# Curtain walls for building retrofit purposes


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## Abstract


The first part of this paper describes how a façade of a 40 years old campus building in Prague has been replaced. This replacement served as an impulse for a) a discussion about energy performance, b) our own development work. As the replacement used quite high-quality curtain wall elements, the resulting situation in terms of energy performance of the building is quite different: the transmission heat losses have been minimized. The ventilation strategy has become a key factor in both the energy use and indoor environment quality. Given the low g-value of the high-quality glazing and efficient shading system, solar gains are not significant compared to internal heat gains. All these aspects should be considered advantageously when creating overall new energy solutions and setting targets for the building design.

The second part of this paper presents the development of the curtain wall element (panel) itself with a special focus on the environment. Renewable materials replacing aluminum and oil-based products with wood or wooden products are used to the highest possible extent together with active renewable energy components (PV). It is also possible to use units for de-centralized ventilation and other features (supporting grid for greenery, etc.) The paper contains thermal analysis, material solutions and environmental assessment of the newly developed products, and the lessons learned from prototyping.


## Introduction

Since 1960´s, a significant share of facades on non-residential buildings has used light-weight curtain walls [1]. In the past, such solutions were characterized by a high energy-demand in terms of space heating. Moreover, the curtain walls with their large glazed areas and low thermal inertia have contributed to overheating the buildings and/or led to a significant cooling energy demand.

Many of these facades have already been replaced, however, many of them remain more or less in their original state, including more than 300 school buildings solely in the Czech Republic [2]. Other countries in Central Europe appear to be in the same situation. An advanced, industrialized way of assembly can be used for new and more efficient generation of building envelopes.

## Real case study

One example is a 40 years old campus building in Prague that was refurbished during 2013 (Fig. 1). The old curtain wall with very poor performance was completely removed and replaced by a new element façade [3] of a significantly higher quality which meets today’s recommendations in matter of energy efficiency.

### Building description

This tall building has a form of a simple cuboid with 15 floors and was finished in 1971. It was constructed using a curtain wall corresponding to existing requirements and the state of the technology. Probably due to high investment costs, the originally planned mechanical cooling of the building was not installed. The offices are oriented mainly to the SW façade. Seminar and meeting rooms are situated predominantly on the opposite side (NE). Ever since the building has been in use, problems with overheating and high energy consumption have been reported. Old elements were completely removed. New elements [3] differ in size (double width) and in overall quality (see Tab. 1). The new façade uses more appropriate size and type of window openings (Fig. 1). Motor-operated and locally/centrally controlled venetian blinds are integrated into the SW elements.

**Figure 1 - left: the original curtain wall during disassembly (March 2013), right: the new curtain wall (July 2013). In both cases we can observe indoor and outdoor venetian blinds and different window openings.**

### Technical data and energy performance discussions

Table 1 compares main technical data of the original and new elements, respectively. Generally, the fundamental change in the quality of the building envelope implies necessary changes in the heating and ventilation of the building, otherwise the optimum and indoor quality cannot be reached. Table 2 presents the results of an indicative calculation of heat losses and heat gains for the selected floor of the building during the heating season. The results of this calculation are always subject to uncertainty associated with highly variable occupancy of the building; it is possible to make only rough estimates of heat gains from the office equipment, as well as of the volumetric flow rate of ventilation air.

It is also evident that even at very cold external air temperatures, internal heat gains (metabolic heat and office equipment) in daytime are significant. On the other hand, passive solar gains are generally low during this period. They are influenced by a low-intensity solar radiation and by the use of the glazing (low g-value) designed to prevent the risk of overheating in summer.

Table 3 illustrates a theoretical temperature of the external air above which there is no need to use conventional heating (at this temperature, heat gains and heat losses are balanced). Such temperature is surprisingly low, especially due to higher occupancy and the use of heat recovery in the mechanical ventilation system. In the case of not sufficient ventilation (B, D in Table 3) such threshold temperature could be even lower but the comfort requirements would not be fulfilled.

