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M4.3 Modelling guidelines for Complex Fenestration Systems

WP4. Modelling, T4.2

Authors. De Michele G., Demanega I., Avesani S. (EURAC), Hauer M. (BB), Plörer D. (UIBK), Papaiz L. (gA)

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1 Introduction

Complex Fenestration Systems are characterized by optical and thermal performance depending on the angle of incidence of solar radiation, due to complex geometries and/or highly reflective surfaces of glazing and/or shading systems. In addition to the complexity of the shading system itself, the CFS could also be characterized by different types of cavities such as naturally ventilated ones. All those peculiarities have to be covered by adequate thermal and optical models.

Implementing Complex Fenestration Systems (CFS) in the modern architecture of non-residential buildings is a trend driving the need for improved methods and validated tools supporting the design. Especially for highly glazed building facades, the detailed modelling of CFS plays a major role in enabling reliable simulations for thermal and daylighting performance predictions as well as for comfort evaluation.

The models' development to evaluate CFS within building energy simulation tools has increased significantly in recent years (Kirimtat et al. 2016). Although the number of tools is increasing, clear workflows including important aspects like high modelling flexibility, usability and efficient runtime while preserving detailed results are still rarely available – particularly in the field of CFS modelling (Loonen et al. 2016).

Finally, besides the topic of the most suitable toolchain selection and correct implementation, the issue of which environmental boundary conditions' set to be chosen is to be faced by every modeller. Norms and standards often refer to extreme simplified conditions, resulting in a oversizing of the system. This problem has been faced by the definition of a new tool, called FACADEgis, supporting in the identification of the most adequate boundary conditions depending on the analysis target and based on measured data.

This report briefly presents some possible procedures for the modelling of Complex Fenestration Systems (CFS) and the setting of the most appropriate boundary conditions, as developed and experienced by the FACEcamp partners. Further insights into the toolchains are reported in the FACEcamp Milestone M4.1. For any more detailed information, please refer to direct contact with Eurac Research, Institute for Renewable Energy.

2 Objectives

The work presented in this reported aimed at defining improved modelling procedures for the modelling of CFS and summarising them into a guidelines for modellers and simulators working in the façade value-chain (e.g. design teams, technical offices of façade manufacturer, researchers, …). In such guidelines, the setting of the most adequate environmental Boundary Conditions is of central relevance to obtain meaningful results. The wider scope is to support practitioners daily design work in the façade field through the correct use of the most adequate existing tools, linked one to the other in a unique workflow, called "toolchain".

3 Toolchains

With “toolchain” is defined a sequence of tools used to perform a specific assessment of a chosen façade component or system. Table 1 summarises such currently available toolchains. The table is to be read from left to right. The first two columns identify the Complex Fenestration detail level (from single component to room or building) and the target performance indicator to be calculated. Each row is a possible toolchain for such technology and indicator.

The other chapter’s paragraphs describe synthetically the toolchains main features, and give the most relevant references, for further detailing the underneath modelling and simulation procedures.

3.1 The “Step 0”: components characterisation

The toolchains presented in this report, and in general thermal/optical simulations that involves optically complex layer in the façade system, require a detailed characterization of the elements composing the fenestration system. A correct characterization of the façade is the first requirement for obtaining reliable results from simulation toolchains. In particular, the characterization of reflection and transmission properties by means of BSDF Bidirectional Scattering Distribution Function is essential for both thermal/energy and visual/optical performance evaluation of complex façades.

For standard system, the BSDF can be directly calculate, for example, with the LBNL WINDOW software. WINDOW provides also a database (CGDB) of more than 100 system and allows to customise multi-layer glazing systems for different configurations of a façade system. From this software, data files can be exported for use in toolchains.

Especially when innovative fenestration systems are considered, it may happen that the optical behaviour of the fenestration system is not yet available in the CGDB. In this scenario, two options are available to obtain the necessary bi-directional optical data: i) experimental characterisation by means of Gonio-photometer (e.g. scanning-based or imaged-based) or ii) modelling/simulation using TracePro/ genBSDF’ Radiance.

