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METHODS OF ASSESSING THE THERMAL PERFORMANCE OF CURTAIN WALL FACADES. SPECIFIC ENERGY AUDIT PROBLEMS

BY

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Abstract. To achieve a significant national reduction of greenhouse gas emissions in the construction sector, the Romanian government has aligned national policies with European regulations on the energy efficiency of buildings. For that, when constructing new buildings or renovating existing ones, the criteria associated with the concept of *nearly zero-energy building* (nZEB) are respected. Achieving this objective involves knowing the tools for evaluating the energy performance of the building envelope, considering the important weight it plays in the total energy consumption for normal use. The purpose of this paper is to highlight the possibilities of designers and energy auditors for buildings to evaluate, with a satisfactory degree of accuracy, the energy performance (EP) of curtain wall facades using the calculation methods proposed in SR EN ISO 12631:2018. A study on the influence of some representative parameters on thermal transmittance, carried out on a generic curtain-type facade element,

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supports those involved in the process of optimizing the solutions for new buildings or the renovation of existing ones.

.Keywords: Curtain walls, energy efficiency, linear bridging, thermal transmittance, energy audit.

1. Introduction

In today's world, the construction sector holds a key role in addressing critical challenges. Energy efficiency in construction is paramount, as buildings contribute significantly to global energy consumption and greenhouse gas emissions. This report delves into the vital interplay between energy efficiency, climate change, and the architectural features known as curtain wall facades. Curtain Wall Facades offer an opportunity to enhance sustainability while posing design complexities. Our exploration aims to reveal strategies for achieving energy goals and mitigating environmental impacts.

Buildings with curtain wall cladding facades take up an increasingly important place in the current urban landscape, covering from the simplest to the most sophisticated forms and constructive systems. For these buildings, of which the vast majority are used for offices or commercial spaces, it is necessary to elaborate on the Energy Performance Certificate, and in some cases the Energy Efficiency Audit.

The complexity of this facade system and the great diversity of constructive solutions make it difficult to apply the energy performance evaluation procedures recommended by the regulations in this field. These procedures refer exclusively to traditional structures (brick masonry, concrete frames with infill walls, large panels etc.).

An additional difficulty arises from the fact that, in general, the design of the curtain facades in terms of the type of glass, the sections of the components, the way to solve the joints etc., falls to the manufacturer, which makes it almost impossible for the building energy auditor to access the documentation details.

The present paper aims to present the methodology for calculating the energy performance (EP) for curtain walls, following the European regulations in force, namely EN ISO 12631:2017, based on which the main parameters that influence the value of thermal transmittance can be identified and evaluated.

2. Curtain Wall general elements; constructive structures

From an architectural point of view, the curtain wall facade system can be characterized as a facade system with a predominantly transparent surface, even the opaque areas integrated into the system being placed behind glazing. Currently, to increase energy efficiency, recent curtain wall facades also include photovoltaic panels (Figure 1).

Structurally, the curtain wall facade is characterized by the fact that the imposed loads from the self-weight and wind action are transmitted to the building structure through its self-bearing framed grid system. The self-bearing frame is composed of mullion (vertical) and transom (horizontal) bars made of aluminium or steel, anchored to the building, in most cases, at the floor slab level.

The structural elements (mullions and transoms) of an aluminium curtain wall system are usually made of extruded profiles from special aluminium alloys with closed cross-section (or tubular profiles for mullions) or with any cross-section shape (for transoms), machined in a factory and under the quality control of the manufacturing company.

Mullions transfer loads applied of the curtain wall systems to the main structural system of the building. The transom bars transfer part of the loads from the infill panels to the mullions.



Fig. 1 – Curtain wall facade with photovoltaic panels included (Theatre Heerlen, Heerlen, Netherlands, <https://www.schueco.com>).

The expansion that this constructive system currently knows is justified primarily by the association with the architectural perception of tall buildings, where the structure must be relieved as much as possible of additional loads from closing or compartmentalizing elements, but also by the technology based on modularity, prefabrication, elimination of wet time-consuming processes.