Additional use of the waste heat from local server units on the given floor (approx.10 kW in our case) would again change the results dramatically. It is necessary to use smart technical systems with intelligent control in order to actually exploit these heat gains

**Table 1: Main data concerning the original and new curtain wall**

| | | |
|---|---|---|
| Original curtain wall | | |
| | Short characteristics | Thermal transmittance [W/(m²K)] |
| Opaque part (42 %) | Polystyrene 60 mm | 0.6 |
| Transparent part (58 %) | Double glazed in metal frames | 4.0 |
| | Estimation taking into account significant thermal bridges | Mean value $U_{mean}$ 3.0 |
| Shading | Blinds alternatively placed on the interior side or between glazing panes, sun protective foil additionally placed on the interior surface | |
| New solution | | |
| Opaque part<br>SW: 48 %<br>NE: 37 % | Mineral wool 140 mm,<br>extruded polystyrene 50 mm | 0.19 |
| Transparent part<br>SW: 52 %<br>NE: 63 % | Triple glazing, insulating edge | SW: $U_g$ 0.5<br>NE: $U_g$ 0.6 |
| | | Mean value<br>SW: $U_{mean}$ 0.68<br>NE: $U_{mean}$ 0.87 |
| Shading | SW: integrated venetian blinds, motor controlled + movable indoor blinds<br>NE: movable indoor blinds | |

**Table 2: Simplified estimation of specific heat losses for one floor, comparison of the original and new solution (according to EN ISO 13789)**

| | Original state 1) 2) | New state (2013) | Difference [%] |
|---|---|---|---|
| Specific transmission heat loss $H_T$ [W/K] | 1364 | 360 | -74 |
| Specific ventilation heat loss $H_V$ [W/K] at full occupancy (120 person) 3) | 550 | 550 | 0 |
| Total specific heat loss H [W/K] | 1914 | 910 | - 53 |
| Heating load at winter design temperature (-13 °C for Prague) [kW] | 65.1 | 30.9 | - 53 |
| Estimated heat gains caused by persons and office equipment (90 students + 30 members of the staff) [kW] | 14 | 14 | 0 |

1) Negative change in the quality in time (air-tightness etc.) is not taken into account.
2) Improvements of massive gable walls performed in the 1990´s have been considered.
3) Expected ventilation rate of 25 $m^3$/h.Pers.

**Table 3: Selected theoretical operational mode and rough estimate of the limiting temperature of the external air for heating off (simplified approach)**

| | Number of persons per floor | Ventilation rate [$m^3$/(h.pers.)] | Limiting temperature for heating (heating system no more in use) [°C] | |
|---|---|---|---|---|
| | | | No heat recovery from the exhaust air | Efficiency of heat recovery 70 % (in bracket: use of waste heat from server rooms) |
| A | 120 | 25 | +6 | -6 (-13) |
| B | 120 | 12.5 [1)] | -1 | not applicable |
| C | 60 | 25 | +10 | +5 (-8) |
| D | 60 | 12.5 [1)] | +6 | not applicable |
| E | 30 | 25 | -- | +12 (-3) |
| F | 0 | 0 | -- | -- (+4) |

[1)] Estimation for insufficient natural ventilation, often even worse in reality.

## Light-weight curtain wall made of wooden based panels

Inspired by the retrofit of the campus building, an alternative solution has been studied and proposed. System solution using a light-weight curtain wall of a panel type (Fig. 2) giving preference to wood-based materials has been designed in the framework of the Preseed06 research project at the University Centre for Energy Efficient Buildings [4]. The solution should primarily replace the obsolete type of curtain walling, but it can also be applied to new constructions. Main structural materials (panel supporting frame, exterior and interior design boards) and supplementary materials (thermal insulation and façade cladding, window frames and sash) of the proposed wall system are made of wood-based materials. The new panel is designed to allow easy assembly with the possibility of rectification. The system is executed with attention to detail. Where possible, the elements are prefabricated using precise CNC machines; main elements are made of advanced renewable materials. The joints connecting the panels enable installation without any extra work (no need of scaffolding on site) and thanks to flexible seals expansion movements are possible. Anchoring into the load-bearing ceiling plate is situated at the bottom part of the window sill. The panel is made in two variants: one with a window (transparent) and without it (opaque).

