Facade Structures for Energy-efficient Buildings

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Abstract. In recent years, there is a growing interest in energy-efficient building all over the world. This paper presents an analysis of the link between the upgrading of the building structures and overall sustainability of a building in the case of facade structures. This research combines such important aspects in design and construction as installation time of façades, energy efficiency and also flexibility of the architectural appearance of a building. The comparative analysis of different facade structures has been conducted in terms of energy efficiency, operation and installation time. The energy efficiency parameters of a facade structure are determined by thermo technical characteristics. The installation and labor costs are analyzed considering factory-assembled panels that are most frequently used in hard-to-reach regions with extreme weather conditions. The additional options for facade structures are also reviewed in the paper, that include microclimate control systems and ventilation facilities. Based on this study, the new type of the façade panel was created. This type of panel combines benefits of the studied facades. The paper presents the description of constructive solutions and thermo technical characteristics.

1. Introduction
Research and design of modern energy efficient facade structures make it possible to solve the problems of renovation of the existing buildings and constructing buildings within the shortest possible time, and also the problem of construction in inaccessible areas with harsh climatic conditions [1]. The present study describes most common facade solutions. The detailed analysis of facade structures and the comparison of strengths and shortcomings allowed to develop a new facade panel type.

The most important aspect of building construction in inaccessible areas or in regions with harsh climatic conditions is construction operation, the installation speed and simplicity of construction, to be more precise [2,3]. In most cases, it is preferable to manage without highly qualified builders. Both issues can be solved using modular wall structures. Furthermore, consideration should be given to thermo technical properties and performance of the structure.

2. The overview of different façade structures
In this section several different types of facade structures are described, which served as the basis for the development of the new type of facade panels [4].

2.1. Facade thermo panel
The facade thermopanel has two-layer structure: the external finishing layer and insulation (Figure 1). Clinker or ceramic tiles, ceramic granite or stone are mostly used as a finishing layer; and
polyurethane foam or stone wool served as an insulation layer. Some manufacturers add the third layer composed of oriented shaving moisture resistant plate to provide rigidity. Panel’s installation is produced with glue and anchors, joints between the panels are sealed with the elastic materials, which are compensate for thermal expansion of the external layer. The panels are compatible with any type of wall surface, however the surface should be perfectly flat otherwise the panel can deform. In that case, the purlin structure is installed on the wall surface for fastening the panels. The most significant shortcoming of this façade structure is condensation between the panel and wall. The reduction of construction and variety of facing layer are the main benefits of thermo panels [5].

Figure 1. Façade thermo panel.

2.2. Double-skin facade
The founder of DSF (double-skin facade) concept is Le Conbusier in the early 20th century. His idea of “neutralizing wall” involved the insertion of heating and cooling pipes between the glass layers. DSF is a glazed façade consisted of two layers of glass with a gap between them. Air flow in the gap is controllable. Depending on the weather conditions and loads on premises, the air flow can enters the gap space. The air flow from the gap can get directly to the premises or into the ventilation system (both in the supply and in the exhaust). DSF or climatic façade can be applied both in new construction and renovation [6,7].

The distance between glass layers of DSF ranges from 20 to 200 centimeters. Normally, low-emissive glass is used. The space between the glazings is a channel for the passage of air, which can be connected with the street, premises and ventilation system by means of opening valves. The gap serves not only as the air circulation channel but also a location for electric drives for internal and external transoms, sunscreen devices and service passages [8].

In winter, DSF operates as follows: air is supplied into the space between glazings through the opened outer transoms, where it is heated using hot walls and solar energy, and finally, the air enters the premises (Figure 2). In summer, the constant flow of outdoor air is going through the natural thrust along the façade allowing cool down the building slightly without artificial refrigeration use (Figure 3).

Furthermore, there is additional scheme of DSF usage: the cold outdoor air is taken away in the bottom part of façade, runs along the wall and gets heated at the same time there, and then flows into the supply ventilation system. In the air handling unit (AHU) the air is heated to required temperature, and after that the air comes into the building immediately (Figure 4). Accordingly, the building’s heat losses do not waste permanently but are taken by the air flow and return to the building back [9].
In terms of energy efficiency, the benefits of DSF are evident. The significant energy savings by using natural ventilation, pre-heating of intake air in winter, solar energy and reduction of conditioning period. Climatic facades get enough natural light and protect the premises from traffic noise at the same time. However, DSF’s cost is considerably larger. In comparison to the standard façade, DSF is comprised about 170-250% of its cost. The operating costs for the DSF maintenance are doubled. The usable floor space in buildings with climatic facades is declining.

