DEVELOMENT AND EVALUATION OF ENVIRONMENTALLY FRIENDLY FAÇADE ELEMENTS FOR DEEP RETROFITTING OF BUILDINGS

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ABSTRACT

The paper describes development and evaluation of a building envelope panel system based on advanced natural materials (thermally modified wood, laminated veneer lumber, wood fibre and cork thermal insulation). Properties of the product were proven by modelling, calculations and experiments inline with current standards on curtain walls systems and in addition life cycle assessment (LCA) has been performed. Heat and moisture simulations proved that the design does not suffer from thermal bridges and has U-values at levels suitable for passive housing; air tightness testing proved high quality of design. LCA calculations compared the system to an aluminium-based alternative and show significant potential for savings in embodied energy and carbon footprint by using the developed system.

Keywords: curtain wall, modular façade systems, panels, natural materials, deep retrofitting

INTRODUCTION

Efficiency of energy production and consumption became a key subject of European legislation and regulation of the recent years [1]. Proposed targets of 20% reduction in primary energy consumption in EU until 2020 focus on the sectors with the highest saving potential for the lowest investment – transportation and construction industry. In the construction industry of Central Europe the focus is shifting from new buildings to retrofitting. According to the study *Europe's buildings under the microscope* [2], 25 % of the European building stock is represented by non-residential buildings and 48 % of existing buildings was built between 1961 and 1990. Research and development presented in this paper is focused on non-residential buildings featuring light panel curtain walls built in the former Czechoslovakia between 1961 and 1990. Authors estimate that each tenth non-residential building built in the time period has the target type of envelope, so the results are generally applicable to approximately 1,2 % of building stock in the Czech Republic.

METHOD

Review of typical Central European buildings with light curtain wall envelope

The buildings of interest were those with a load bearing superstructure (typically made of reinforced concrete or steel) with light curtain walls. These structures were usually used for typologies like schools, kindergartens, office buildings, medical centres, firemen and police stations, railway facilities, hotels, and restaurants (see Figure 1).

Figure 1: Typical representatives of the target typology – buildings with envelope made of light panels. Left: Main train station in Munich, Germany. Right: Elementary school in Pilsen, Czech Republic. Façade segment with smaller windows already replaced.

These buildings are now after 30 to 55 years due for renovation. The typical issues related to light building envelopes are: faded colors, obsolete look and loss of attractiveness for potential tenants; insufficient level of thermal insulation; malfunction of window hinges and locks rendering some windows out of order, failures of fixing and seal elements, water leakages, consequent insufficient air tightness and related winter discomfort and high operation cost. These buildings also lack shading devices resulting in summer overheating and some of the elements may contain asbestos boards (health risks).

In addition to the issues assigned to the envelopes, these buildings also suffer in building services and related low level of user comfort: obsolete heating systems with poor control; outdated electric installations and water piping; malfunctioning or often non-existent HVAC systems; ad-hoc-made data infrastructures.

Many of these buildings have been successfully renovated in the past 15 years, but a significant portion of the building stock still waits for renovation. Basically there are two most typical retrofitting scenarios, in both cases the obsolete envelope is completely removed. In the first (low-cost) scenario, mullion walls made of light autoclaved aerated concrete bricks with external thermal insulation system (ETICS) and plastic windows are used. In the second scenario the envelope is replaced by some modern curtain wall system, typically made of steel or aluminum. The research challenge was to make it from more environmentally friendly materials with lower embodied energy, whilst matching or surpassing the other typical technical features.

Design methodology

The research objective was to find a technical solution, which would serve the same purpose as traditional metallic building light envelope systems, whilst having lower environmental impact and comparable or better thermal properties, over 50% of the mass consisting of renewable materials, maximally utilizing local materials (produced in the country), dismantling and recyclability of the envelope system being as simple as possible.

The development has been made by a multidisciplinary team comprising structural engineer, building engineer, building physicist, experts on fire resistance, acoustics, air tightness, manufacturing of prefabricated timber elements and structures, and life cycle assessment. The design strategies were inline with the methodology developed in IEA EBC Annex 57, Subtask 4 [3, 4]. The optimized product was developed by utilization of the design strategies: components' service life optimization, substitution for bio-based materials, use of innovative materials with lower environmental impacts, design for deconstruction and use of recyclable materials. The design process has been iterative, step-by-step developing samples and continuously testing their properties.