The panel can be used with different additional components. An opaque part can have the form of a ventilated façade equipped with active renewable energy components (photovoltaic, solar heat collectors), supporting grid for greenery purposes or traditional cladding materials (glass, wood, fiber-cement, etc.). Units for de-centralized mechanical ventilation with heat recovery, motor controlled external blinds and other devices can be used as well to improve the overall energy balance of the building.

Typically, the basic module (panel) is extended with an additional wall with a cavity on the interior side. The piping (electrical wiring, weak current systems, heating distribution) or heating bodies can be installed here. Furthermore, it can contain control elements of the blinds, heating, cooling and ventilation.


**Figure 2: Scheme of a curtain wall made of wood-based panels.**

**Figure 3 left: The prototype during assembly - notice the cork insulation, right: View of the completed prototype No. 2.**

**Thermal analysis**

The technical solution meets a higher level of current requirements on thermal protection of buildings in the Czech Republic. The total thickness of the panel is 250 mm in the basic version and the thermal insulation material is 220 mm thick. Depending on the type of the thermal insulation material, this construction reaches thermal transmittance values ranging from 0,22 to 0,19 W/($m^2$.K). The quality of the thermal insulation can be further improved by using new generation materials (vacuum insulation panels, aerogels) which represent an advantage, as they can be placed into the protected position already in the factory without the risk of being damaged during the construction process. The "transparent variants" of the curtain wall are fitted with wooden windows Slavona Progression [5]. These windows are certified by the Passive House Institute and meet the requirements of the highest energy class A. The technical solution of the casement allows the window to be fitted without the frame being visible from the exterior. Triple glazing thermal transmittance ranges from 0.70 to 0.54 W/($m^2$.K)

These properties help decrease the thermal loss through the building envelope by 70 % in comparison to the old type of the curtain wall. Annual energy demand for heating and related costs of heating can be decreased by more than 50 % by changing solely the building envelope.

**Environmental assessment**

One of the important goals of and the motivation for the development of the new generation curtain wall was to achieve better performance in comparison to traditional metal-based curtain walls in the environmental assessment. Replacing the aluminum and oil-based products by wood or wooden products is the first step in the process of creating an environmentally efficient design. Specifically, the design used laminated veneer lumber, oriented strand board, cork and wood-fiber insulation, fiber board, etc. (see Fig. 2). This curtain wall contains 93 % by weight of wood-based materials in its opaque variant and 65 % by weight in its transparent variant. The following chart (Fig. 4) compares the mass distribution of the materials in the wood-based curtain wall (design in question) and in the standard aluminum curtain wall.

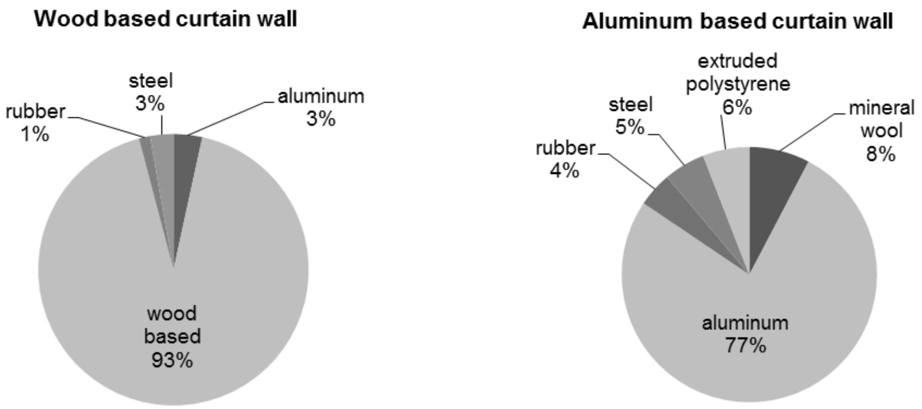


**Figure 4: Mass distribution of the materials in the wood-based and aluminum curtain wall (an opaque variant) with the dimensions of 3.3 (h) x 1.5 (w) meters.**

The next step consisted of an environmental assessment of the panel through a simplified analysis of the life-cycle assessment (LCA). For the purpose of the evaluation, the opaque variant of the curtain wall panel with its typical dimensions of 3.3 x 1.5 m has been chosen. The wood-based panel has been compared with other two alternatives for retrofitting a building.