Within working package 4, an investigation has been made in comparing standard procedure of modelling shading system in WINDOW with a more accurate methodology that involves experimental characterization and simulated BSDF. The comparison highlighted the importance of using the correct fenestration model and makes researchers and designers aware of possible pitfall and errors in employing not appropriate models in detailed simulation toolchains.

Further insights on the characterization procedures for façade components and results of the comparison between different methodologies can be found in the following published journal paper and Ph.D. Thesis[1].

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[1] De Michele, G., Loonen, R., Saini, H., Favoino, F., Avesani, S., Papaiz, L., Gasparella, A. (2018). Opportunities and challenges for performance prediction of dynamic Complex Fenestration Systems (CFS). Journal of Facade Design and Engineering, 6(3), 101–115. http://doi.org/10.7480/jfde.2018.3.2531

De Michele, G. (2019). Assessment of detailed thermal models for complex fenestration systems (cfs) and development of an effective control strategy. Ph.D. Thesis. Faculty of Science and Technology, Free University of Bozen-Bolzano.

Table 1: Toolchains summary.

What to be assessed		**Possible series of tools (tool chains)**			
		Tool 1 (Geometry & Input) →	**Tool 2 (Visual) →**	**Tool 3 (System)→**	**Tool 4 (Energy)**
Window + shading (both as single components and as assembled system)	U-value, g-value, Temperatures, Visual and Solar Transmission, BSDF (non-standard geometry and material)	Input geometry and material complexity management (es. Rhino[2])	Radiance [3](only for the non-standard complexity) + post-processing (es. Python)	Optics[4], Window[5], gA[6]	
	As above but with airflow		Radiance	Optics, Window, gA	Concentrated parameters solver (es. TRNSYS Type56CFS & TRNflow, E+, …)
	As above but with 2D – 3D domain dependence and with airflow		Radiance	Optics, Window, gA	2D-3D FEM or FVM software COMSOL, ANSYS
	U-value, g-value, LT, BSDF (standard geometry and materials)	Window / gA			
Overall façade system (Window + Shading + Frame)	U-value, g-value, Control strategies, Temperatures, Air flow rates	Input geometry and material complexity management (es. Rhino)	Radiance	Optics, Therm, Window, gA	Concentrated parameters solver (es. TRNSYS Type56CFS & TRNflow, E+, …)
			Radiance	Window, gA	2D-3D FEM or FVM software (es. COMSOL, ANSYS)
Building (or single room) with CFS	Heating and cooling demand, Control strategy	Input geometry and material complexity management (es. Rhino)	Radiance	Window, gA	Concentrated parameters solver (es. TRNSYS Type56CFS & TRNflow, E+, …)
	Daylight performances				
	Coupled thermal and daylight performance			Window	DALEC

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[2] www.rhino3d.com/it/

[3] www.radiance-online.org/

[4] https://windows.lbl.gov/software and https://windows.lbl.gov/software/window

[5] https://windows.lbl.gov/software and https://windows.lbl.gov/software/window

[6] www.glassadvisor.com

3.2 Toolchain 1 and 2: from Rhino to E+/TRNSYS

Goal of this toolchain is to evaluate a CFS from the system point of view and eventually its impact on a room and/or whole building.

Among all tools which underwent screening , EnergyPlus and TRNSYS are the tools, which are most widely used and provide the necessary functionalities to perform a coupled thermal and daylight evaluation. Based on these tools, two toolchain workflows have been defined starting from the shared geometry platform Rhinoceros. The free available Grasshopper plugins Ladybug and Honeybee connect EnergyPlus and Radiance, while TRNLizard in combination with Artlight connects TRNSYS with Radiance. The geometrical modelling is done in Grasshopper, the model set up as well as the transition into the simulation input files to perform the simulations in EnergyPlus (*.idf) and TRNSYS (*.d18, *.b18) has been implemented via Grasshopper.