RESULTS

Description of developed light envelope system based on natural materials

The research resulted in utilization of several advanced bio-based materials. Thermally modified wood with improved durability against decay well suited to applications involving demanding weather conditions (λ_d = 0,12 W/m^2·K), has been used for exterior elements. Cork thermal insulation (λ_d = 0,064 W/m^2·K), has been utilized for detailing in the window structure. The main structural elements of the façade panels were made of laminated veneer lumber (λ_d = 0,18 W/m^2·K), engineered wood product that uses multiple layers of thin wood assembled with adhesives. Wood fibers (λ_d = 0,038 W/m^2·K) were used as thermal insulation.

The resulting product is panel-based envelope system dubbed Envilop consisting of panels, which can have width between 1.2 and 1.8 meters; height can vary from 2.5 to 4.2 meters. There were designed two basic panels – transparent (Figure 2) and opaque. Standard thickness of the opaque parts of panels is 240 mm with mean thermal transmittance values ranging from 0.24 to 0.16 W/(m^2.K), depending on the type of the thermal insulation material used (basic panel comes with wood fibres). The panels' anchoring to the superstructure is designed in a way that all the modules are independent of each other and the design allows the panels to be installed quickly and it is also possible to deal with the entire load the envelope has to bear. For external surface can be used any type of light double-skin ventilated facade cladding or even standard ETICS. Default options come with glass, wood, and fibre-cement boards. Transparent panels are fitted with wooden windows Slavona Progression certified as class A by Passivhaus Institut; thermal transmittance of used triple glazing ranges from 0.70 to 0.54 W/(m^2.K). Technical solution of the casement allows the window to be fitted without the frame visible from the exterior. For limitation of summer sola heat gains, the panels are equipped with motor-controlled venetian blinds in an imbedded lintel box, separated from the structure by a vacuum insulation panel to limit thermal bridges. There were developed also design alternatives utilizing active renewable energy components (photovoltaic panels, solar heat collectors, or hybrid PV-T panels) and units for de-centralized mechanical ventilation with heat recovery. Default options for the interior side finishing are gypsum boards or standard additional wall with a cavity for electrical wiring, data cabling or heating system elements.

Figure 2: Typical composition of transparent panels.

Analyses and laboratory testing of real performance

Comparative life cycle assessment

The main motivation for the development of the new generation of light building envelope system was to achieve improved environmental performance in comparison with traditional metal-based light envelope systems. The optimization and evaluation of environmental performance was based on a simplified LCA, which compared two panels – typical aluminium panel (produced by SKANSKA LOP company) and the new wooden panel. Both products have the same U-values, thus the operational energy consumption and environmental performance of building operation are considered as equal and the main difference lays in embodied energy and embodied environmental loads. Details of the LCA are described in [5].

During the development was important to find the main critical points in the environmental performance of the envelope system. Therefore the contribution of different materials to the overall impacts was studied. All key environmental indicators of the wood-based variant were lower than in case of the aluminium-based variant (non-renewable primary energy input 41%; global warming potential 3%; ozone depletion potential 98%; acidification potential 30%; eutrophication potential 84%; and photochemical ozone creation potential 34%). The objective of creating a structure, which is friendlier to the environment than the conventional aluminium-based solution has been reached.

Hygro-thermal analyses

Set of 2-D dynamic simulations of both opaque and transparent panels and their crucial details have been performed. Special attention was given to the details with the highest potential for creation of systematic thermal bridges – horizontal and vertical joints of panels, box for rolled up blinds and installation of glazing units into window frames.

Durability testing

Envilop panels are subject to long-term testing. Four prototypes of full-scale modules were manufactured and installed in a façade opening of 3 x 3 m in size (Figure 3, left). The installed modules are of two different compositions using: wood-fibre and vacuum insulation; and wood-fibre and aerogel insulation. Two modules placed above each other have the same composition, both bottom opaque panels have the same wooden cladding and the upper panels with glazing are equipped with photovoltaic panels and electric-run shading system. The installed samples face the natural outdoor environment on their exterior side and a simulated interior environment of conventional buildings on their interior side. The behaviour of the samples is monitored using temperature sensors, relative humidity sensors and weight of moisture sensors embedded in panels and in modules' connections. The test started in November 2014 and is designed to run for at least 12 months to acquire the year-round data.

