Journal of
Composites Science

MDPI

Review

Multilayer External Enclosing Wall Structures with Air Gaps or Channels

Nurlan Zhangabay [1], Askhat Tagybayev [1,*], Islambek Baidilla [1], Bayan Sapargaliyeva [2], Bekbulat Shakeshev [3], Kanat Baibolov [4], Bolat Duissenbekov [1], Akmaral Utelbayeva [5,*], Alexandr Kolesnikov [6,*], Aizhan Izbassar [7] and Pavel Kozlov [8,*]

1. Department of Construction and Construction Materials, M. Auezov South Kazakhstan University, Av. Tauke Khan, 5, Shymkent 160012, Kazakhstan; nurlan.zhanabay777@mail.ru (N.Z.); islam2022@rambler.ru (I.B.); maraltai@mail.ru (B.D.)
2. Abai Kazakh National Pedagogical University, Almaty 050010, Kazakhstan; bonya_sh@mail.ru
3. Department of Architecture and Construction, West Kazakhstan Innovative and Technological University, Nazarbayev Avenue, 208, Uralsk 090000, Kazakhstan; galym2022@rambler.ru
4. Department of Engineering, Tashenev University, Street, Tokaeva, 27A, Shymkent 160000, Kazakhstan; gulnura1131@mail.ru
5. Department of Chemistry, M. Auezov South Kazakhstan University, Avenue Tauke Khan, 5, Shymkent 160012, Kazakhstan
6. Department of Life Safety and Environmental Protection, M. Auezov South Kazakhstan University, Avenue Tauke Khan, 5, Shymkent 160012, Kazakhstan
7. Department of Construction Engineering, Sh. Yesenov Caspian University of Technology and Engineering, Aktau 130002, Kazakhstan
8. Polytechnic Institute, Far Eastern Federal University, 690922 Vladivostok, Russia

* Correspondence: t.ashan2021@rambler.ru (A.T.); mako_01-777@mail.ru (A.U.); kas164@yandex.kz (A.K.); opiv.uvc@yandex.ru (P.K.)

Citation: Zhangabay, N.; Tagybayev, A.; Baidilla, I.; Sapargaliyeva, B.; Shakeshev, B.; Baibolov, K.; Duissenbekov, B.; Utelbayeva, A.; Kolesnikov, A.; Izbassar, A.; et al. Multilayer External Enclosing Wall Structures with Air Gaps or Channels. *J. Compos. Sci.* **2023**, *7*, 195. https://doi.org/10.3390/jcs7050195

Academic Editor: Francesco Tornabene

Received: 1 April 2023
Revised: 19 April 2023
Accepted: 4 May 2023
Published: 10 May 2023

Abstract: Precise meanings of thermophysical processes taking place in air gaps have decisive importance in composite cladding structure systems' calculation and modeling. The climatic load conditions in Kazakhstan can significantly affect the microclimate of premises in general. In this work, a review study is carried out to obtain the relevant scientific literature on enclosing structures with air gaps under various climatic conditions. The review mainly covers research institutes from Sweden, Norway, France, Saudi Arabia, Russia, and China. On the issue of the air gap parameter's influence on thermophysical processes, 16 papers were analyzed, and on the issue of air infiltration, 12 papers were analyzed. However, the review shows a lack of research in this area under various climatic conditions. At the same time, experience has shown that the principle of multilayer protection from climatic influences creates a favorable microclimate in buildings, but due to a possible temperature drop, wall structures made of composite building materials can be quite favorable under some conditions, and under others they may be less favorable. Therefore, working out a new energy-saving design with air gaps for climatic conditions with large temperature fluctuations during summer and winter is an urgent task.

Keywords: heat-insulating material; air gap and channel; thermophysical processes; air infiltration; cladding; composite building materials

1. Introduction

Intensive growth in the consumption of electricity and power resources over the past decades has resulted in difficulties arising from environmental contamination and misallocation of power resources, as well as an increase in the cost of maintaining energy complex facilities [1–4]. This is especially reflected in servicing residential buildings for the comfortable residence of the population. According to evidence [5], buildings expend about 30% of all finite energy worldwide; in the European Union, this figure is greater than

40% of the common energy expendable [6]. The reason for this is that more than 80% of the energy goes into heating buildings [7]. Against outside environmental conditions, there is a need to specify temperature regimes suitable for people to reside in buildings.

In Kazakhstan, according to the government technical standard SN RK 2.04-04-2011, "Government standards in construction, architecture, urban planning", the estimated air temperature in residential building premises during a cold spell is about 20 °C in living rooms at a relative air moisture of 30–45%, and in summer these figures are 22 °C and 50–60%, respectively [8]. Given the peculiarity of the climate of Kazakhstan, which is characterized by its continentality and includes a large fluctuation between winter and summer temperatures (Figures 1 and 2) [9,10], maintaining a favorable climate in the building premise requires special care, especially given that the heat loss occurring in residential buildings is up to 40% through facing walls, up to 30% through venting systems, up to 25% through doors and windows, up to 20% through roofs, and up to 6% through basements [11]. The development of power-efficient wall claddings is still a hot topic. Taking into account the insulation of walls and roofs can generally save up to 77% of the energy used for heating [12,13].

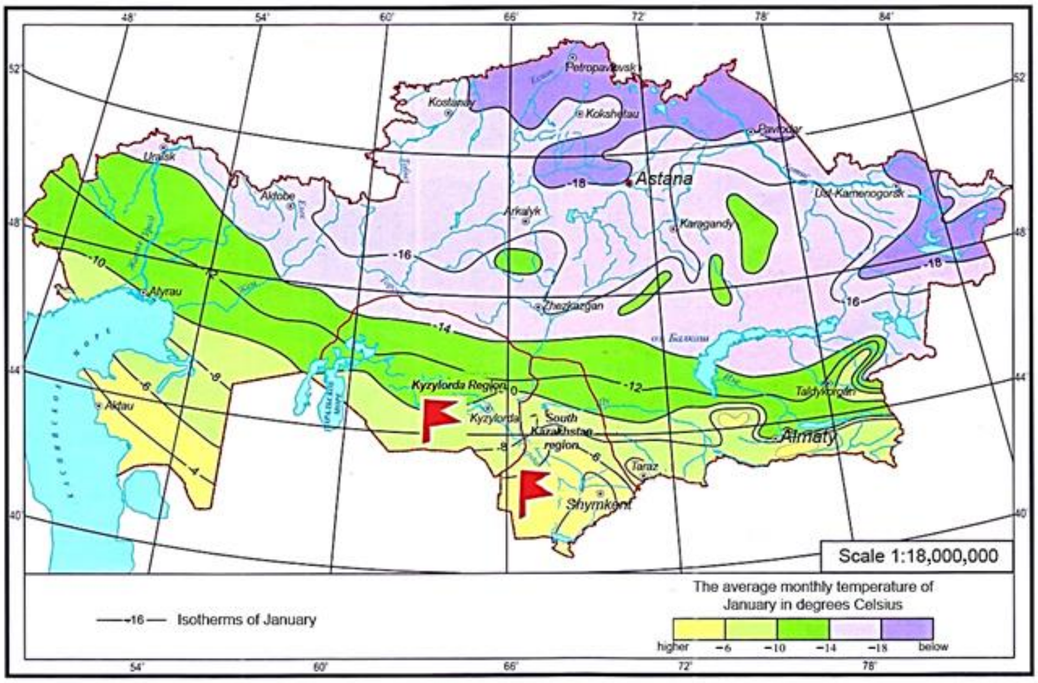

Figure 1. Climate map of Kazakhstan for the month of January in degrees Celsius [9,10].