The concern for energy efficiency arose in the general context of the imperative need to reduce energy consumption from non-renewable sources and greenhouse gas emissions in the terrestrial atmosphere, responsible for climate change and global warming. As a result, the improvement of technologies implicitly includes the optimization of the system under the energy aspect in the

sense of increasing the thermal protection capacity, but also that of harnessing energies from renewable sources, respectively solar energy.

Regardless of the construction system adopted the configuration of a curtain wall facade system includes most of the following components (Fig. 2):

- the **own structural system** consisting of **mullions** (vertical elements) and **transoms** (horizontal elements) of tubular aluminium profiles, attached with brackets to the main structural elements of the building (usually at floor slab or perimetral beam level). “Mullions are assembled first, then horizontals are fastened to the mullions with clips or spigots” (Memari, 2013);
- **infill panels** are fitted into the rectangular openings (Anzia, 2019) created by the mullions and transom. The infill panels can be: transparent insulated glass panels or opaque spandrel panels (of composite aluminium sheet, stainless steel or even granite panel);
- **support brackets system** – of fixing, sealing and finishing devices (special parts, gaskets and putties);
- **opening components** (any combination of opening sashes for mobile window panel) and different types of sun screens, louvres and fins can be incorporated to provide shading.

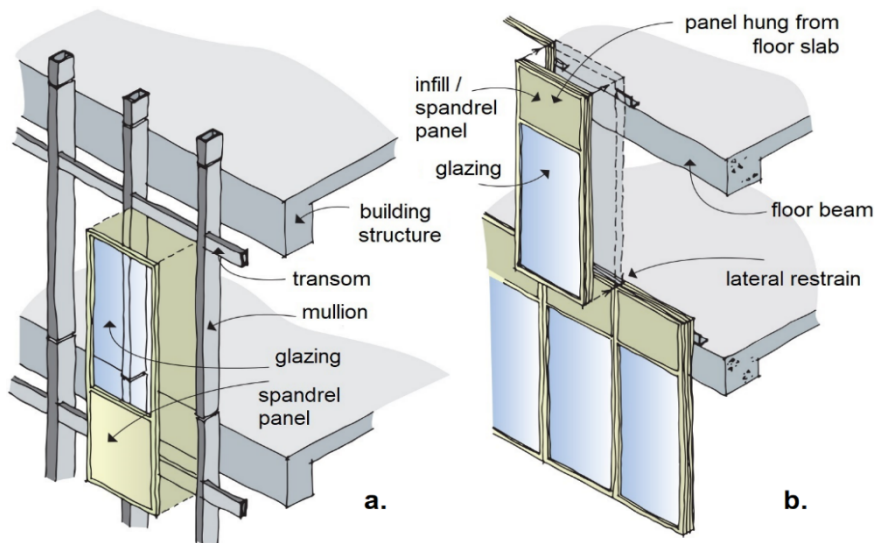


Fig. 2 – Curtain wall constructive systems: a. stick systems, b. unitised systems (Anzia, 2019).

3. Energy performance evaluation of existing buildings with curtain wall facades

The energy performance (EP) evaluation criteria for buildings with curtain wall facades are generally similar to those applied to all types of buildings, namely

the specific annual energy demand for heating/cooling (Kassem & Mitchellb, 2015). In this type of building, the area of the façade walls has a significant weight in the total area of the envelope, as a result, it is important to use an indicator specific to curtain wall facades, able to express their energy performance. This indicator is the thermal transmittance (overall heat transfer coefficient) U - measured in the international system of units (SI) in $[W/m^2K]$. U is calculated as the inverse of the adjusted thermal resistance, R' , considering the effect of thermal bridges of the analysed cladding element.

The assessment of the energy performance of existing buildings with curtain wall facades involves the following steps:

- the determination of the adjusted thermal transmittance, U_{CW}' / adjusted thermal resistance – R_{CW}' , for facade areas with curtain walls;
- the estimation of linear thermal transmittances (ψ_i) for external corner, wall-roof, wall-plinth or curtain wall-traditional facade joints, if applicable.