After thorough laboratory testing and further fine-tuning of details, the final elements will be installed on a testing steel frame in front of south façade of the University Centre for Energy Efficient Buildings in total area of 48 m^2 (see scheme on Figure 3, right). The main purpose of the installation is to show to potential producers and customers the system as a whole in various dimensions, levels of equipments (venetian blinds, horizontal shading devices,) and exterior finishes.

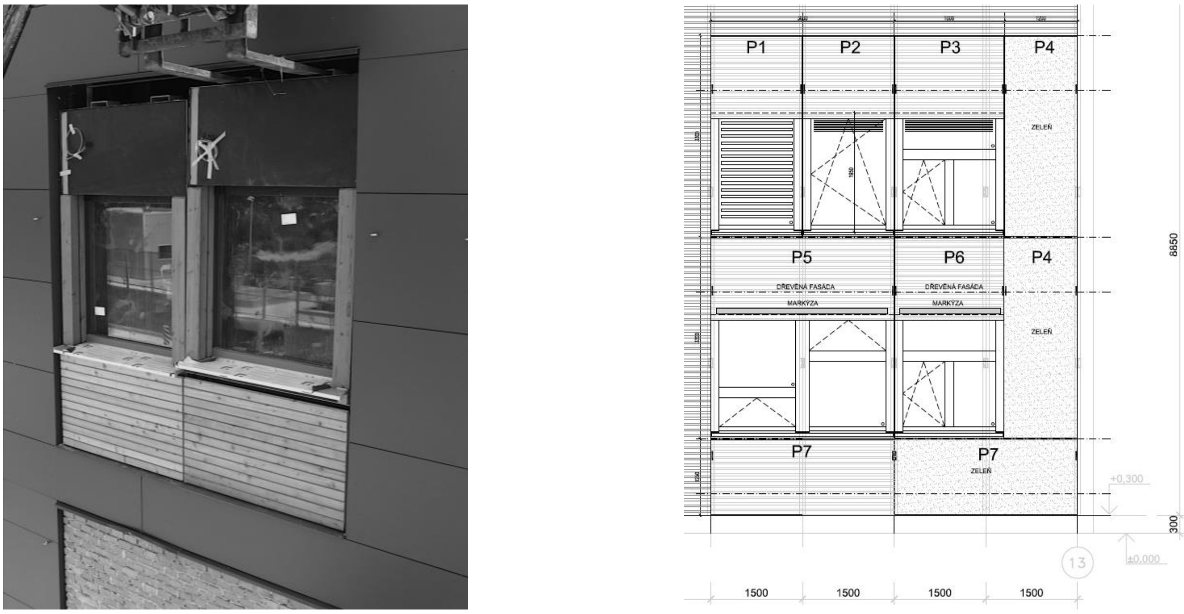

Figure 3: Long-term durability testing of the light bio-based envelope system. Left: Installation of four panels equipped with temperature sensors, relative humidity sensors and weight of moisture sensors embedded in panels and in modules' connections (measurement since November 2014). Right: Experimental setting of panels with various surface finishing (total area 48 m^2, installation June 2015).

Laboratory testing of acoustics and fire resistance

The Envilop panels have undergone accredited tests in a professional acoustic chamber according to standards ČSN EN ISO 10140-1, 2 and 4 and ČSN EN ISO 717-1. The measured weighted airborne sound insulation R_W (C; C_{tr}) of the opaque panels was 41 (-2; -6) dB and 38 (-2; -5) of the transparent panels (with triple-glazed wooden windows). Special fire resistant variant of the panel was designed by replacing interior and exterior wooden oriented strain boards by fire resistant boars; fire expansion tapes were installed into joints' sealing. The measured fire resistances were 60 and 90 minutes EI(I>O) 60 DP3 and EI(I<O) 90 DP3 according to ČSN EN 1364-3:2014 (Figure 4).

Figure 4: Testing of fire resistance EI(I<O) of EnvilopFIRE – laboratory setting, view into fire chamber after 90 minutes of experiment, and thermal monitoring of surface temperatures.

CONCLUSIONS AND FUTURE WORK

The project has proved that bio-based envelopes for buildings represent a viable alternative to the traditional metallic systems. The future development will continue with focus to reach higher flexibility in shape and sizing, to improve external design and to integrate additional features. The research results are further developed within H2020 project MORE-CONNECT (Development and advanced prefabrication of innovative, multifunctional building envelope elements for MOdular REtrofitting and smart CONNECTions) which aims at development of prefabricated modular solutions for a quick massive renovation of existing buildings to nearly zero energy standard.

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