Since TRNSYS18, a free plug-in for Grasshopper named TRNLizard is released, which allows to perform parametric thermal and daylight simulations based on a 3D-geometry in Rhinoceros. It combines the advantages of the parametric architecture from Grasshopper tools with the powerful solving engine of TRNSYS kernel. For coupling the thermal modelling in TRNSYS with the daylight modelling in Radiance, the user-defined component Artlight is implemented. The daylight simulation routine is based on the Radiance 3PM, while the detailed thermal modelling of the CFS is done using the latest model implementations in Type56 within TRNSYS 18.

For EnergyPlus, Honeybee[+] as an improved version of Honeybee legacy, allows an extensive analysis of daylighting performances of CFS. In fact, the tool includes several matrix methods of Radiance and allows to employ BSDF with different resolutions (i.e. Klems and Tensor-tree) as well as a 3D geometry of the shading device.

Within Work package 4, an extensive investigation has been made in comparing those tools on a common reference model as well as against measurements. Both toolchain workflows have proven to be powerful and highly flexible approaches enabling a detailed modelling of CFS. On the other hand, applying those workflows in the daily planning process needs a comprehensive basic knowledge in doing simulations as well as experience in data and tool handling. Despite the fact, that user-friendly interfaces are increasing to access highly complex tools like Radiance, EnergyPlus and Radiance, their interrelations must be clear for the user – therefore, this work of elaborating two promising toolchains might be a good guide and support for interested people from planning departments and industry.

For further detailed readings on toolchain properties as well as results, it can be referred to FACEcamp Milestone M4.1 as well as the published paper at International Building Simulation Conference 2019 in Rome *Modelling of complex fenestration systems – application of different toolchain approaches on real case scenarios; Authors: Hauer M., De Michele G., Babich G., Plörer D., Avesani S.*

3.3 Toolchain 3: from Rhino to DALEC

Goal of this toolchain is to evaluate a CFS from the system point of view and eventually its impact on a room and/or whole building.

In addition to the unmentioned Toolchain 1, which focuses on tools enabling detailed evaluation of complex façade systems, with DALEC – "Day- and Artificial Light with Energy Calculation" (www.dalec.net)[7] an easy and fast evaluation of different façade solutions is possible. With DALEC an online concept evaluation tool for lighting designers, architects, building engineers and building owners has been developed by Bartenbach together with Zumtobel Lighting and the University of

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[7] DALEC, "Day- and Artificial Light with Energy Calculation", www.dalec.net.

Innsbruck[8]. Although easy to use, the software accounts for the complex thermal and lighting processes in buildings and allows a simple evaluation of heating, cooling and electric lighting loads. Not only energy, but also user behaviour is considered, and visual and thermal comfort is evaluated (glare, overheating frequency).

In FACEcamp, first proof-of-concepts have been made by coupling DALEC with Rhino as a geometry platform. While the official DALEC version is applicable via the Web-Interface, an integration into the BIM-environment via IFC will be established soon. Therefore, a plug-in for Revit is developed in order to specify the needed data in a Revit model to run a DALEC-calculation.

3.4 Toolchain 4: 2D and 3D analysis of CFS

Goal of this toolchain is to calculate the 2D (or 3D) fields of temperatures, heat fluxes, fluid velocities and pressures to characterise a CFS and its main parts.

In this modelling procedure, solar radiation is treated apart from the coupled fluid flow and heat transfer simulation. The solar absorption resulting from the optical modelling is assigned as heat rate to the coupled heat transfer and fluid flow simulation.