As seen in the flow chart of Figure. 3 the determining process of the overall U_{CW} can follow two ways, by measurement and / or by calculation. Since the measurement of the U_{CW} is too costly and time-consuming and it is not usually available to energy auditors for buildings, the calculation method according to standards in use (mentioned in the figure) can be used with good results, as a part of the input data for calculating building energy consumption.

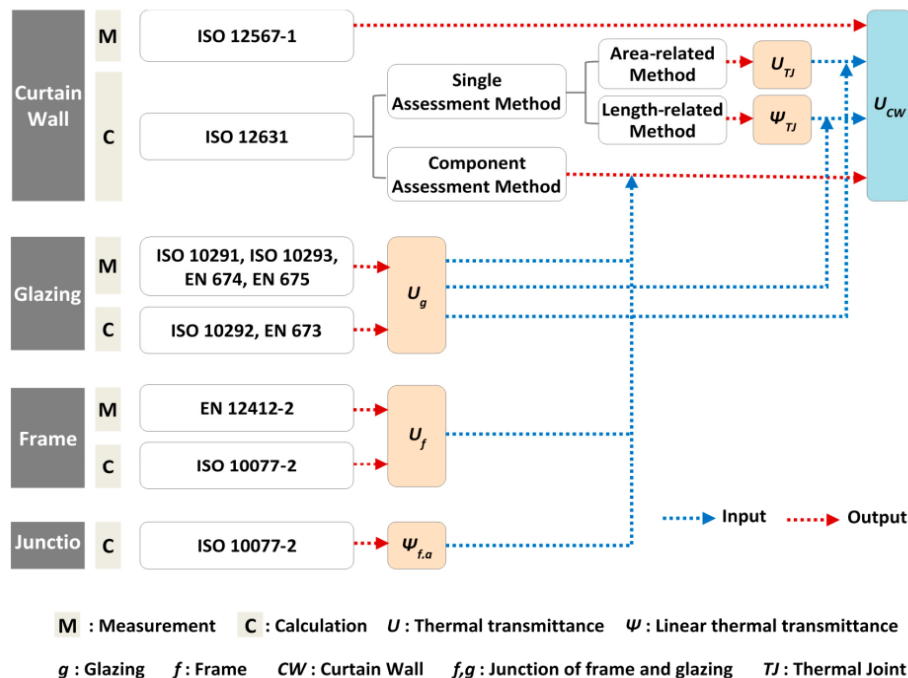


Fig. 3 – Flow chart of U_{CW} determining process (Oh H. O. *et al.*, 2016).

In the current practice of energy certification and energy audit of a building, the following situations can be encountered:

1) Existing building for which there is a design project, including for the curtain wall facade and certain information regarding its thermal characteristics, made available by the wall system supplier or producer.

It is the simplest case, in which the data provided by the supplier are used in the evaluation of the thermal performance of the building facade.

In addition, it is necessary to establish the linear coefficients of heat transfer (linear thermal transmittances) for the building thermal bridges that occurs at junctions between two or more building elements (facade corners, wall to roof, wall to plinth or curtain wall to traditional facade) if applicable.

2) Existing building for which there is a design project, including for the curtain wall facade but without certain information regarding its thermal characteristics. Based on this, the following information can be established:

- the geometry of the facade, respectively the distribution of mullions, transoms, opaque panels, glazing areas, movable or fixed parts;
- the presence of opaque panels;
- the geometric characteristics of the metal elements;
- details of joints;
- the thermal characteristics of the opaque/glazed part.

In these situations, the evaluation of the thermal performance of the curtain wall facade is carried out in compliance with the indications of SR EN ISO 12631:2018.

3) Existing buildings for which there is no building project or there is, but it does not contain the information about the curtain facade that would justify the inclusion in situation 1) or 2).

This is the most frequently encountered situation in practice and for which it is desired to develop a method or some recommendations, both in terms of energy performance evaluation and solutions to improve it, which would offer a unitary approach in terms of energy audit of buildings in this category.