Another important issue about DSF is possible atmospheric moisture condensation on the internal structures of façade. The question about the fire safety is required attention also. In case of fire the smoke can be diffused to other premises via internal space of climatic façade. The small, sound and virus diffusion are also possible the same way.

The latter problems can be solved by complexity the façade system using vertical and horizontal partitions [10].

2.3. Ventilated facade

The pre-hung insulated and ventilated facades have a number of advantages. They include energy savings, “breathability” of the façade that obstruct the condensation, considerable diversity of architectural appearance, low maintenance cost. Other benefits are the reduction of outside noise, easiness for cleaning and correction the imperfections of the front façade. The first issue worth mentioning is high resource intensity.

The second problem regarding the ventilated facades is deterioration in insulation quality. Shrinking, deformation and compaction of wool insulation lead to sharp reduction of thermo physical properties and, as a consequence, increase of building heat losses. In humid weather conditions the water penetrates into the façade structure through the slots of façade system. Over time, the wool insulation is destroying as a result of mass loss and reduction of the strength of material, especially with no windproof membrane. Part of wool fiber breaks down and turns into dust. For example, 9-storey building with ventilated façade may emit into the atmosphere about 75 kilograms of dust annually according to experimental studies [11]. This dust contains phenol which is dangerous for health. The use of windproof membrane to protect the insulation is dangerous from the fire safety point of view. Consequently, the use of windproof membrane is the third issue which needs to be resolved [12].

3. Research on new climatic façade type

The establishment of the new facade structure is based on prefabricated elements - facade panels. The panels are secured to the outer walls or barrier structures. They perform both thermal insulating and aesthetic functions.

The prefabricated panels may have the modular size, for example multiple of 300 millimeters. Angular panels, window jambs elements, trims are designed individually.
The prefabricated facade panel (hereinafter referred to as "PFP") consists of minimum four layers (Figure 5):
- thermal insulation;
- aquapanel by KNAUF;
- air gap formed by perforated girder;
- composite material.

For these PFP the insulation layer is composed of high density stone wool which is resilient to fire. Fire safety is required for this façade structure. The stone wool is protected from the environment impact with the Aquapanel Cement Board Outdoor by KNAUF. Aquapanel is made of durable construction materials: the core is based on portland cement and lightweight fill mineral material. Aquapanel provides such advantages as absolute resistance to moisture, resilience to mold, high impact strength, frost resistance and non-combustibility. It is ecologically clean material that protects the insulation from destruction. The retention and connection elements of panel structure are the perforated girders. The composite layers of the PFP that comprise the exterior façade surface are continuous due groove hermetic fastening. The composite layer is not conventional composite façade panels: the mineral filler in that case is made of stone wool and its sickness is about 50-60 millimeters.

For this façade structure several use cases are possible. In the research article two most efficient operation schemes in cold season are described.

In first case (Figure 6) the inlet cold air is moving into the ground heat exchanger, thereby heating the air temperature up ground’s temperature that is above zero. The air goes from the heat exchanger into the air gap of PFP. Therefore, the outdoor sub-zero temperature impact is offset by heated air flow moving along the façade. Then the intake air flows into the air handling unit (AHU) with filter, air heater and recuperator. Filtered and warmed to the required temperature air enters the premises. The exhaust air also goes through the recuperator, where it partially heats the supply air, thereby the energy consumption is decreasing.

In second use case (Figure 7), the intake air firstly enters the ground heat exchanger, and then it goes to the AHU. In the AHU it is warmed up and then the air enters the premises. The exhaust air is passing through the recuperator and then flows into the air gap of façade with the temperature approximately equal to ground’s temperature.

In summer period the use of such operation schemes leads to the heat gain reduction. As a consequence, the required capacity of air conditioning systems is decreasing.
Figure 6. The first use case of PFP application.

Figure 7. The second use case of PFP application.

4. Conclusion

The research is particularly useful for design and construction in regions with harsh climatic conditions and in hard-to-reach areas, where the short construction period is urgent [13,14].

Prefabricated façade panels were developed based on comparative analysis of different façade systems dealing with challenges and merging their features. The new façade structure type with PFP application requires further examination, experimental development and economic evaluation.

The investigation will be continued by the authors since the novelty and relevance of this issue are evident.

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