- light-weight curtain wall made of aluminum-based panels
- aerated concrete masonry with ETICS with expanded polystyrene

Selected indicators describing the environmental performance of three different types of a building envelope are compared in the Table 4 and the Chart (Fig. 5). The wood-based panel achieves the best values in case of most of the evaluated parameters. For comparison, the energy consumption of the original panels was about 3050 MJ/$m^2$.

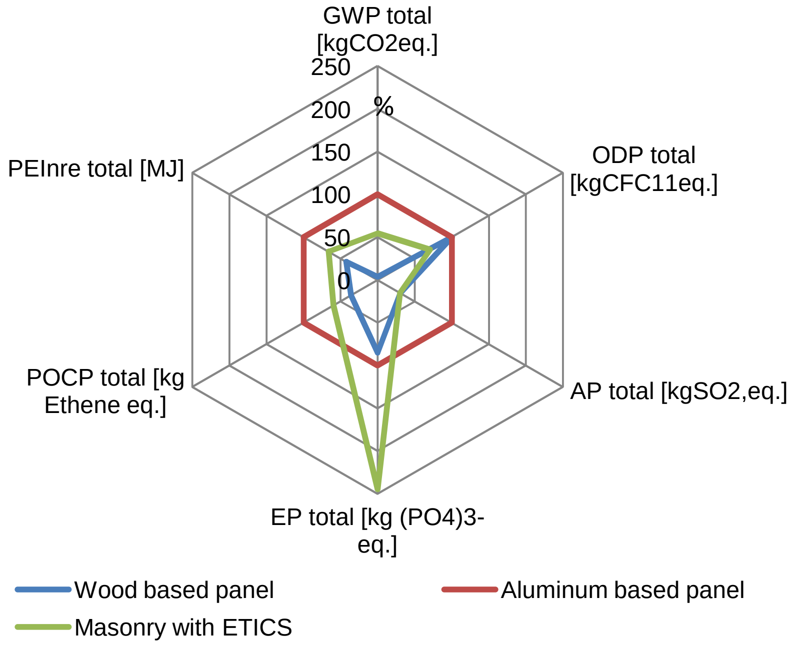


**Figure 5: Simplified multi-criteria evaluation of the environmental quality on the net chart.**

**Table 4: Comparison of the two main environmental indicators**

| | Wood based panel | Aluminum based panel | Masonry with ETICS |
|---|---|---|---|
| Embodied energy, *PEI* [MJ/m$^2$] | 1868 | 3225 | 2257 |
| Global warming potential, *GWP* [$CO_2$/m$^2$] | 6 | 168 | 92 |

**Concluding remarks**

We have shown that curtain walls meeting today's requirements and recommendations can result in a basically different energy performance. Ventilation strategy seems to be more important than the heat transmission (already significantly reduced), as far as indoor comfort and energy demand are concerned, especially in case of highly occupied buildings (schools, office buildings). Passive solar gains are no longer important as an energy source. In the campus building described in this paper, additional installation of a ventilation system with heat recovery is now under preparation. Hopefully, the waste heat from the local server situated in the building will be integrated into this action, too. Detailed monitoring of the resulting performance is planned as well.

The designed curtain wall system described in the second part of the paper will be tested as a prototype in the newly opened University Centre for Energy Efficient Buildings of the Czech Technical University in Prague [4]. The test will focus on thermal transmittance and thermal inertia, humidity and moisture related problems and the technology of assembling. Development should continue in order to reach high flexibility in sizing, to improve external design and to integrate additional features. Special attention will be paid to the problem of fire-safety. It can limit the use to a certain extent in line with the national legislation. Naturally, the proposed solution is suitable both for old and new buildings.

## Acknowledgment

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## References

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