3.1. Energy performance evaluation of curtain wall facades according to SR EN ISO 12631:2018

The application of the provisions of SR EN ISO 12631:2018 implies the existence of the curtain facade project, which includes all information related to:

- Geometry of the facade;
 - Sections of profiles for mullions, transoms, fixed parts, mobile parts;
 - Sections of joints;
 - Thermophysical characteristics for the metal part and the glazed part;
 - The composition of opaque panels and the thermophysical characteristics of the component materials.
- It is necessary to complete the following steps:

a) Delimitation of the characteristic domain, respectively of the representative reference areas.

The characteristic domain, respectively representative reference areas, represent portions of the facade that include all the elements with different thermal characteristics and are delimited by sectioning planes. Sectioning planes can be:

- a symmetry plane or
- a plane according to which the thermal flow can be considered unidirectional, not influenced by the presence of physical or geometrical discontinuities. This plane is perpendicular to the plane of the curtain wall facade (see Figure 4).

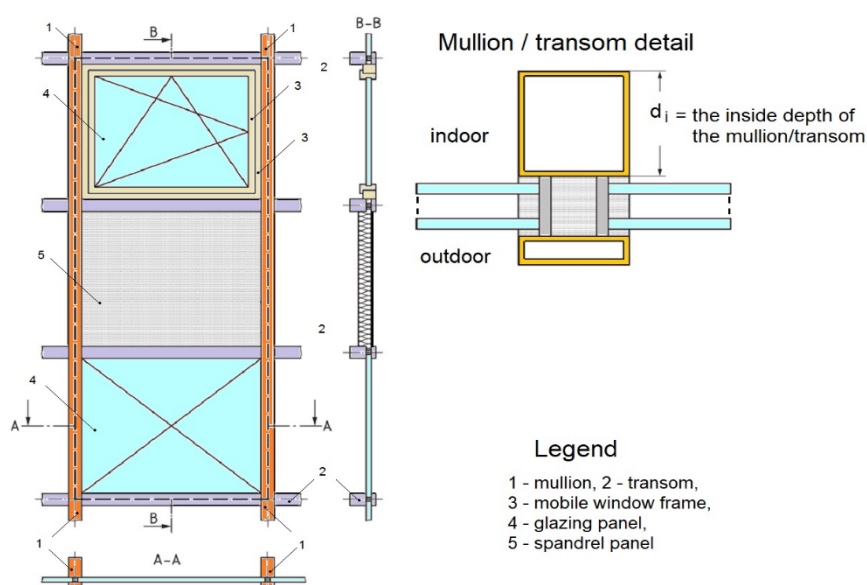


Fig. 4 – Representative area of a curtain wall façade.

Note: Figure 4, Figure 5 and Figure 6 are authors' own work designed in concordance with SR EN ISO 12631:2018 and standard drawn representation of Curtain Wall Facades.

b) Calculation of thermal transmittance U , for the characteristic domain.

The calculation of the thermal transmittance, U , for the characteristic domain can be performed by 2 methods, according to SR EN ISO 12631:2018:

- Single assessment method;
- Component assessment method.

The single assessment method can be applied to all types of curtain facades (unitised systems, stick systems, patent glazing, structural sealant glazing, rain screens, structural glazing).

Through detailed computer calculations of the heat transfer in the field (through the opaque and/or glazed elements) and the numerical modelling of the heat flow through each joint between two filling elements, will be obtained the heat transfer coefficients for the glazed panels, U_g , and for the opaque panels, U_p , and for the joints between two filling elements, either the area-related joint thermal transmittance, U_{TJ} , or the linear joint thermal transmittance, Ψ_{TJ} will be estimated. By weighting the U values (U_g , U_p , U_{TJ} , or Ψ_{TJ}) of the joints and the filling elements, depending on the corresponding area occupied in the facade, the U_{CW} value for the whole facade can be calculated. According to how the influence of the joints between two filling elements is estimated, there are two possible alternatives to this method, considering the area-related thermal transmittances U_{TJ} or the linear joint thermal transmittances Ψ_{TJ} .

The component assessment method is based on the same calculation principle that applies to closing elements with thermal bridges.