To solve heat loss problems, enclosing structures with air spaces or ventilating façade structures (a similar name is often found in most sources) have recently been widely used. In Kazakhstani territory, the system of "venting façades" appeared at the end of the 1990s and immediately received recognition and good reviews from customers and contractors.

Venting façades are used to improve the thermotechnical and aesthetic characteristics of building façades. The design is presented in the form of a system of holding brackets, lathing profiles in two directions, a layer of insulation, and facing material. The latter can be natural stone, ceramic granite, metal panel, etc. Glass wool, stone wool, extruded polystyrene foam, or other materials are used in the insulation.

Air space is a characteristic element of venting façades. Due to the pressure difference, air circulates between the layers, ensuring the removal of moisture and condensate. In addition, the air space acts as a temperature buffer, reduces heat loss, and promotes air permeability through the enclosing structure. Systems with air gaps use noncombustible and nonflammable materials to meet fire safety requirements. The requirements for mechanical properties and thermal insulation density reduce the possibility of turbulent flows that deform the insulant fiber and prevent shrinkage.

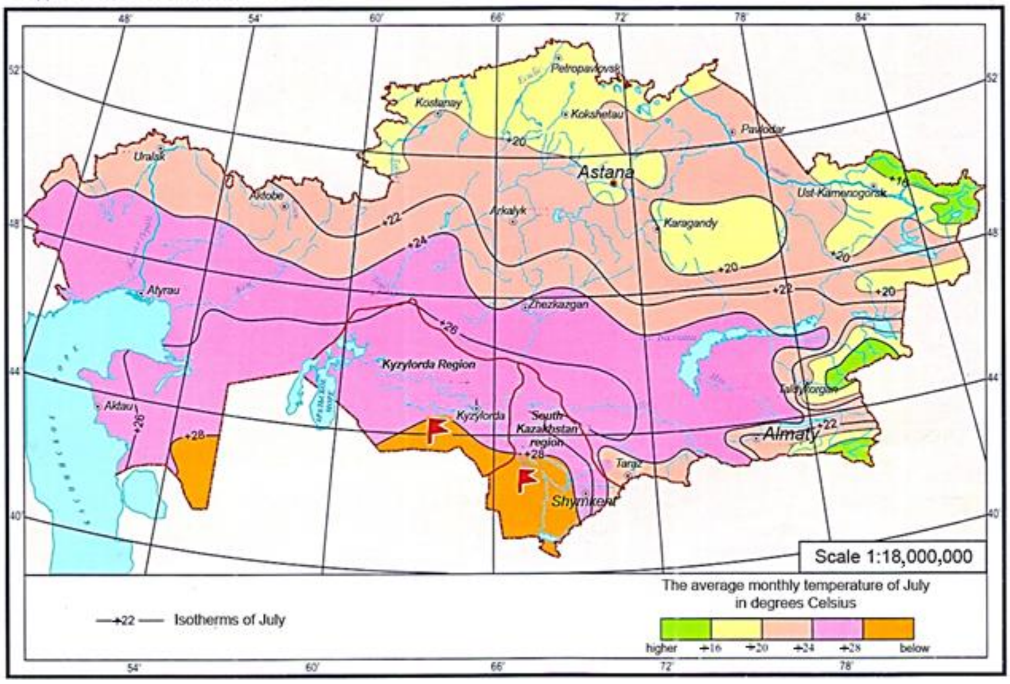

Figure 2. Climate map of Kazakhstan for the month of July in degrees Celsius [9,10].

Air spaces may be applied for thermal insulation of walls, since air in an enclosed space is an imperfect heat conductor [14], and condensed construction materials hinder heat transfer by radiation, conduction, and convection. Heat transfer at the interface between air and the rigid layers of a wall structure is a more complicated phenomenon than heat transfer within a rigid layer [15]. Given these circumstances, after multiple investigations, the United States Department of Energy recommended using air gaps in building structures to increase their energy efficiency [16].

A traditional multilayer cladding is shown in Figure 3. The standard [17] specifies very generally accepted characteristics of thermophysical processes, but does not take into account many geometric and physical indicators of structures. As a disadvantage, it can be noted that the norm does not sufficiently cover indicators such as the nature of the gap (closed and/or venting) and the geometric indicator of the air gaps and channels, including the width, height, and location of the channels themselves (horizontal or vertical).

The study of thermophysical processes occurring in a multilayer enclosure with the subsequent elaboration of a new energy-saving design for Kazakhstani climate will solve a number of energy-saving issues that are covered by the norms and laws of the Republic of Kazakhstan: Energy Efficiency and Energy Saving Law; Environmental Code; Requirement for security of buildings and structures, building materials and products; Requirement for energy efficiency of buildings, structures and their elements which are enclosing structures' part; Law on architectural, urban planning and construction activities. In this regard, the following research questions are posed before the work:

a. To develop the cladding's multilayer wall structure, taking into account the availability of air gaps, as well as to study the influence of the venting layer parameter on thermophysical processes taking place in the multilayer structure.
b. To research the thermophysical processes in the developed multilayer energy-saving structure of the building cladding, taking into account air permeability.

To reply to these research matters, a systemic survey of the research literature was conducted using various library databases, and according to historians, the first hinged façades appeared in medieval Norway several centuries ago [18–20].

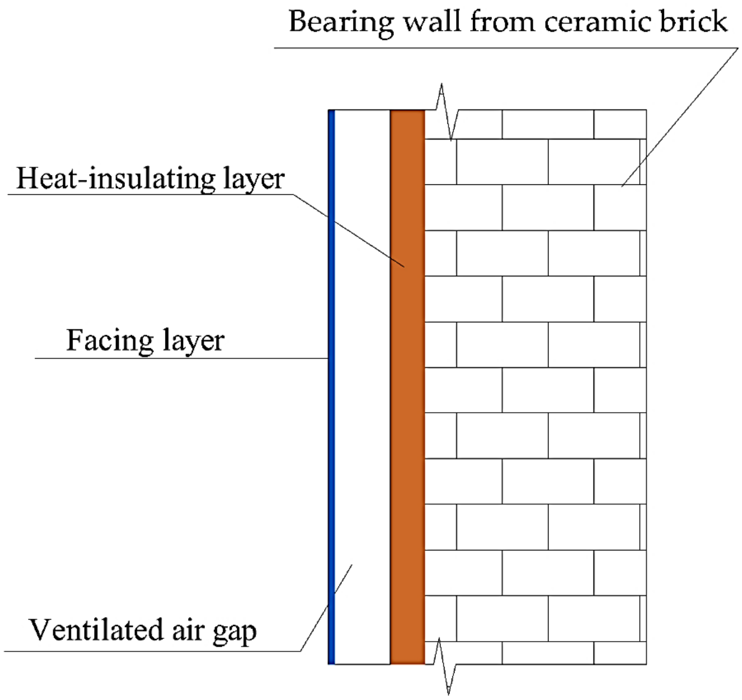

Figure 3. Traditional multilayer structure of a cladding with an air gap.