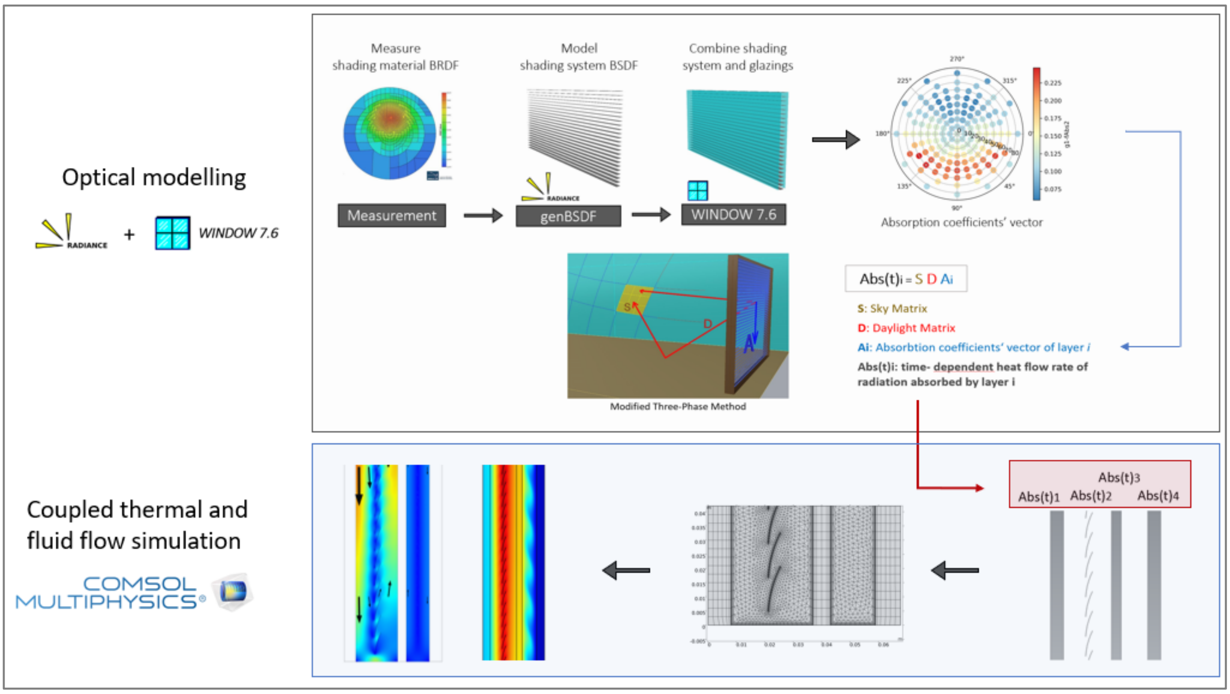

Figure 1: Schematic representation of the modelling approach for CFS.

In particular, solar radiation is treated with a detailed optical model based on ray tracing and using the software Radiance. Complex shading systems with specular behaviour can be modelled starting from the measured angular distribution (BRDF) of the material. This material is applied to a 3D geometry representing the shading system. The software Radiance, through the function *genBSDF* and using ray tracing, generates the BSDF file of the entire shading system. This file, containing the optical behaviour of the shading system, is assigned to the WINDOW 7 software that combines the BSDF of the shading with the properties of the glass layers, in order to get the BSDF for the entire fenestration system. This permits to compute for each direction of incident radiation the direction and share of transmitted and reflected one and the rate of absorbed radiation (absorption coefficient vector). With a modified version of the Three-Phase Method, the direct and diffuse horizontal irradiances are used to generate the sky matrix to be coupled with the absorption coefficient vector

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[8] M. Werner, D. Geisler-Moroder, B. Junghans, O. Ebert, W. Feist, "DALEC – A Novel Web-Tool for Integrated Day- and Artificial Light & Energy Calculation", Journal of Building Performance Simulation, Volume 10, Issue 3, 2017.

of the analysed fenestration system via the daylight matrix that considers the real building and surrounding geometry. This allows to get, for each time-step, the absorbed share of solar radiation.

The resulting solar absorption is assigned as heat rate to each solid element of the fenestration system (i.e. glass panes and shading device) within the software COMSOL Multiphysics. With this Finite Elements (FEM) software the coupled heat transfer and fluid flow is computed. In this simulation, also the surface to surface long-wave radiation exchange among the solid elements is computed using the radiosity method. For the CFD simulation an adequate mesh is required: typically, a structured quad mesh is used for the solid domains, while a free triangular grid is applied to the fluid domain. Furthermore, the mesh is refined near the boundaries to guarantee a smooth transition from the non-zero fluid velocity to the zero velocity on the surface. The results from the coupled heat transfer and fluid flow simulation are the temperature, velocity, pressure and radiosity field over the entire domain. From these data different key performance indicators (KPI), such as the U-value, the secondary heat flux, the peak temperatures, etc. can be derived. Further insights related to this modelling procedure can be found at the references indicated below[9].