The general relationship for determining the adjusted thermal transmittance for a characteristic facade element is applied:

$$U_{CW} = \frac{\sum A_g U_g + \sum A_p U_p + \sum A_f U_f + \sum A_m U_m + \sum A_t U_t + \sum l_{f,g} \Psi_{l,g} + \sum l_{m,g} \Psi_{m,g} + \sum l_{t,g} \Psi_{t,g} + \sum l_p \Psi_p + \sum l_{m,f} \Psi_{m,f} + \sum l_{t,f} \Psi_{t,f}}{A_{CW}} \quad (1)$$

where:

U_g, U_p - are the thermal transmittances of glazing and panels;

U_f, U_m, U_t - are the thermal transmittances of frames, mullions and transoms;

$\psi_{f,g}, \psi_{m,g}, \psi_{t,g}, \psi_p$ - are the linear thermal transmittances due to the combined thermal effects of glazing or panel with frame or mullion or transom;

$\psi_{m,f}, \psi_{t,f}$ - are the linear thermal transmittances due to the combined thermal effects of frame mullion and frame transom;

The area of the curtain wall is given by:

$$A_{CW} = A_g + A_p + A_f + A_m + A_t \quad (2)$$

where:

A_{CW} - is the area of curtain wall facade; A_g - is the total area of glazing;

A_p - is the total area of panels; A_f - is the total area of frames;

A_m - is the total area of mullions; A_t - is the total area of transoms.

The characteristics areas (from constructive and heat transfer considerations) are determined according to Figure 5.

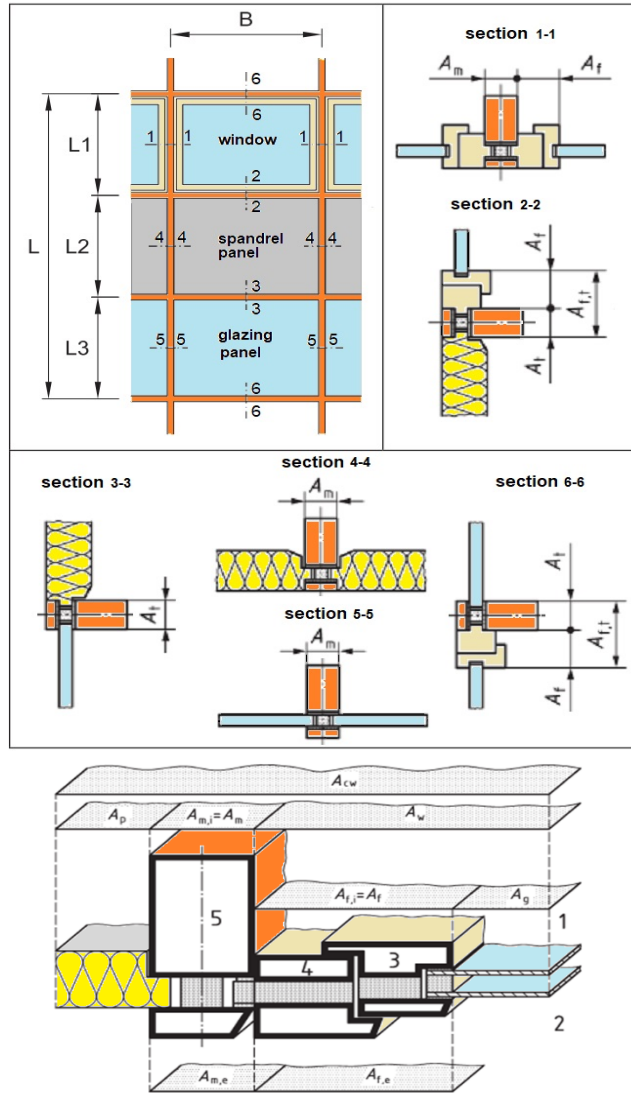


Fig. 5 – The characteristic areas of the component elements.

Legend:

- | | | |
|------------------------|-----------------------------------|---------------------------------|
| 1 – internal / indoor | A_{cw} - curtain wall facade | A_f – frame area |
| 2 – external / outdoor | A_p - panel area | $A_{f,e}$ – external frame area |
| 3 - sash (movable) | A_m - mullion area | A_g – glazing area |
| 4 - frame (fixed) | $A_{m,i}$ - internal mullion area | |
| 5 – mullion or transom | $A_{m,e}$ - external mullion area | |

3.2. Existing buildings for which there is no design project or there is, but it does not contain information about the curtain façade that would justify the inclusion in the case 1 or 2

Analyzing the calculus relationship of the thermal transmittance for the curtain façade by the component evaluation method, the main parameters that intervene and the factors that directly influence them can be identified (table 1).

