Conceptual Designs of Kinetic Facade Systems

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Abstract. To make buildings more energy-efficient, reduce harmful atmospheric emissions, improve the quality of the indoor environment, researchers from several countries have designed (and in some cases, made) conceptual kinetic facades. These have different designs, materials, and control methods. Kinetic facades as an architectural solution are still at infancy in Russia for several reasons. This paper presents the concept of a building featuring kinetic facades for a city in the south of Russia. The appeal of such innovative shading systems comes from extreme exposure to sunlight during the hot seasons, which overheats the indoors, necessitates expensive air conditioning, and creates luminous discomfort. The paper presents the kinetic facade parameters calculated with adjustment for solar geometry and the orientation of the facade. Computer simulations of two facade designs prove both effective for shielding.

1. Introduction

Today’s architectural trend is dynamics, i.e. the ability to transform and adapt the shape, volume, and shell of a building. The trend is in line with the principles of sustainable architecture that seeks to meet people’s needs exceptionally well. One of the principles lies in finding an optimal combination of “stationary” and “flexible” elements in building design [1]. Stationary systems (the frame, the walls, and the equipment) can be combined with movable systems (shells, covers, and equipment).

Kinetic (dynamic) facades are an architectural design solution that is gaining traction. Kinetic facades can protect the indoors from sunlight, control the exposure to natural lighting, reduce heat losses and noise, etc., while often featuring an expressive appearance.

The EU Member States’ stringent requirements to the energy efficiency of buildings call for innovative solutions that can cut energy use in any section where it is possible. Research and development of adaptive facade systems is prolific in Europe and the United States.

This, unfortunately, is not the case for Russia. This paper presents the author-developed concept of a building featuring a kinetic facade system for a southern region in Russia. The authors view this system first and foremost as an innovative shading solution, which is why the design adjusts the facade orientation for solar geometry.

2. Kinetic facade research

Adaptive facades represent a milestone in the evolution of facade technologies. This new area of research builds upon the existing best practices whilst having new terms and definitions. Thus, some researchers have proposed to classify adaptive facade system on the basis of technology and control systems in use [2]. ‘Smart’ facades include biotechnological, interactive, and intelligent facade systems. Intelligent facades tend to use innovative materials that alter the physical and geometric
properties of the facade by responding to environmental change [3,4]. In this typology, a kinetic facade is a facade system that moves by a certain pattern to change the position or alter the geometry of the facade or its parts [5]. Below are some of the proposed kinetic facade system concepts.

Energy frames [6] are modular frame systems that ‘clip’ onto the outside of the window frame. The dynamic shading solution in this system is quite conventional: (1) movable blinds to protect from sunlight whilst still providing enough illumination and outlook; (2) an opaque screen; (3) a transparent element featuring low-emission glazing. Innovation here lies in the smart facade control system.

Multi-sectional facades [7] split a kinetic shading system into sections to provide comfortable illumination indoors. The upper part is used to let the useful sunlight in. For deep rooms, it is recommended to use blinds, light shelves, and films. The central part uses roller shutters, blinds, or roller shades that are easy to adjust. The lower part can be opaque.

Paper [8] dwells upon the Adaptive Box Window (ABW) concept. This is an adaptive shell that can be used as a system of bay windows, also suitable for renovating the existing buildings. ABW comprises stationary and movable (opaque and transparent) parts. In addition to kinetic shading systems like sun curtains and blinds, ABW uses photovoltaic panels to generate renewable energy. These panels contain innovative dye-sensitized solar cells (DSSC).

European countries are widely adopting active solar energy to electricity conversion, i.e. photovoltaic conversion. Photovoltaic modules are integral to it. The system uses a photovoltaic generator to provide enough power and voltage [9]. Photovoltaic systems can be installed on any sunlit part of the building’s outer shell, be it the roof, the facade, or the sunscreens. Built-in photovoltaic modules provide not only electricity but also esthetics and some other functions.

Paper [10] presents the Adaptive Solar Facade [10] technology. ASF is centered around a dynamic multifunctional module. The module provides shading, electricity generation, and sunlight distribution. The authors designed the mechanics and the architecture of the ASF system as well as a sun tracker for it; they also devised a convenient kinetic facade design algorithm.

Among other things, their study also analyzed the shape of shading structures. Biomimetic methods and uniform approaches to the use of natural and architectural features help design more complex yet more efficient kinetic elements to adapt the building to climate change [11]. Paper [12] takes an opposite approach as it proposes a simpler adaptive facade design methodology that is based on redesigning the existing facades.

This paper analyzes the today’s best practices of kinetic facade design to propose a conceptual office low-rise featuring kinetic shading to be constructed in Rostov-on-Don, a southern Russian city.

3. Building concept featuring kinetic facades for Russian south
Understanding the need to keep indoor temperatures comfortable during summer while minimizing the energy use, Russia has adopted a new standard: SP 370.1325800.2017 Sunscreens for Buildings. Design Guidelines. The fact this document has been adopted emphasizes the need to shield buildings from excessive sunlight, especially in the south of the country [13].

