Organizational and technological sequence of the construction of an innovative type of hinged ventilated facade of a multi-storey building

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Abstract
Introduction: Systems of insulation and decoration of external walls in the format of hinged ventilated facades have an increasingly significant impact on the achievement of consumer and functional quality indicators for architectural (structural, construction) systems of multi-story civil buildings. The achieved variety of constructive solutions, materials and methods of construction requires a meaningful system organization based on multi-criteria assessment of technological methods of design, manufacture and construction.

Materials and methods: a systematic analysis factors, generally accepted theoretical and applied research methods (analysis, systems approach, generalization) aimed at applying modern knowledge to achieve practical goals and solve specific problems of building.

Results: Description of the main features of the innovative facade system. Methods for ensuring the conditions for structural strength, durability and environmental sustainability ventilated facade.

1. Formation features of constructive solutions of a hinged ventilated facade
The effectiveness of the use of the modern type of a ventilated facade, as a system of insulation and decoration of the external walls of building objects, characterizes the composition of the material and intangible features of a particular design solution [1, 2 and 3]:
- technical solutions and distinctive features of constructive implementation;
- system capabilities for tectonic and artistic-aesthetic display of the architectural image composition;
- assortment (grades and sizes) of component materials and products, including supporting structures, insulation, facade cladding materials and fasteners;
- an information database designed to analyze the source data and design indicators of the system functional quality, on base of such parameters as strength, thermal protection, durability, structural, environmental and fire safety;
- technical and economic indicators, including the cost and complexity of manufacturing, transportation, installation and operation during the specified service life;
- quality management system for the manufacture of component materials and products, including organization standards;
organizational and technological sequence and adaptability of installation techniques (construction).

A fundamental constructive solution to all known types of hinged ventilated systems is that a continuous layer of insulation boards and elements of the carrying frame or elements of the cladding support are installed and fixed on the outer surface of the external (supporting or self-supporting) wall from the outside. Placing the facing material in the design position is ensured by means of substructure elements installed with a certain clearance relative to the insulation [4, 5].

The differences between the types of systems are in various ways of attaching insulation plates to the supporting structures of the outer wall, in materials and forms of individual elements of the carrying frame (substructure), in the diagrams of their location on the wall surface, in the choice of facing materials and how they are attached to the supporting elements of the substructure [6, 7, 8].

Figure 1 shows an example of the implementation of an innovative type of hinged ventilated system using copper-aluminum composite cladding elements in the form of panels or cassettes for a new construction project [9, 10].

Figure 1. Hinged ventilated facade with copper-aluminum composite cladding elements.

The main element of the type of facade system under consideration is a modular frame consisting of vertical profiles (guide rails) and brackets with inserts. An air gap of at least 40 mm is provided between the surface of insulation layer mounted on the supporting base of the external wall of the building and an outer cladding. Cassettes of copper-aluminum composite materials are used as an outer cladding of building facades (Figure 2).

Figure 2. Constructive solutions of hinged ventilated facades.
The range of possible structural solutions of the facade system allows the formation of five basic options for assembly scheme of the cladding support construction, differing in [9, 10]:

- type, number and arrangement of brackets;
- type and number of anchor dowels (anchors) designed to be attached to the supporting base of the external wall;
- the number and location of rivets in the joints of elements of the cladding support construction;
- placement of brackets over the entire accessible surface of the wall or only at the locations of floors.

The choice of a particular type of installation system is determined by design decisions that take into account the calculated combination of external loads and influences, the spatial location of walls and floors, the organizational and technological sequence of the construction of load-bearing and enclosing structures of buildings.

The most common method of organizational and technological sequence of installation of a hinged ventilated facade of a multi-story civil building involves the implementation of complex construction process of "element-wise assembly of the system". The structure of the complex installation process of the facade system is formed by a set of working methods, movements and operations carried out directly in the working area of the construction site [6, 10, 12].

The basis of organizational and technological sequence of complex installation process of the facade system includes the following working methods and operations:

- carrying out geodetic works with transfer and fixing of milestones for control and high-altitude mounting horizons on the surface of the walls according to facades drawings;
- filling door and window openings located in the outer walls;
- horizontal and vertical marking in accordance with the designed assembly diagrams;
- control tests of the strength of hammering anchor dowels into the material of the bearing base of the wall;
- installation of openings frames, installation of brackets and installation of insulation on the surface of the external wall;
- installation of a vapor-permeable hydro- and windproof membrane;
- installation of guiding elements of the substructure;
- alignment of guide elements on vertical and horizontal planes;
- installation of cladding materials (plates, panels, cassettes) and removal of traces of dirt from cladding materials.

Installation of cladding material (cassette panels and cassettes) is the most demanding and time-consuming stage of the complex installation process of the facade system of a multi-storey building. It is allocated into independent elementary construction production line.