Table 1

Parameters and factors that influence the thermal transmittance of the curtain façade

No.	Parameter	Symbol	Determining factors
1	Glazing area	A_g	Curtain wall façade geometry
2	Thermal transmittance of the glazed area	U_g	Nature of glass Number of glass sheets Distance between the glass sheets Nature of the panel spacer
3	Spandrel (opaque) panel area	A_p	Curtain wall façade geometry
4	Thermal transmittance of the opaque panel	U_p	Structure of opaque panel (materials, thicknesses)
5	Area of the frames/ mullions/ transoms	A_f A_m A_t	Frame geometry Joint system
6	Thermal transmittance of the: frames/ mullions/ transoms	U_f U_m U_t	Nature of the material used for curtain wall framing elements; Joint composition
7	Length of joints between: glazing-frame, glazing-mullion, glazing-transom, mullion-frame, transom-frame, panel-transom/mullion	$l_{f,g}$ $l_{m,g}$ $l_{t,g}$ $l_{m,f}$ $l_{t,f}$, l_p	Geometry of façade (distance between mullions, distance between transoms, opaque panel dimensions)
8	Linear thermal transmittance of the joints between: glazing-frame, glazing-mullion, glazing-transom, mullion-frame, transom-frame, panel-transom/mullion	$\Psi_{f,g}$ $\Psi_{m,g}$ $\Psi_{t,g}$ $\Psi_{m,f}$ $\Psi_{t,f}$ Ψ_p	Nature of material from which profiles are made up Joint structure with or without thermal break

In order to highlight the influence of variation of the values of specific significant parameters, the thermal transmittances were calculated for some curtain wall façade solutions, using the components evaluation method.

The geometric configuration of the analyzed curtain façade area is that presented in Figure 6.

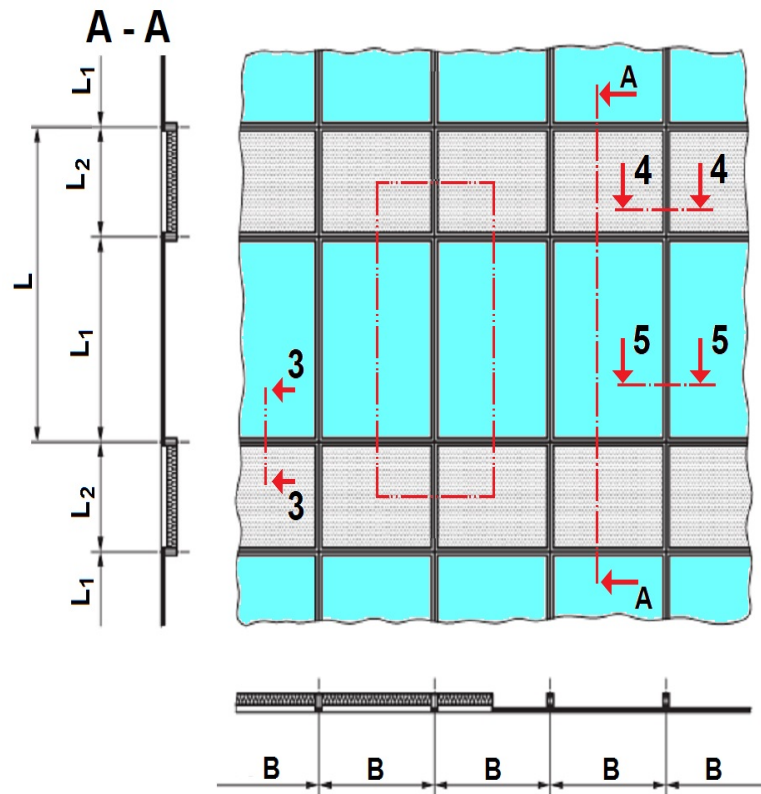


Fig. 6 – The curtain wall facade element used for the comparative analyse (the joints: 3, 4, and 5 are represented in Figure 5).