2. Methodology

In review studies on thermophysical processes in venting and closed air gaps of a multilayer enclosing structure, a literature search technique developed on the basis of [21–23] was determined, where five stages of searching for relevant literature were used (Table 1):

Table 1. Stage names.

No.	Stage Number	Stage Name
1	1st stage	Specifying the research matter
2	2nd stage	Specifying appropriate investigations
3	3rd stage	Investigate choice
4	4th stage	Data graph
5	5th stage	Correlating, generalizing, and reporting the results

A basic algorithm for conducting a literature review is shown in Figure 4.

The search for literature research was performed using such databases as Web of Science, Scopus, ScienceDirect, Google Scholar, Search Crossref, Index Copernicus, WorldCat, CyberLeninka, E.lanbook, and Elibrary. After the list of required articles was found according to Figure 4, they were included in the literature section. Thus, as a result of the search, a list of review literature was made from 85 relevant articles, of which 57 were excluded for the following reasons, for example:

- ✓ The articles consider a wet-type façade without an air gap [24–26];
- ✓ The articles deal with the issue of thermal modernization and/or venting façades with heat-retaining phase transition materials [27–29];
- ✓ The articles consider only a venting façade; a closed gap is not shown [30–32];
- ✓ The articles deal with the issue of enclosing structures for only one climatic zone, i.e., hot or cold [33–36].

Since the climate of the territory has a high thermal gradient between the summer and winter seasons, an additional literature search was carried out regarding the research issues indicated in Section 1.

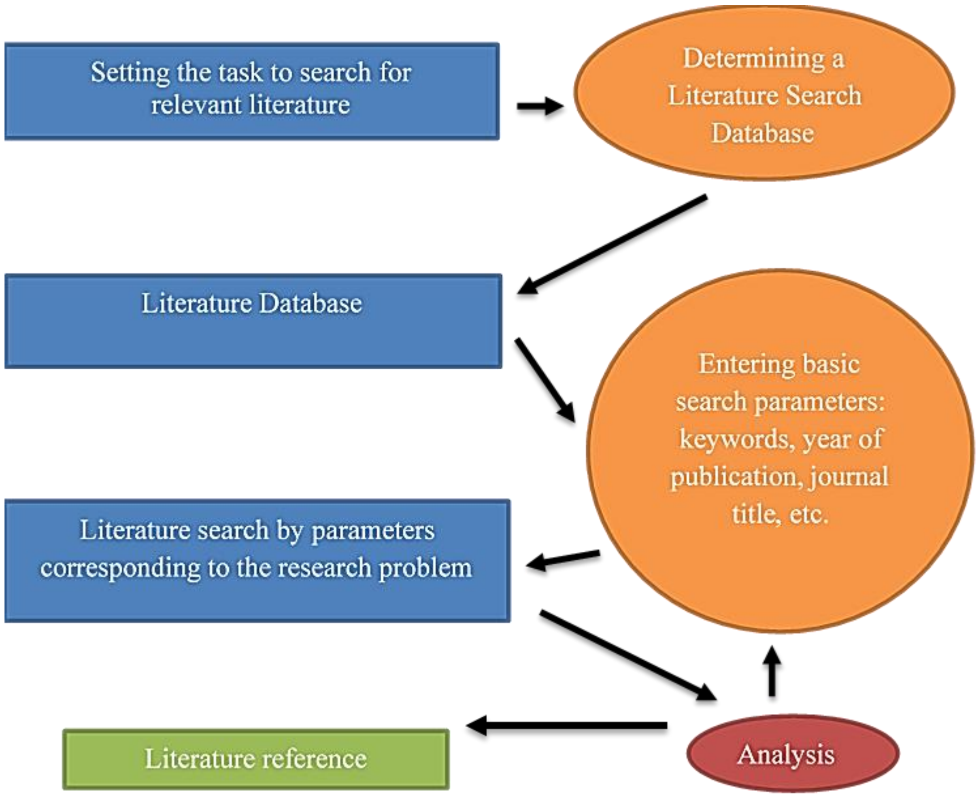

Figure 4. Literature review algorithm.

3. Literature Review Results

3.1. Review of Studies Carried Out in the Field of Claddings, Taking into Account the Influence of the Venting Layer Parameter on Thermophysical Processes

In the studies [37], full-scale field experimental tests and tests of ventilation drying processes on the wall structure model [38,39] were carried out appreciating the gap's air change rate. As a result of comparing studies, data were obtained that were consistent with each other. Measurements also showed that a 40 mm wide gap provides 20–25 times higher drying potential compared to a 5 mm wide gap. In [40], the effect of wind on air pressure in the air gap was considered. Field experiments, laboratory experiments, and calculations were carried out. The findings showed that the geometry of the details and the air cavity near its openings strongly influence the pressure differentials in the air cavity and that the computational techniques are less relevant for complicated cavity geometries. The paper found that in cold climates, it would be enough to apply an initial wind speed of 10 m/s at a height of 10 m over the earth for computations covering the heating season.

