye i grazhdanskoye stroitelstvo* [Industrial and Civil Engineering]. 2014. No. 4. Pp. 76–79. (rus)
31. *Tekhnicheskiy katalog. Stroitelnyye trekhsloynyye sendvich-paneli. Chast 1. Tekhnicheskiye kharakteristiki* [The technical catalogue. Construction sandwich panel. Part 1. Specifications]. Obninsk: OOO «Rukki Rus», 2016. Pp. 24.
32. *SP 50.13330.2012* Teplovaya zashchita zdaniy. Aktualizirovannaya redaktsiya SNiP 23-02-2003 [Thermal protection of buildings. The updated edition of SNiP 23-02-2003]. M: Minregion Rossii [[The Ministry Of Regional Development], 2012. 96 p.
33. Tusnina O.A. Soyedineniya krovelnykh sendvich-paneley s tonkostennymi gnutymi progonami, vypolnyayemyye na vytyazhnykh zaklepkakh [Joints of Sandwich Panels with Thin-Walled Bent Purlins with the Use of Blind Rivets]. *Promyshlennoye i grazhdanskoye stroitelstvo* [Industrial and Civil Engineering]. 2013. No. 3. Pp. 14–16. (rus)

28. Tusnina O. A finite element analysis of cold-formed Z-purlins supported by sandwich panels // Applied Mechanics and Materials. 2014. Vol. 467. Pp. 398–403.
29. Tusnina O. An Influence of the mesh size on the results of finite element analysis of Z-purlins supported by sandwich panels // Applied Mechanics and Materials. 2014. Vol. 475–476. Pp. 1483–1486.
30. Туснина О.А., Туснин А.Р. Программный комплекс для теплотехнического расчета строительных конструкций // Промышленное и гражданское строительство. 2014. № 4. С. 76–79.
31. Технический каталог. Строительные трехслойные сэндвич-панели. Часть 1. Технические характеристики. Обнинск: ООО «Рукки Рус», 2016. 24 с.
32. СП 50.13330.2012 Тепловая защита зданий. Актуализированная редакция СНиП 23-02-2003. М: Минрегион Росси, 2012. 96 с.
33. Туснина О.А. Соединения кровельных сэндвич-панелей с тонкостенными гнутыми прогонами, выполняемые на вытяжных заклепках // Промышленное и гражданское строительство. 2013. № 3. С. 14–16.

Iuliia Vedishcheva,
+7(903)080-50-00; j.s.vedishcheva@urfu.ru

Michail Ananin,
+7(912)211-81-34; m.y.ananin@urfu.ru

Mohamad Al Ali,
00421905359228; mohamad.al.ali@tuke.sk

Nikolai Vatin,
+7(921)964-37-62; vatin@mail.ru

Юлия Сергеевна Ведищева,
+7(903)080-50-00;
эл. почта: j.s.vedishcheva@urfu.ru

Михаил Юрьевич Ананьин,
+7(912)211-81-34; эл. почта: m.y.ananin@urfu.ru

Мохамад Ал Али,
00421905359228;
эл. почта: mohamad.al.ali@tuke.sk

Николай Иванович Ватин,
+7(921)964-37-62; эл. почта: vatin@mail.ru

Vedishcheva I.S., Ananin M.Y., Al Ali M., Vatin N.I. Influence of heat conducting inclusions on reliability of the system "sandwich panel –metal frame". *Magazine of Civil Engineering*. 2018. No. 2. Pp. 116–127. doi: 10.18720/MCE.78.9.