Preliminary design development of the layout of guiding elements of the cladding support structure is the rationale for the designation of dimensions and spatial location of assembly sites. The selected dimensions of cassettes and panels of the facing copper-aluminum composite material take into account geometric parameters of the external wall in the scale of the height of the floor (tier), the strength characteristics of structural elements of cladding support structure and exclude the need for additional measures for trimming or fitting in place.

The panels of facing material are fastened to guides of the cladding support structure using clamps, which are fastened to the side ends of cassettes with rivets. Hitches are installed before mounting the cassettes on the guides.

The main features of organizational and technological sequence of facing material installation and the working area formation are presented in Figure 3.

Installation of cassette panels starts from the upper tier of a multi-storey building and continues in the direction of “top-down” and “from left to right”. After the installation of facing material cassettes
in the upper tier is completed, scaffolding is dismantled on this work zone and moved to the next work zone (lower tier).

Figure 3. Organization of the working area and the direction of development of the elementary construction production line for the installation of cassettes and panels of facing material

The development of the elementary construction production line in “top - down” direction allows us to provide conditions for combining various construction processes in space and time. The most rational combination is the arrangement of structural elements of a hinged ventilated facade (from the outside of the building) and the arrangement of interior decoration of premises (the building interior), as well as engineering systems and equipment of a multi-story building.

The considered organizational and technological sequence of the installation of a hinged ventilated facade allows the use of the following basic methods of logistic support of construction with material resources [13, 14]:

- organization of temporary storage or stockpiling of elements of the facing structure and facing material at the on-site warehouse;
- organization of an integrated construction process using Just in Time technology, in exact accordance with the calculated needs for one-shift (hourly) production of construction products.

Delivery to the working area (at each of the installed mounting levels) of structural elements of facade systems, tools and fixtures is carried out using lifting mechanisms.

2. Factors of influence on the formation of organizational and technological sequence of construction production.

The composition of organizational and technological sequence of the installation of a hinged ventilated facade is influenced by a combination of subjective and objective factors, which can conditionally be divided into two groups: internal and external factors of influence, characterized by objective and subjective features.

Objective factors of influence include [15, 16]:

- compositional and design features, level of responsibility and technical complexity of a building’s structural and construction system;
- quality of the composition and content of design (organizational and technological) solutions;
- type of construction (new construction, reconstruction, renovation);
- time (season) of the year;
- local conditions, climatic features, the presence of special conditions on the construction site;
- established technical and economic indicators and characteristics of the functional quality of construction products.

Subjective factors include the following factors of influence:
- level of qualification and competence of construction personnel;
- personified nature of the implementation of working methods, movements and operations that make up simple construction processes;
- methods of splitting into elementary construction production lines associated with specific structural and technological features of structural elements of a hinged ventilated facade;
- algorithm for assessing the duration and complexity of each work operation (method, movement, process) included in the technological sequence.

The material representation of the modern concept of hinged ventilated facade is a demanding architectural and engineering design, in which various requirements, including conflicting, must be taken into account and optimized. It should be recognized that the best practice in arranging modern types of facade systems (especially those that involve innovative materials and technological methods) is technical support with the participation of developers of the corresponding facade systems. And as for the construction, it should be carried out with the participation of a specialized contractor with the appropriate production base and qualified staff [17, 18].

The analysis of organizational and technological sequence of the installation of hinged ventilated facade of a multi-story civil building (see Figure 1, 3) showed a certain discrepancy between technological and structural solutions of the system elements to the required level of functional quality of construction products and indicators of organizational and technological reliability of construction production.

The conditions for ensuring structural strength, operational durability, fire and environmental safety, artistic and aesthetic and architectural requirements determine the need for a systems engineering approach and the development of methodological foundations for the concept of industrial technology for the construction of facade systems, with the expansion and modification of the composition and capabilities of such components as: insulation, elements of the cladding support structure, as well as shapes, sizes and materials of facing [19, 20].

The obvious advantage of the structural elements of hinged ventilated facade in the form of a high degree of factory readiness can turn into a disadvantage under ill-conceived or unreasonable conditions for transportation, storage, preparation for installation and, in fact, the performance of installation work in the design position.

The methodological foundations of the concept of industrial technology for the construction of facade systems will allow us to develop and put into practice an effective algorithm for the manufacturability of design, production and construction of facade systems. Such an approach will allow not only to predict the directions and methods of development of the necessary characteristics of facade systems and achieve the required performance indicators, but also to get a tool to parry random deviations in the process of construction production.

3. Conclusions and discussions.

The main organizational and technological features of the construction of a hinged ventilated facade of the outer walls of a multi-storey building using innovative cladding materials (copper-aluminum composite panels) and structural elements of a cladding support construction are considered. The analysis of the results of applying the type of facade system under consideration indicates the need to develop a system-technical approach to take into account influence factors using mathematical modeling methods for organizational and technological sequence of assembly, logistics and installation.
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