The study [41] adduces an imitation of an innovative venting enclosing wall structure applying exhaust indoor air. The structure's computational model was developed, which was confirmed by experimental tests. The material influence in the cladding's venting structure and the air flow effect in the cavity on the external structure's thermal properties were also investigated. The findings showed that the venting cladding design possesses superior energy-saving indicators compared to the conventional one. The work [42] describes the possibility of adding one more air chamber, parallel to the current one, both connected with the lower part of the façade, with an installation at the top to control the air flow in the chambers in relation to the temperature between the building's outside and inside. For this purpose, a peer study of the energy performance, as well as the thermal and hydrodynamic properties of the offered two-chamber system, the customary venting façade system with a closed connection, was carried out in different seasons. The findings showed that the offered system increases efficiency by 38% compared to a customary venting façade with a closed seam. However, the difference in the geometric dimensions of the gap itself was not taken into account in this work. The paper [43] experimentally investigated the thermal performance of venting façades under standard Mediterranean summer meteorological conditions by applying a high-scale test building. The results of the experiments showed that the heat flow reduction strongly hinges on the external rain screen finishing, the availability of ventilation grills and open seams, as well as the cladding's air gap thickness. However, the study's aim [44] was to provide an idea of the advantages of multilayer thermal insulation in buildings arranged in aggregate with two air spaces. A numerical technique was developed to specify the effect of air gap thickness on the total thermal resistance of a multilayer wall. A total of nine different configurations were chosen as the initial state, where the theoretical thermal resistances were computed and compared, resulting in an empirical polynomial equation that computes the total wall complex thermal resistance, based on two air space thickness values. A study that reported a reduction in heat losses due to the effective selection of an air gap's parameters, thermal insulation, was performed in Malaysia [45]. It was demonstrated that heat losses reduced by 24% and 26% when a 2 cm air gap and 3–5 cm thermal insulation were used in place of an enclosure excluding air gap or thermal insulation. The manuscript [46] examined the efficiency of applying façades involving closed air gaps in a sweltering climate. Three enclosure types were simulated—excluding thermal insulation, applying an air gap as thermal insulation, and including a foam insulating layer. It was deduced that closed gaps in sweltering climates are less impactful than in cold ones. The manuscript [47] is dedicated to the force of closed air gaps in double walls on the enclosure's heat-insulating properties. Six double-wall patterns involving 1–6 cm thick gaps were tentatively investigated. It was deduced that an increase in gap thickness results in an asymptotic increase in the enclosure's thermal resistance; the effective gap thickness is 6 cm, which reduces heat losses by 19.45% against a 1 cm gap. In the study [48], the authors described the advantages of a customary venting façade system, where it was noted that the availability of a venting air gap can significantly improve the thermal insulation layer's moisture state. The condensation zone shifts into the outer heat-insulating layer, which borders the venting air gap. The placement of the thermal insulation on the outside increases the wall array's heat storage capacity. In [49], two types of façades were considered: hinged venting façades and wet façades. It was shown that hinged façades are mounted faster than "wet" ones, and also that their soundproofing properties are much higher than those of wet façades and the initial readings are increased by several times. A comparison was also made on the maintenance of façades and on their protection from moisture. It was shown that hinged venting façades are superior to "wet" ones in frost resistance, sound insulation, and thermal insulation due to the absence of aqueous solutions in the composition and thicker layers of insulants, which is very important for areas with a cold, humid climate. The article [50] considers the features of applying only venting double skin façades to provide better thermal and visual comfort conditions, which were proposed as flexible building systems to improve the performance of enclosing structures. The investigation carried out by the authors of the manuscript [51] included design approaches and pilot research on the thermal insulation characteristics of closed gaps. Constructive solutions for ceilings and coatings of external walls, insulated with screen thermal insulation, were presented. The outcomes of the calculations and pilot research showed that applying screen thermal insulation will essentially increase the heat transfer resistance and energy efficiency of enclosing structures in buildings, resulting in a relatively low cost of construction and installation. In [52], a comparative analysis of façade systems was carried out. As an example, three façade options were chosen: a traditional façade, a plaster insulated façade, and a venting façade. As a result of the analysis, a venting standard façade (Figure 3) was presented as the most effective façade.

In general, it can be seen that there are practically no studies on thermophysical processes occurring in venting air gaps that take into account the presence of an additional closed gap in a multilayer wall structure (combined design). The impact of air gap width on the thermophysical processes occurring in the multilayer combined structure of a cladding also requires additional research.

3.2. Review of Studies Carried Out in the Field of the Process of Moving Air through a Multilayer Wall Structure of a Cladding

In [53], the authors, based on the model of a porous medium and the method of numerical simulation, studied the internal flow of the environment in the outer wall of building implements and built a computational model of water microflow from cracks. The impact of wind pressure, height, and local structure on the crack flow was analyzed. The findings showed that initial water velocity is associated with wind pressure and building height. The study [54] presents an air penetration prediction model with additional holes. The enclosing structure was divided into impermeable and permeable parts, and it was supposed that the air leakage paths were evenly and continually arranged in the permeable shell. A linear arrangement of pressure across the building façade was supposed, and the air flow rate was unified in the horizontal and vertical planes to theoretically forecast the air penetration rate. The realizability of the offered model was examined by collating the air penetration rates modeled by this model with those specified by applying the trace gas attenuation technique in a pressurized building. The initial test findings showed that this model is mathematically forceful and admissive of simulating building air infiltration in a full range of scenarios. A sound compromise was identified between the examined and simulated findings. This study can ensure primary theoretical support for the analysis of the effectiveness of air tightness in buildings. In the manuscript [55], based on the findings of computations and the likelihood for each scenario, statistical indicators of the contemplated air penetration rates were defined. The findings showed that the average yearly penetration rate was 0.26 h^{-1} with a typical deviation of 0.11 h^{-1}. In addition, the penetration rate was positively related to wind speed, negatively related to dwelling capacity, and insensitive to floor level. When the location of neighboring buildings ensured a free way for wind, the penetration rate was larger. In [56], the authors proposed a simplified method for predicting the rate of penetration of winter air into buildings of large areas caused by joint wind forces and buoyancy. This technique relies on a theoretical indoor space model and outdoor CFD wind modeling. Against the full-scale CFD model inside and outside, the simplified method forecasts the air penetration rate with a mean absolute deviation of 5.4% (maximum: 11.0%). The authors of [57] consider the issue of defining the air flow via cracks in enclosing structures by applying computational methods. Based on the investigation of the data received within the exterior check, it was detected that many apartment buildings have considerable physical deterioration, which is mainly manifested by the presence of cracks. A special focus was placed on the assumptions adopted for the design scheme. Based on continuity and dynamics equations, a mathematical model was received that allowed for forecasting air flow via a crack. In [58], numerical modeling was carried out to determine the characteristics of the flow inside the air gap of the hinged façade system and longitudinal filtration through the heat-insulating layer caused by wind effects. According to the simulation results, it was found that the air stream velocity in the hinged façade system's air gap is on average 1–3 m/s, and filtration with an indicator of 0.001–0.003 m/s was established in the heat-insulating layer. As shown by the numerical study [59], the presence of even such a low rate in the insulant layer has a significant impact on the thermal properties enclosing structures. In [60], the author studied the process of heat transfer through a porous external enclosing structure during infiltration and exfiltration. To define the level of thermal shutdown of enclosures with air permeability, the author took into account not only the coefficient of thermal conductivity but also the porosity of the material. The calculations performed taking into account the porosity of the material showed that the temperature values obtained for the inner enclosure surface and its resistance to heat transfer correlate much better with the experimental values and are not overestimated. In the study performed by the authors of the work [61], an assessment was made of the heat storage capacity of an energy-active structure of the external wall, which has a system of passive use of solar energy, considering the conditional outside air temperature. The interrelation between the heat and mass transfer of an energy-active wall with the heating system and natural ventilation of the building has been shown; according to the calculation model, the temperature value of the heated air leaving the venting air gap in a certain amount allowed for approximately estimating the efficiency of heat recovery brought about by the accumulating structural layer [62–72].

The infiltration process is entailed by the difference in air pressure between the shell element's outer and inner surfaces. Wind later strengthens penetration, and high-rise buildings possess a stack effect that draws air into the lower part of the building and forces it up [62,72–77].

