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Building Simulation (Innovation, Rapid Design, Design Support) & ICT

Design of a glazed double-façade by means of coupled CFD and building performance simulation

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Abstract

Gruner is involved in the engineering for a new eight-story laboratory building with a double-skin glazed façade to be built in Basel. Through the coupling of a Building Performance Simulation (BPS) and a Computational Fluid Dynamics simulation (3D-CFD) with a specifically developed interface which uses the commercial tools IDA-ICE and Star-CCM+, the behavior of the double-façade was investigated for a warm day cycle and effects on the interiors were evaluated. The temperatures and heat gains on the surfaces and internal glazing were determined, and the temperature load for sensitive components was analyzed. The model is also intended to serve in energy optimization over one year by varying design parameters such as, window absorptivity, or the position and size and location of the ventilation slots.

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Keywords: double-skin glazed façade, Computational Fluid Dynamics (CFD), building performance simulation, Coupling StarCCM+ and IDA-ICE

1. Introduction

More and more buildings employ double glazed façades [1]. From an architectural point of view, the second glazed skin gives expressive power to the buildings (see Fig. 1) and allows for pragmatic implementation of the functional requirements such as parapets, daylight-regulated shading louvers and maintenance ramps [2]. Further advantages are: increased comfort through control of the interior glazing temperature, the protection of the components in the façade cavity from environmental factors and improved soundproofing, discretion and security.

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Double façades have a significant effect on the thermal conditions in the interior of the building. While the heat-insulating effect is energetically advantageous during heating periods, it can lead to overheating in warm seasons. Overheating must be avoided by special measures such as particular glazing and appropriate natural or mechanical ventilation of the façade cavity throughout the day. Careful design must be implemented to ensure a favorable energy balance and reasonable thermal loads for components within the double façade cavity.

This paper presents a calculation method for the determination of the expected conditions in the double façade and its application, with focus on high thermal loads as shown for a current building project (see left in Fig. 1). The object of investigation is the building for the Department of Biomedicine (DBM) to be constructed on the Campus of the University of Basel. The 8-storey building will have a double facade, in which the cavity is naturally ventilated by breathable joints on the outer glazing on the lower floors and by openings in the roof area.

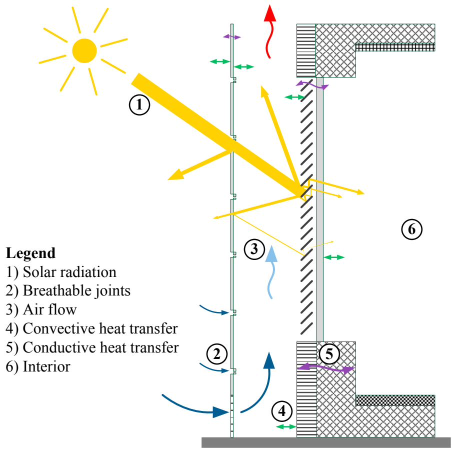

Fig. 1: (a) Visualisation of the planned DBM building (© Caruso St John Architects); (b) heat fluxes and air flow in the ground floor.

In cases with simple geometries, the thermal behaviour of a double façade can be grossly estimated with simplified approaches without simulations [4, 5]. However, for minor special features such as ventilation openings located at different heights (see right in Fig. 1), such methods are no longer applicable [6]. At present, no commercially available planning tool fulfills all requirements for an investigation with reasonable effort: Current flow simulation tools (Computational Fluid Dynamics, CFD) are missing adequately simplified and validated models for radiative heat exchange thus making long term calculations very demanding [7, 8, 9]. On the other hand, the simplified flow models contained in current building performance simulation tools (BPS) usually do not reach the necessary modeling depth. For this reason, combinations of specialized and often self-developed tools have been used [3, 6]. To date, validated commercial tools are available for the different aspects of the analysis. This paper demonstrates the coupling of two such tools. The increased computational power available today allows for an iterative coupling, where both BPS and CFD results are progressively improved by several iterations.

2. Method

In the present study, the comprehensive and well-established tool IDA-ICE (Indoor Climate and Energy, version 4.7.1) from EQUA Simulation AB has been used for the building performance simulation (BPS). It includes a technically mature and commonly accepted model for the estimation of the radiative heat exchange in double-glazed façades. IDA-ICE is tested and validated according to ANSI/ASHRAE Standard 140-2004, CEN Standard EN 15255-2007, EN 15265-2007 and IEA Task 12 BESTest. The IDA-ICE computation was coupled with StarCCM+ v11.02 from Siemens that was used for the computation of the flow and the convective heat transfer. StarCCM+ is an internationally recognized commercial tool for the simulation of general three-dimensional flows, originally derived from aerospace, automotive and engine development, and also increasingly used in the construction sector.

2.1. Concept

The computation is performed by coupling the perfomance building simulation with the CFD simulation. In the first iteration of the coupled calculation, the BPS is performed with approximate values for the flow-induced heat transfer (convection). The resulting surface temperatures are used as boundary conditions for the first CFD simulation that yields the flow field, the temperatures of the air and the heat fluxes to and from the façade components. The second iteration uses these heat fluxes instead of the initial approximate values to improve the BPS estimation, yielding increasingly accurate values for the surface temperatures as input for the following CFD computation and so on (see Fig. 2). Since the models have different spatial resolutions, the surface temperatures from the BPS are applied as average boundary conditions in the CFD and the heat flows computed in the CFD are transferred to the BPS as surface fluxes. In this approach, the equations of the fundamental physical processes are solved independently in each tool, however both computations converge progressively to a common solution. The underlying differential equations are highly non-linear, but the thermal and aerodynamic inertia and slow changes lead to damped and locally continuous solutions yielding a good convergence. In the investigated case, the deviations of the common parameters of BPS and CFD were already below 10 % after 5 iterations. This was considered as sufficient, with respect to the variance of the input parameters and to the intended application, therefore the calculations were terminated. Although the conditions in the double-glazed façade change with time, the variations are slow compared to the time constants of the components, and the system is close to thermal equilibrium most of the time. Thus the transient behavior of the façade was approximated by quasi-steady simulation based on steady state CFD computations.