In terms of total insolation, Russia can be divided into five regions, each of which has a specific season of overheating (the hot season). For this season, windows need to be shielded from sunlight.

To develop a kinetic shading facade concept, the research team chose the region that is exposed to high total insolation: ~1200 kWh/m². Rostov-on-Don is located in Region IV, where it is recommended to shield translucent fencing and shells from sunlight from April 22 to August 22. These requirements served as the foundation for designing the conceptual kinetic facade presented herein.

3.1. Building Design Concept
Presented herein is a concept design of a two-storey office building. A popular riverside location nearby and a great view of the Don River to the south of the building were the decisive factor when choosing the site.

The glazed south- and west-facing facades both feature a kinetic system comprising several parallel fins. This solution provides a sunscreen effect while using less materials and optimizing wind
resistance. The fins are horizontal on the south-facing facade and vertical on the west side to best protect the indoors from insolation and overheating, see Figure 1. The goal was to fully protect the indoors from direct sunlight during the hot season while maximizing the use of natural illumination indoors.

3.2. Horizontal kinetic fins on the south-facing facade

Normally, the south-facing facade is shielded using stationary outside horizontal blinds, the strips of which are either perpendicular or otherwise fixed in a specific angle to the facade plane. The kinetic system proposed herein adjusts this angle as the Sun moves through the sky. The south-facing facade needs sun shielding the most in summer from 9 am to 3 pm.

To calculate the facade geometry, the authors used data on the position of the Sun during the hot season at 48°N (Rostov-on-Don). Figure 2 shows the calculation diagram.

The shading system parameters arise from the position of the Sun as follows:

\[
\begin{align*}
  a - b \cos \beta &= \frac{\tan h}{\cos \alpha}, \\
  b \sin \beta &= \cos \alpha \\
\end{align*}
\]

where \(a\) is the distance between the fins, \(b\) is the fin width, \(h\) is the sun’s altitude, \(\alpha\) is the angle between the solar azimuth and the facade azimuth, \(h^* = \arctg \left( \frac{\tan h \cdot \sec \alpha \right), \beta\) is the fin-to-facade inclination angle, the maximum angle at which the glass under the fin is shaded.

The fin width \(b = 0.95\) m; the inter-fin distance \(a = 1.60\) m based on the preliminary calculations for the three summer months.
To exemplify the method, Table 1 shows the position of the Sun and the calculated angles for August, 12 to 3 pm. Figure 3 shows the results of a computer simulation of how these horizontal kinetic fins would work. To verify the shielding efficacy of the system, the research team used Autodesk Revit, a software suit where the user can set the Sun’s position according to the calendar day and time for a specific geographic latitude.

**Table 1.** Position of the Sun and horizontal fin inclination to the facade in August.

| Time, h | Solar azimuth angle | α  | β  |
|---------|---------------------|----|----|
| 12.00   | 180                 | 0  | 53 |
| 13.00   | 203                 | 23 | 41 |
| 14.00   | 225                 | 45 | 36 |
| 15.00   | 241                 | 61 | 30 |

**Figure 3.** Horizontal fin positions, August 14: (a) 12 pm; (b) 2 pm; (c) 3 pm.

3.3. **Vertical kinetic fins on the west-facing facade**  
To determine the width and the inclination of the vertical fins that would completely shield the window from insolation, the research team assumed the following. When solar beams fall perpendicularly to the facade, a fin should fully cover the glazed section to protect it from insolation. The inter-fin distance $a_1 = 1 m$. Thus, the fin width $l$ is also $1 m$. Figure 4 shows that for beam-to-facade azimuth angle $α$, the vertical fin-to-facade angle $γ = 2 α$. Table 2 shows solar azimuth values and the angles $γ$ and $α$ for the second half of the day, August 14th.

**Figure 4.** Vertical fin calculation diagram.

**Table 2.** Solar azimuths and vertical fin inclination to the facade in August

| Time, h | Solar azimuth angle | α  | γ  |
|---------|---------------------|----|----|
| 14      | 225                 | 45 | 90 |
| 15      | 241                 | 29 | 58 |
| 16      | 255                 | 15 | 30 |

**Figure 5** shows how efficiently the kinetic facade shields the windows as its vertical elements rotate.
4. Conclusions
This article proposes a direction-adjusted kinetic facade design. The design uses conventional horizontal fins on the south-facing facade and vertical fins on the west-facing facade; however, they are movable and rotate as the Sun passes through the sky. A dynamic facade protects the indoors from solar heat during the hot season to control natural lighting, ensure that the indoor temperature is comfortable, and help save energy that would be spent on air conditioning.

However, further research is required to make this design into an actual building. Kinetic facades are a promising architectural solution for Russia’s south.

Figure 5. Vertical fin positions, August 14: (a) 2 pm; (b) 3 pm; (c) 4 pm.

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