To decrease intermediate condensation and aeration, two membrane layers must be applied along the outer shell of the LSF building [72–79]. The first barrier, known popularly as the vapor seal, must be arranged on the warm insulation layer side. This keeps moisture from the air from getting inside the LSF elements and keeps condensation from forming on colder, usually steel, elements. The windproof membrane must be arranged on the cold side and must be vapor-permeable to enable moisture to come out of the LSF elements [80]. The most prevalent air leakages discovered in field observations in the literature were at the joints between an external wall and a floor or ceiling, an external wall and a door or window, and an external wall and openings in barrier films [80]. Sealing strips must also be applied in combination with the aforementioned membranes to improve overall tightness.

As a result of the review, it can be seen that studies of air movement through enclosing structures are scarce and require additional research, as well as the development of a new energy-saving multilayer cladding, taking into account air infiltration in different climatic environments.

4. Discussion

The literature review showed that the literature aimed at studying façade structures has a rich archive. We would especially like to note claddings with a "wet" façade. However, since this work was aimed at studying claddings with air gaps, and some sources considered hinged venting façade structures, the corresponding studies on the influence of the venting gap parameter on the thermophysical processes occurring in the structure amounted to 16 works, and the number of studies related to the air transfer through the enclosing structures amounted to 12 works.

Many of these manuscripts use a single climatic condition (hot or cold) of the gap for computations or simulations, excluding studies with comprehensive citations and studies that point out whether they correspond to real conditions. In any case, these manuscripts demonstrate the need for further study of thermophysical processes in air gaps and air infiltration.

Moreover, the appropriate literature presented in this review comes from a fairly low number of researchers from several research institutes in Sweden, Norway, France, Saudi Arabia, Russia, and China. In practice, only 7 experimental studies were identified on the impact of air gap parameter on thermophysical processes at the appropriate scales and climate, 7 studies related to process modeling, and 2 studies on analysis and review. In the air infiltration direction, a total of 12 papers were identified, of which 8 papers were related to modeling and 4 papers were based on experimental studies. It should be noted that some investigations lack faithful pictures of study parameters, such as an exact structure design or climate data for the study period, making it difficult to reproduce or validate the findings. The investigations are also too diverse to directly compare the findings with each other.

It was also found that the wider international literature touches these issues to a greater or lesser degree, depicting investigations that cover the environmental conditions of cold or hot climates separately, which may not fully appreciate the merits of the proposed design solutions for venting enclosing structures in the climatic conditions of the Republic of Kazakhstan, where the temperature load difference is quite large (Figures 1 and 2) [9,10].

Given these circumstances, for a complete understanding, it is necessary to carry out computations according to [17] in diverse weather conditions, for example, at the absolute minimum temperature of the outside air, at the absolute maximum temperature of the outside air, at the medium temperature of the coldest five days with 0.92 occurrence, and at the medium April temperature [81,82], which is the authors' initial research in this direction. We would also like to note that when reviewing the literature of local scientific research institutes in this area, relevant works were not found.

5. Conclusions

This investigation revealed that the volume of research on thermophysical processes in air gaps in venting building façade systems, as well as air transfer through venting enclosing structures, is scarce. There is a universal lack of comparable investigations and quantitative findings. Research is limited by the fact that studies on venting façade systems for cold climates are carried out mainly in Norway and Sweden, and for hot climates mainly in South Asia, and regions with large temperature differences remain largely unexplored.

The consequence of the lack of research is that, at present, there is no reliable information on the ongoing thermophysical processes in the gaps and the air transfer through claddings in different climatic conditions, taking into account the temperature difference. Experience shows that the principle of multilayer protection against climatic influences creates a favorable microclimate in buildings, but due to the possible temperature difference, wall structures may be favorable in some conditions, while in others, they may not be effective enough. At present, it is hard to forecast how designs can be improved to handle these problems, as climatic loads in air spaces have not been well investigated.

In this connection, the following work must be carried out taking into account the simulation in the software package and confirm the obtained simulation results with the condition of experimental verification of the data, where the collection of sensor data should be carried out from fragments of the developed wall structure (experimental models) located in different climatic zones for a sufficient period of time to obtain the full scope of information. The relationship between the outside climate - for example, as described in the climate data in the simulations- and the climatic conditions of the air gaps needs to be additionally explored. The sensor data can be compared with climate data to appreciate the correlation between the outside climate and the cavity microclimate and to define required corrections when applying climate data to model venting and closed air gap conditions. Such modeling is necessary for a complete assessment of the processes occurring in multilayer enclosing structures involving air gaps or channels in order to create a favorable microclimate in buildings, including long-term wear of the structure itself.

Author Contributions: Conceptualization, N.Z. and B.S. (Bayan Sapargaliyeva); strategy, N.Z., I.B., A.T. and A.U.; research, N.Z. and B.S. (Bayan Sapargaliyeva); data curation, I.B., A.T. and A.I.; writing—original draft preparation, N.Z., K.B., B.S. (Bekbulat Shakeshev) and A.U.; writing—review and revision, B.S. (Bekbulat Shakeshev), B.D., K.B., P.K. and A.I.; supervision, I.B. and A.T.; project management, N.Z., B.D. and A.K.; funding acquisition, N.Z., B.D., I.B., A.T., P.K. and A.K. All authors have read and agreed to the published version of the manuscript.