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[9] Demanega, I., De Michele, G., Pernigotto, G., Avesani, S., Babich, F., Gasparella, A. (2018): CFD and ray tracing to evaluate the thermal performance of Complex Fenestration Systems. In Proceedings of the 2018 Building Simulation and Optimization Conference in Cambridge, 460-466.

Demanega, I., De Michele, G., Hauer, M., Avesani, S., Pernigotto, G., Gasparella, A. (2019): Numerical and experimental characterization of the thermal behaviour of Complex Fenestrations Systems under dynamic conditions. Building Simulation Applications conference in Bolzano.

4 Simulation Boundary Conditions: FACADEgis

When talking about guidelines for modelling and simulation, a well-known issue is related to the input data. The way to say “Garbage in – Garbage out” is one of the main first golden rule for any reliable performance calculation activity. This chapter will focus on the topic of the environmental boundary conditions for facades simulations, as mandatory complement for any simulation related to the façade performance.

4.1 Why a weather-based assessment?

When performing CFS simulations, final results strictly depend on the boundary conditions used. If relative values as Light Transmittance and Solar Factor are usually expressed in percentage and don’t change drastically from one boundary condition to another, absolute values as Temperature and Stress on glass are extremely dependent on them so having a corrected assessment is vital during façade design.

Understanding for instance the secondary heat flow generated through infrared radiation is important during thermal comfort assessment, and analysing the frequency for which a certain temperature is reached could give important input during façade design.

Moreover, together with light/thermal comfort and performance assessment, façade design also need through structural analysis, which in the case of CFS is mostly the analysis of stress on glass, which again is strictly dependent on the boundary conditions.

With explicit reference to structural and stress analysis, it is important to note that it is not wise to operate considering typical boundary conditions based on TMY (Typical meteorological year) of a certain location, since the scope of such analysis is to understand if the façade could be resilient even for very critical situations that where historically registered.

As an example, the graph below shows the worse winter climatic load (namely the pressure that make the glass panes of a double-glazing collapse to towards the cavity) calculated for each year of the period 2002-2016. Should we base ourselves on typical year analysis we would most certainly miss the historically registered stressful hours of 2012 that have led to several glass ruptures in buildings.

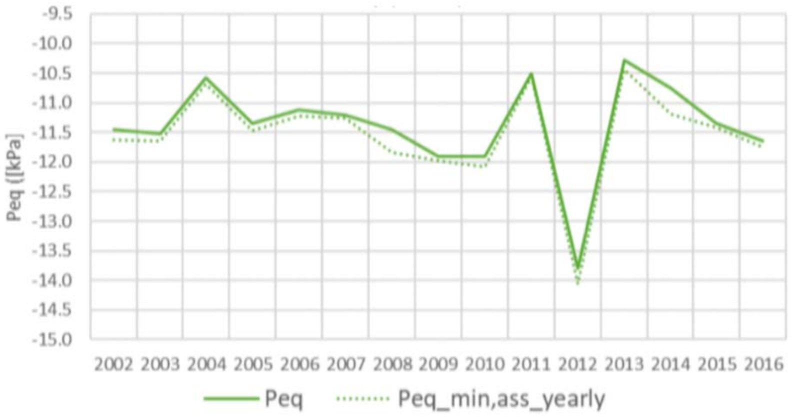

Figure 2: Winter climatic load for every year on the period 2002-2016 based on weather file (source: E. Polizzotti, M. Sommer 2018).

Boundary conditions from norms and directives may lead to under/overestimations of critical situations which in turn leads to façade unfeasibility or higher cost.

Moreover, the critical boundary condition to be used during design depends on what we are designing so the most reliable way is to perform a dynamic simulation on the CFS that can lead us to highlight the critical boundary conditions for each CFS composition.