The constructive solutions of the curtain wall that have been analysed differ by the following parameters:

- the distance between mullions, varying with a step of 20 cm, between 1.20 m and 1.80 m;
- the presence or the absence of mobile glazed panels;
- the thermal transmittance of the glazed and opaque panels;
- the linear thermal transmittance coefficient of the joints.

For this comparison, the thermal transmittance values from the calculation example presented in SR EN ISO 12631, called "standard" here, were used in relation to those obtained based on improved values of the thermal characteristics of the wall components, called "improved" in tables 2 and 3.

Table 2

The thermal characteristics of the curtain wall façade component elements used for the comparative evaluation.

No.	Parameters	Symbol	M.U.	Values		
				Standard	Improved glazing + panel	
1.	Thermal transmittance of glazing	U_g	W/m ² K	1.20	0.70	
2.	Thermal transmittance of the opaque panel	U_p		0.46	0.26	
3.	Thermal transmittance of metallic elements	Mullion		U_m	2.20	2.20
		Transom	U_t	1.90	1.90	
		Frames	U_f	2.40	2.40	
4.	Linear thermal transmittance of the joints	Mullion-frame joint	$\Psi_{m,f}$	W/mK	0.07	0.07
		Transom-frame joint	$\Psi_{t,f}$		0.07	0.07
		Glazing-mullion joint	$\Psi_{m,g}$		0.11	0.08
		Glazing-frame joint	$\Psi_{f,g}$		0.17	0.08
		Panel joint	Ψ_p		0.18	0.13

Table 3

Thermal transmittance values, U_{cw} , (W/m²K) for different constructive variants of the curtain façade

No.	Constructive variant	Distance between mullions (m)			
		1.2	1.4	1.6	1.8
1	Standard, with mobile opening panels	1.700	1.653	1.635	1.602
2	Improved, with mobile opening panels	1.207	1.237	1.137	1.232
3	Standard, without mobile opening panels	1.508	1.58	1.545	1.519
4	Improved, without mobile opening panels	0.989	0.972	0.948	0.888

The thermal transmittance values for the analysed variants highlight the significant influence of the considered factors. Of these, only the geometric ones can be evaluated without knowing the façade design. Or, it is observed that the influence of the thermal transmittance of the glazed and opaque part, which can only be appreciated through measurements, is significant. Even more significant and difficult to appreciate is the influence of the linear heat transfer coefficients corresponding to the joints. As a result, the evaluation with a satisfactory degree of precision of the thermal transmittance of curtain façades in the absence of information from the designer or manufacturer is practically not possible.

A parametric study highlighting the correlation between the thermal transmittance and various parameters could provide a possibility for an approximate evaluation of the thermal transmittance of the curtain walls. For fully glazed façades, this could be based on the correlation between the thermal transmittance and the percentage of the frame area of the entire façade area (Bae *et al.*, 2015) presented as a nomogram type diagram in Figure 7. But even in this case, the thermal transmittance of the glazed area cannot be ignored, which is decisive. However, in the most cases, the curtain façade also includes opaque areas, whose influence is more difficult to appreciate.