Funding: The study is funded by the authors of M. Auezov South Kazakhstan University.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Suleimenov, U.; Zhangabay, N.; Utelbayeva, A.; Masrah, A.A.M.; Dosmakanbetova, A.; Abshenov Kh Buganova, S.; Moldagaliyev, A.; Imanaliyev, K.; Duissenbekov, B. Estimation of the strength of vertical cylindrical liquid storage tanks with dents in the wall. *East. Eur. J. Enterp. Technol.* **2022**, *7*, 6–20. [CrossRef]
2. Zhangabay, N.; Suleimenov, U.; Utelbayeva, A.; Kolesnikov, A.; Baibolov, K.; Imanaliyev, K.; Moldagaliyev, A.; Karshyga, G.; Duissenbekov, B.; Fediuk, R.; et al. Analysis of a Stress-Strain State of a Cylindrical Tank Wall Vertical Field Joint Zone. *Buildings* **2022**, *12*, 1445. [CrossRef]
3. Tursunkululy, T.; Zhangabay, N.; Avramov, K.; Chernobryvko, M.; Suleimenov, U.; Utelbayeva, A. Influence of the parameters of the pre-stressed winding on the oscillations of vertical cylindrical steel oil tanks. *East.-Eur. J. Enterp. Technol.* **2022**, *5*, 6–13. [CrossRef]
4. Zhangabay, N.; Suleimenov, U.; Utelbayeva, A.; Buganova, S. Experimental research of the stress-strain state of prestressed cylindrical shells taking into account temperature effects. *Case Stud. Constr. Mater.* **2022**, *18*, e01776. [CrossRef]
5. Available online: http://www.energimyndigheten.se/forskning-och-innovation/ (accessed on 28 December 2022).
6. Shandilya, A.; Streicher, W. Performance and Cost Analysis of Retrofit Strategies Applied to a Sample Single Family House Located in New Delhi India Assisted by TRNSYS Energy Simulation Tool-A Case Study. *Inte. J. Eng. Tech. Res.* **2017**, *6*, 304–312. [CrossRef]
7. Shandilya, A.; Hauer, M.; Streicher, W. Optimization of Thermal Behavior and Energy Efficiency of a Residential House Using Energy Retrofitting in Different Climates. *Civ. Eng. Arch.* **2020**, *8*, 335–349. [CrossRef]
8. GOST 30494-96. Residential and Communal Buildings. Microclimate Parameters in Premises. Available online: https://ventsila.by/wp-content/uploads/2015/10/GOST-30494-961.pdf (accessed on 28 December 2022).
9. Code of Rules of the Republic of Kazakhstan 2.04-01-2017 Building Climatology: State Standards in the Field of Architecture, Urban Planning and Construction. Code of Rules of the Republic of Kazakhstan.–JSC "KazNIISA", LLP "Astana Stroy-Consulting". 2017. Available online: https://online.zakon.kz/m/document/?doc_id=37599018 (accessed on 28 December 2022).
10. Available online: https://yandex.kz/images/search?text=%D0%9A%D0%B0%D1%80%D1%82%D0%B0%20%D0%BA%D0%BB%D0%B8%D0%BC%D0%B0%D1%82%D0%B8%D1%87%D0%B5%D1%81%D0%BA%D0%B8%D1%85%20%20%D0%B7%D0%BE%D0%BD%20%D0%9A%D0%B0%D0%B7%D0%B0%D1%85%D1%81%D1%82%D0%B0%D0%BD%D0%B0&stype=image&lr=221&source=serp (accessed on 28 December 2022).
11. Cholewa, T.; Balaras, C.A.; Nižetić, S.; Siuta-Olcha, A. On calculated and actual energy savings from thermal building renovations–Long term field evaluation of multifamily buildings. *Energy Build.* **2020**, *223*, 110145. [CrossRef]
12. Hasan, A. Optimizing insulation thickness for buildings using life cycle cost. *Appl. Energy* **1999**, *63*, 115–124. [CrossRef]
13. DOE: 2011 Building Energy Data Book. Energy Efficiency and Renewable Energy; USA, Maryland, Department of Energy. 2011. Available online: https://ieer.org/wp/wp-content/uploads/2012/03/DOE-2011-Buildings-Energy-DataBook-BEDB.pdf (accessed on 25 December 2022).
14. CLEAR: Cavities and Air Space. Comfortable Low Energy Architecture. Available online: http://new-learn.info/packages/clear/thermal/buildings/building_fabric/elements/cavities_andair_spaces.html (accessed on 28 December 2022).
15. CIT: Resistance of Air Layers and Surface Layers. Intelligent Energy Europe. Cork Institute of Technology. 2016. Available online: http://tea.ie/wpcontent/uploads/2011/09/Module-3.2-Resistance-of-air-layers-and-surface-layers.pdf (accessed on 5 March 2016).
16. Pacific Northwest National Laboratory (PNNL); Oak Ridge National Laboratory: Building Technologies Program, Building America best practices series, Vol. 17. Energy renovations: Insulation a guide for Contractors to Share with Homeowners. PNNL-20972 May 2012. Available online: https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-20972.pdf (accessed on 30 December 2022).
17. Code of Rules of the Republic of Kazakhstan 2.04-107-2013 Building Heat Engineering: State Standards in the Field of Architecture, Urban Planning and Construction. Code of Rules of the Republic of Kazakhstan. 2013. Available online: https://online.zakon.kz/m/document/?doc_id=37599018 (accessed on 30 December 2022).
18. Svendsen, S.D. The Principle of One-Stage and Two-Stage Seals. In Proceedings of the International Symposium on Weathertight Joints for Walls, Oslo, Norway, 25 September 1967; pp. 298–301.
19. Birkeland, Ø. The Mechanism of Rain Penetration. In Proceedings of the International Symposium on Weathertight Joints for Walls, Oslo, Norway, 25 September 1967; pp. 33–34. Available online: https://scholar.google.com/scholar_lookup?title=The+Mechanism+of+Rain+Penetration&author=Birkeland,+\T1\O.&publication_year=1967 (accessed on 28 December 2022).
20. Isaksen, T. Rain Leakage Test on Open Joints in Ventilated Claddings. In Proceedings of the International Symposium on Weathertight Joints for Walls, Oslo, Norway, 25 September 1967; pp. 349–354.
21. Arksey, H.; O'Malley, L. Scoping Studies: Towards a Methodological Framework. *Int. J. Soc. Res. Methodol.* **2005**, *8*, 19–32. [CrossRef]
22. O'Brien, A.M.; Mc Guckin, C. The Systematic Literature Review Method: Trials and Tribulations of Electronic Database Searching at Doctoral Level. In *SAGE Research Methods Cases*; SAGE Publishing Ltd.: New York, NY, USA, 2016. [CrossRef]
23. Ingebretsen, S.; Erlend Andenæs, E.; Kvande, T. Microclimate of Air Cavities in Ventilated Roof and Façade Systems in Nordic Climates. *Buildings* **2022**, *12*, 683. [CrossRef]