4.2 Workflow developed

FACADEgis is a software workflow suited to perform historical weather analysis in order to assess typical façade design problems as: climatic load, Thermal Stress, Thermal comfort, Condensation risk.

A dynamic simulation using a simple radiation/thermal model is performed considering a hourly timestep through a period of 11 years, statistical filters are applied and frequency distribution is analysed in order to highlight the boundary conditions to be used, which are then applied to a more precise and time consuming radiation/thermal simulation.

At the base of this workflow a weather database supplies geographical based data starting from latitude and longitude inputs. Figure 3 shows a scheme of the filters and the variables analysed.

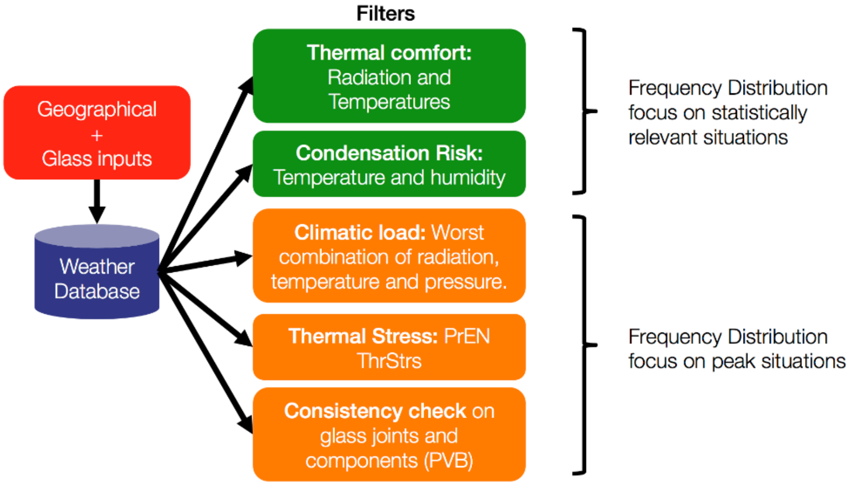

Figure 3: Conceptual scheme of the FACADEgis main calculation modules.

4.3 Implementation of the workflow and easy-to-use platform

The FACADEgis is a webservice accessible at the link www.facadegis.com The complexity of the workflow makes it suitable for research and highly prepared technicians, so the main scope of FACADEgis was to automatize most of it with the support of an easy to use graphical interface so that to make this assessment available for any professional of façade design and building supply chain.

The steps to perform such an analysis are:

1- Define the CFS
2- Select the filter to be used during the analysis (i.e. System Minimum Temperatures, Maximum temperatures, etc.)
3- Select the point on earth on a map
4- Define the orientation of the façade (if relevant)
5- Define the ground albedo (if relevant)
6- Define the time filter for the frequency distribution, namely the amount of hours to isolate so that to consider the worst scenario (low-e values for peak stress analysis, higher values for comfort analysis).

Boundary conditions are then calculated and offered to the user with to further effort, and the user may use them to perform a more precise and time consuming CFS simulation, obtaining the values needed.

5 Conclusions

A brief overview of possible usable toolchains for modelling and simulating Complex Fenestration System performances (thermal and visual comfort, energy) has been given in this report together with the main references where to find more detailed information on the calculation approach.

As a summary, FACEcamp project has deepened the following toolchains.

1. And 2. From Rhino to EnergyPlus or TRNSYS: for analysis at system level and its impact on a room / building.
2. From Rhino to DALEC: for analysis at system level and its impact on a room / building.
3. From Radiance to COMSOL: for 2D and/or 3D analysis at system level with detail on single components.

The software selections has been based purely on the authors' working experiences, but a wide range of further adequate tools exist to support the design of buildings through modelling and simulations. Please, find comprehensive lists and overview at the following website *www.buildingenergysoftwaretools.com*

6 References

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FACEcamp partners

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FRENER REIFER	F&R, FRENER & REIFER SrL	Partner

Contact points:

Project coordinator, Stefano Avesani stefano.avesani@eurac.edu

FACEcamp website www.facecamp.it

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