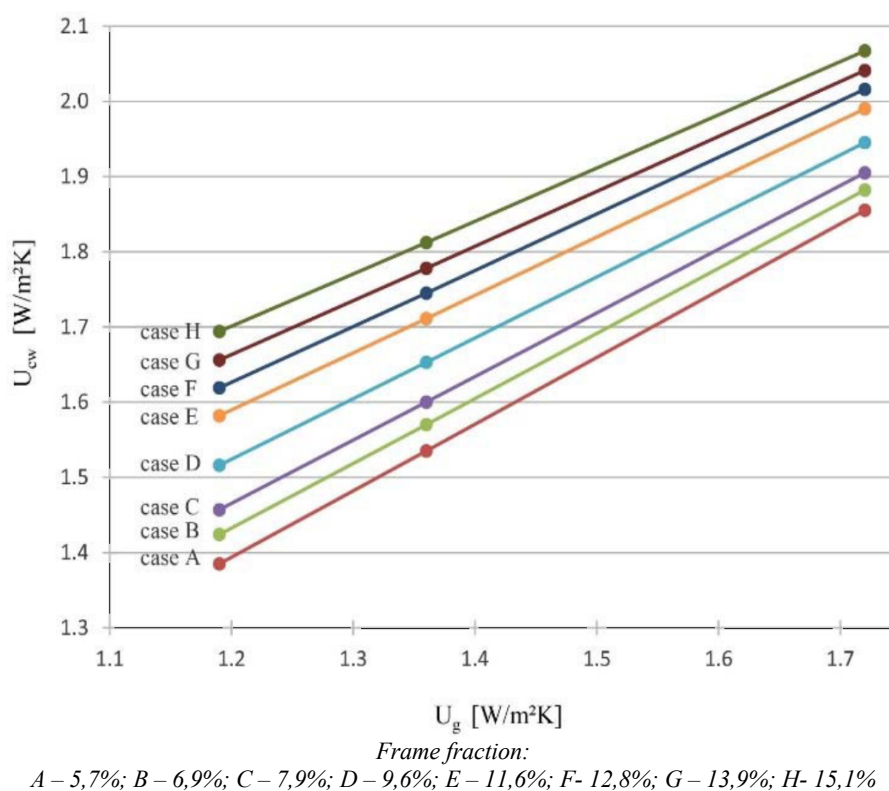


Fig. 7 – Nomograms for determining the thermal transmittance of fully glazed curtain façades (Bae *et al.*, 2015).

4. Conclusions

Curtain wall façades are complex systems in terms of structure and operation, the concerns for increasing the energy performance contributing to the increase in the complexity level.

The evaluation of the thermal transmittance of these systems presents a certain degree of difficulty and requires knowledge of the design data. In their absence, it is not possible to obtain an acceptable level of precision.

An approximate method that would ensure an acceptable level of precision would be necessary and useful. This requires an in-depth study in which as many constructive solutions as possible are analysed and then systematized in guides or spreadsheets, based on significant parameters.

It is also useful if the manufacturers of glazed curtain wall facade systems could provide data with the values of the main thermotechnical parameters that characterize the systems produced by them.

We might recommend:

- Simplify assessment: Develop user-friendly methods for evaluating.
- Data standardization: Promote industry-academia collaboration to standardize thermotechnical data.
- Innovation focus: Explore energy-efficient materials and techniques (Dussault J.-M., *et al.*, 2011, and also Oh J.-M. *et al.*, 2016).
- Interdisciplinary cooperation: Encourage collaboration between architects, engineers, and manufacturers.

These recommendations can improve curtain wall facades' role in energy-efficient, sustainable construction.

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**METODE DE EVALUARE A PERFORMANȚEI TERMICE A FAȚADELOR
CORTINĂ. PROBLEME SPECIFICE AUDITULUI ENERGETIC**

Pentru a obține o reducere semnificativă la nivel național a emisiilor de gaze cu efect de seră în sectorul construcțiilor, guvernul României s-a aliniat la reglementările europene privind eficiența energetică a clădirilor, care vizează ca la realizarea clădirilor noi și renovarea celor existente să fie respectate criteriile asociate conceptului de *Clădire al cărei consum de energie este aproape egal cu zero* (nZEB). Îndeplinirea acestui obiectiv implica o cunoaștere a instrumentelor de evaluare a performanței energetice a anvelopei clădirii, având în vedere ponderea importantă cu care aceasta intervine în consumul total de energie pentru utilizare normală. Scopul acestei lucrări este de a evidenția posibilitățile proiectanților și auditorilor energetici pentru clădiri de evaluare, cu un grad de precizie satisfăcător, a performanțelor energetice (PE) a fațadelor tip cortină utilizând metodele de calcul propuse în SR EN ISO 12631:2018. Un studiu privind influența unor parametri reprezentativi asupra transmitanței termice, realizat pe un element generic de fațadă tip cortină, vine în sprijinul celor implicați în procesul de optimizare a soluțiilor destinate clădirilor noi sau renovării celor existente.