24. Tao, S.; Yu, N.; Tao, Z.; Zhao, K.; Jianga, F. Investigation of convective heat transfer at the façade with balconies for a multi-story building. *J. Build. Eng.* **2023**, *63*, 105420. [CrossRef]
25. Arslan, H.; Yıldırım, K. Perceptual evaluation of stadium façades. *Alex. Eng. J.* **2023**, *66*, 391–404. [CrossRef]
26. Pescaria, S.; Budăua, L.; Vîlceanub, C. Rehabilitation and restauration of the main façade of historical masonry building–Romanian National Opera Timisoara. *Case Stud. Const. Mat.* **2023**, *18*, e01838. [CrossRef]
27. Zhangabay, N.; Abshenov, K.; Bakhbergen, S.; Zhakash, A.; Moldagaliyev, A. Evaluating the Effectiveness of Energy-Saving Retrofit Strategies for Residential Buildings. *Int. Rev. Civ. Eng.* **2022**, *13*, 118–126. [CrossRef]
28. Kudabayev, R.; Suleimenov, U.; Ristavletov, R.; Kasimov, I.; Kambarov, M.; Zhangabay, N.; Abshenov, K. Modeling the Thermal Regime of a Room in a Building with a Thermal Energy Storage Envelope. *Math. Model. Eng. Probl.* **2022**, *9*, 351–358. [CrossRef]
29. Kudabayev, R.; Mizamov, N.; Zhangabay, N.; Suleimenov, U.; Kostikov, A.; Vorontsova, A.; Buganovs, S.; Umbitaliyev, A.; Kalshabekova, E.; Aldiyarov, Z. Construction of a model for an enclosing structure with a heat-accumulating material with phase transition taking into account the process of solar energy accumulation. *East.-Eur. J. Enterp. Technol.* **2022**, *6*, 26–37. [CrossRef]
30. Picallo-Perez, A. MaríaSala-Lizarraga, Energy and exergy analysis of an experimental ventilated façade. *Energy Build.* **2023**, *280*, 112737. [CrossRef]
31. Suáreza, M.J.; Sánchez, M.N.; Blanco, E.; Jiménez, M.J.; Giancola, E. A CFD Energetic study of the influence of the panel orientation in Open Joint Ventilated Façades. *Energy Rep.* **2022**, *8*, 665–674. [CrossRef]
32. Stanevich, V.T.; Bulyga, I.I.; Vyshar, O.V.; Girnis, S.R.; Rakhimova, G.M. Analysis of energy efficiency of building envelopes of JSC Station EGRES-2. *AIP Conf.* **2021**, *2559*, 050006. [CrossRef]
33. Shao, Y.; Parks, A.; Ostertag, C. Lightweight concrete façade with multiple air gaps for sustainable and energy-efficient buildings in Singapore. *Build. Environ.* **2022**, *223*, 109463. [CrossRef]
34. Elmalky, A.M.; Mohamad, T. Computational fluid dynamics using finite volume method: A numerical model for Double Skin Façades with renewable energy source in cold climates. *J. Build. Eng.* **2022**, *60*, 105231. [CrossRef]
35. Lobaccaro, G.; Carlucci, S.; Croce, S.; Paparella, R.; Finocchiaro, L. Boosting solar accessibility and potential of urban districts in the Nordic climate: A case study in Trondheim. *Sol. Energy* **2017**, *149*, 347–369. [CrossRef]
36. Afren, R.; Benabbas, M.; Zemmouri, N.; Djaghrouri, D. Impact of the typology of school buildings on the internal thermal conditions, in a hot and dry climate. *Energy Procedia* **2017**, *122*, 505–510. [CrossRef]
37. Falk, J.; Sandin, K. Ventilated Rainscreen Cladding: Measurements of Cavity Air Velocities, Estimation of Air Change Rates and Evaluation of Driving Forces. *Build. Environ.* **2013**, *59*, 164–176. [CrossRef]
38. Falk, J.; Sandin, K. Ventilated Rainscreen Cladding: A Study of the Ventilation Drying Process. *Build. Environ.* **2013**, *60*, 173–184. [CrossRef]
39. Falk, J.; Molnár, M.; Larsson, O. Investigation of a Simple Approach to Predict Rainscreen Wall Ventilation Rates for Hygrothermal Simulation Purposes. *Build. Environ.* **2014**, *73*, 88–96. [CrossRef]
40. Uvsløkk, S. The Importance of Wind Barriers for Insulated Timber Frame Constructions. *J. Therm. Insul. Build. Envel.* **1996**, *20*, 40–62. [CrossRef]
41. Liu, L.; Yu, Z.; Zhang, H. Simulation study of an innovative ventilated facade utilizing indoor exhaust air. *Energy Procedia* **2017**, *121*, 126–133. [CrossRef]
42. Santa Cruz, J.; Porras-Amores, A.C. Ventilated Façade with double chamber and flow control device. *Energy Build.* **2017**, *149*, 471–482. [CrossRef]
43. Marinosci, C.; Semprini, G.; Morinia, G.L. Experimental analysis of the summer thermal performances of a naturally ventilated rainscreen façade building. *Energy Build.* **2014**, *72*, 280–287. [CrossRef]
44. Mavromatidis, L.E.; Bykalyuk, A.; El Mankibi, M.; Michel, P.; Santamouris, M. Numerical estimation of air gaps' influence on the insulating performance of multilayer thermal insulation. *Build. Environ.* **2012**, *49*, 227–237. [CrossRef]
45. Sadrzadehrafiei, S.; Mat, K.; Sopian, S.; Lim, C.H. Determining the cost saving and emission reduction of optimum insulation thickness and air gap for building walls. *Aust. J. Basic Appl. Sci.* **2011**, *5*, 2287–2294.
46. Alhefnawi, M.A.M.; Abdu-Allah Al-Qahtany, M. Thermal Insulation Efficiency of Unventilated Air-Gapped Façades in Hot Climate. *Arab. J. Sc. Eng.* **2016**, *42*, 1155–1160. [CrossRef]
47. Hassan, K.A.; Saja, H.F. Experimental study for the effect of air gap in building walls on heat gain reduction. *Mater. Today Proc.* **2021**, *61*, 1043–1051. [CrossRef]
48. Zhukov, A.D. Ventilated façade systems. *Sc. Const. Educ.* **2016**, *1*, 1–15.
49. Vasiliev, N.B.; Stuglev, N.A.; Utkov, E.O.; Melnik, I.S. Hinged ventilated facades and wet. *Stroymnogo* **2018**, *1*, 1–19.
50. Harun, M.; Tunjay, C. Features of the use of ventilated double-skinned façades to provide better thermal and visual comfort conditions. *Inter. J. Appl. Sc. Tech.* **2022**, *1*, 105323.
51. Vytchikov, Y.u.S.; Saparev, M.E. Investigation of the heat-shielding characteristics of closed air gaps in building enclosing structures using screen thermal insulation. *Bull. SGASU* **2014**, *1*, 98–102.
52. Kiryudcheva, A.E.; Shishkina, V.V. Efficient façade systems. *Const. Unique Build. Struc.* **2015**, *4*, 248–262.
53. Qiana, J.; Gub, Y. Research on antileakage construction of building engineering exterior wall based on improved attribute recognition model. *Case Stud. Const. Mat.* **2022**, *17*, e01410. [CrossRef]
54. Yongming, Y.; Duanmu, L.; Songtao, S. Prediction model of air infiltration in single-zone buildings with high airtightness. *Energy Built Environ.* **2022**. [CrossRef]

55. Ho, K.D.; Chun, C. Air infiltration rates in residential units of a public housing estate in Hong Kong. *Build. Environ.* **2022**, *219*, 109211. [CrossRef]
56. Liu, X.; Liu, X.; Zhang, T.; Lin, C.; Zhong, H.Y.; Ooka, R.; Kikumoto, H. Winter air infiltration induced by combined buoyancy and wind forces in large-space buildings. *J. Wind. Eng. Ind. Aerodyn.* **2021**, *210*, 104501. [CrossRef]
57. Duloglu, T.A.; Grigoriev, V.I.; Ruslyakov, D.V. Application of numerical methods in solving problems of air exchange through enclosing structures with physical wear. *Eng. Bull. Don.* **2017**, *4*, 296.
58. Guvernyuk, S.V.; Kozlov, V.V.; Ledenev, P.V. Numerical modeling of longitudinal air filtration in the underface layer of a hinged façade system. *Build. Sc.* **2010**, *1*, 341–343. Available online: https://cyberleninka.ru/article/n/chislennoe-modelirovanie-prodolnoy-filtratsii-vozduha-v-podoblitsovochnom-sloe-navesnoy-fasadnoy-sistemy (accessed on 2 April 2023).
59. Gagarin, V.G.; Kozlov, V.V.; Mekhnetsov, I.A. Longitudinal air filtration in modern enclosing structures. *ABOK* **2005**, *8*, 60–69. Available online: https://www.abok.ru/for_spec/articles.php?nid=3077 (accessed on 2 April 2023).
60. Umnyakov, P.N. Influence of infiltration and exfiltration on the thermal protection of enclosing structures, taking into account the porosity of materials. *Hous. Constr.* **2014**, *10*, 46–50.
61. Beregovoy, A.M.; Beregovoy, V.A.; Viktorova, O.L. Heat storage properties of an energy-active wall in a natural ventilation and heating system. *Reg. Arch. Const.* **2017**, *1*, 74–77.
62. Guillén-Lambea, S.; Rodríguez-Soria, B.; Marín, J.M. Air infiltrations and energy demand for residential low energy buildings in warm climates. *Renew. Sustain. Energy Rev.* **2019**, *116*, 109469. [CrossRef]
63. Kolesnikova, O.; Syrlybekkyzy, S.; Fediuk, R.; Yerzhanov, A.; Nadirov, R.; Utelbayeva, A.; Agabekova, A.; Latypova, M.; Chepelyan, L.; Volokitina, I.; et al. Thermodynamic Simulation of Environmental and Population Protection by Utilization of Technogenic Tailings of Enrichment. *Materials* **2022**, *15*, 6980. [CrossRef]
64. Kolesnikov, A.S.; Sergeeva, I.V.; Botabaev, N.E.; Al'zhanova, A.Z.; Ashirbaev, K.A. Chemical and phase transitions in oxidized manganese ore in the presence of carbon. *Steel Transl.* **2017**, *49*, 605–609. [CrossRef]
65. Volokitina, I.; Vasilyeva, N.; Fediuk, R.; Kolesnikov, A. Hardening of Bimetallic Wires from Secondary Materials Used in the Construction of Power Lines. *Materials* **2022**, *15*, 3975. [CrossRef] [PubMed]
66. Volokitin, A.; Naizabekov, A.; Volokitina, I.; Kolesnikov, A. Changes in Microstructure and Properties of Austenitic Steel AISi 316 During High-Pressure Torsion. *J. Chem. Technol. Metallur.* **2022**, *57*, 809–815.
67. de Azevedo, A.R.G.; Marvila, M.T.; Antunes, M.L.P.; Rangel, E.C.; Fediuk, R. Technological Perspective for Use the Natural Pineapple Fiber in Mortar to Repair Structures. *Waste Biomass Valorization* **2021**, *12*, 5131–5145. [CrossRef]
68. Fediuk, R.; Amran, M.; Vatin, N.; Vasilev, Y.; Lesovik, V.; Ozbakkaloglu, T. Acoustic Properties of Innovative Concretes: A Review. *Materials* **2021**, *14*, 398. [CrossRef]
69. Abid, S.R.; Gunasekaran, M.; Ali, S.H.; Kadhum, A.L.; Al-Gasham, T.S.; Fediuk, R.; Vatin, N.; Karelina, M. Impact Performance of Steel Fiber-Reinforced Self Compacting Concrete against Repeated Drop Weight Impact. *Crystals* **2021**, *11*, 91. [CrossRef]
70. Amran, M.; Fediuk, R.; Murali, G.; Vatin, N.; Karelina, M.; Ozbakkaloglu, T.; Krishna, R.S.; Kumar, S.A.; Kumar, D.S.; Mishar, J. Rice Husk Ash-Based Concrete Composites: A Critical Review of Their Properties and Applications. *Crystals* **2021**, *11*, 168. [CrossRef]
71. Fediuk, R. High-strength fibrous concrete of Russian Far East natural materials. *IOP Conf. Ser. Mater. Sci. Eng.* **2016**, *116*, 012020. [CrossRef]
72. Fediuk, R.S.; Lesovik, V.S.; Svintsov, A.P.; Mochalov, A.V.; Kulichkov, S.V.; Stoyushko, N.Y.; Timokhin, R.A. Self-compacting concrete using pretreatmented rice husk ash. *Mag. Civ. Eng.* **2018**, *79*, 66–76.
73. Fediuk, R.; Pak, A.; Kuzmin, D. Fine-Grained Concrete of Composite Binder. *IOP Conf. Ser. Mater. Sci. Eng.* **2017**, *262*, 012025. [CrossRef]
74. Fediuk, R.; Smoliakov, A.; Muraviov, A. Mechanical properties of fiber-reinforced concrete using composite binders. *Adv. Mater. Sci. Eng.* **2017**, *2017*, 2316347. [CrossRef]
75. Zhanikulov, N.N.; Khudyakova, T.M.; Taimasov, B.T.; Sarsenbayev, B.K.; Dauletiarov, M.S.; Kolesnikov, A.S.; Karshygayev, R.O. Receiving Portland Cement from Technogenic Raw Materials of South Kazakhstan. *Euras. Chem.-Technol. J.* **2019**, *21*, 333–340. [CrossRef]
76. Lezhnev, S.; Naizabekov, A.; Volokitina, I. Features of change of the structure and mechanical properties of steel at ecap depending on the initial state. *J. Chem. Technol. Metal.* **2017**, *52*, 626–635.
77. Lezhnev, S.; Naizabekov, A.; Volokitin, A.; Volokitina, I. New combined process pressing-drawing and impact on properties of deformable aluminum wire. *Proc. Eng.* **2014**, *81*, 1505–1510. [CrossRef]
78. Zhangabay, N.; Sapargaliyeva, B.; Utelbayeva, A.; Kolesnikov, A.; Aldiyarov, Z.; Dossybekov, S.; Esimov, E.; Duissenbekov, B.; Fediuk, R.; Vatin, N.I.; et al. Experimental Analysis of the Stress State of a Prestressed Cylindrical Shell with Various Structural Parameters. *Materials* **2022**, *15*, 4996. [CrossRef]
79. Bari, A.; Vigneshkannan, S.; Bari, J.A.; Easwaran, P. A General Study of Light Gauge Steel Structures—A Review. *Int. J. Adv. Res. Methodol. Eng. Technol.* **2017**, *1*, 1–4.
80. Gullbrekken, L.; Schjøth Bunkholt, N.; Geving, S.; Rüther, P. Air leakage paths in buildings: Typical locations and implications for the air change rate. *Web Conf.* **2020**, *172*, 05010. [CrossRef]

81. Zhangabay, N.; Baidilla, I.; Tagybayev, A.; Sultan, B. Analysis of Thermal Resistance of Developed Energy-Saving External Enclosing Structures with Air Gaps and Horizontal Channels. *Buildings* **2023**, *13*, 356. [CrossRef]
82. Zhangabay, N.; Tagybayev, A.; Utelbayeva, A.; Svetlana, B. Analysis of the heat-insulating material volume influence on thermal resistance of the developed facade structures with closed horizontal air channels. *Case Stud. Constr. Mater.* **2023**, *18*, e02026. [CrossRef]