For the BPS computation of long-term behavior – in this case over one day – the coupled calculation was carried out for a limited number of times of the day and of operating points which were representative in terms of solar radiation and position of the shading louvers. The BPS input parameters for intermediate times were interpolated based on the results of the coupled computations. Comparison of results based on interpolated input values with results based on fully coupled computations showed a fair agreement confirming the appropriateness of this approach.

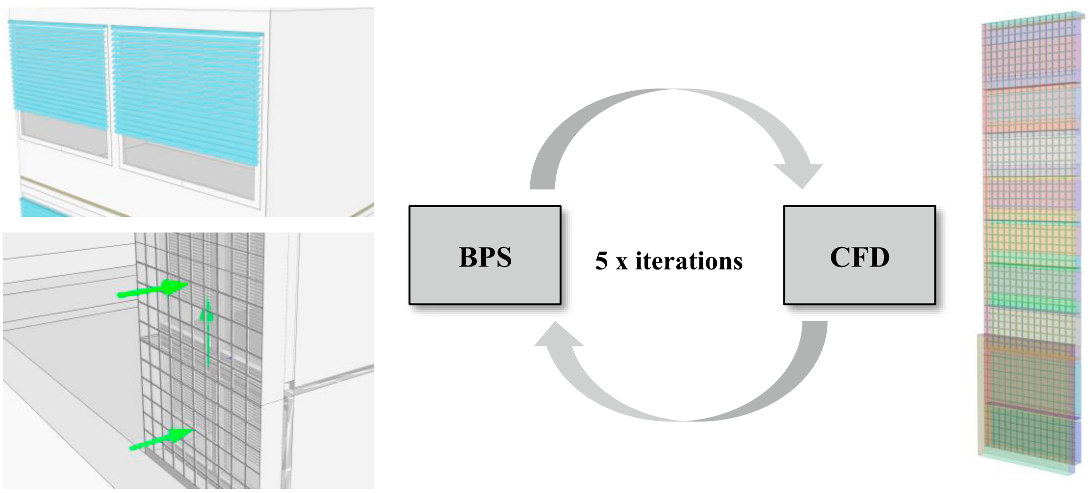

Fig. 2: Illustration of the coupling between the BPS model and the CFD model.

2.2. Climate Conditions

The presented analysis aimed at investigating the risk of overheating for high thermal loads. Thus the calculations were carried out for representative boundary conditions based on SIA 2028 at the location Basel-Binningen for a hot summer day without wind. Four support points were selected for the coupled calculation (Fig. 3). Inside the building an air temperature of 26.0 °C is used (setpoint cooling).

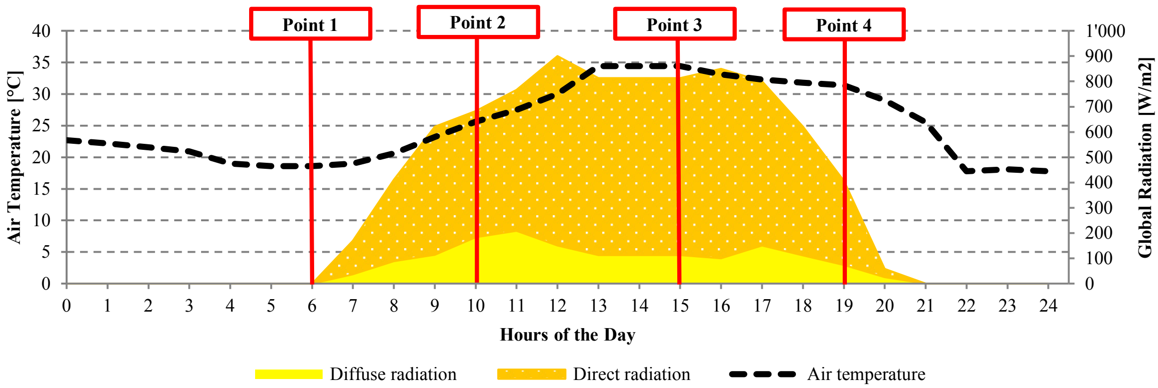

Fig. 3: Climate conditions and selected times of the day for the coupled computations.

2.3. Building Performance Simulation (BPS) with IDA-ICE

For the BPS, a façade element of 7 m width, including the first room behind each floor, was modeled in detail (see Fig. 4). This area of the southwest façade, with maximum exposition to the sun during the warmest hours, was suitable for studying the risk of overheating. The radiation model for the double façade calculates the heat transfer by solar radiation and long wave radiation, depending on the daytime, the orientation and shading of the façade and the wavelength-dependent and material-dependent propagation, multiple reflection and absorption between the glass layers and façade components, such as shading louvers. The thermal model coupled internally to the radiation model takes into account the properties of the façade components, such as thermal mass, heat conductions, operating points in the adjacent room zones at different operating times and the effect of heating ventilation and cooling as needed.

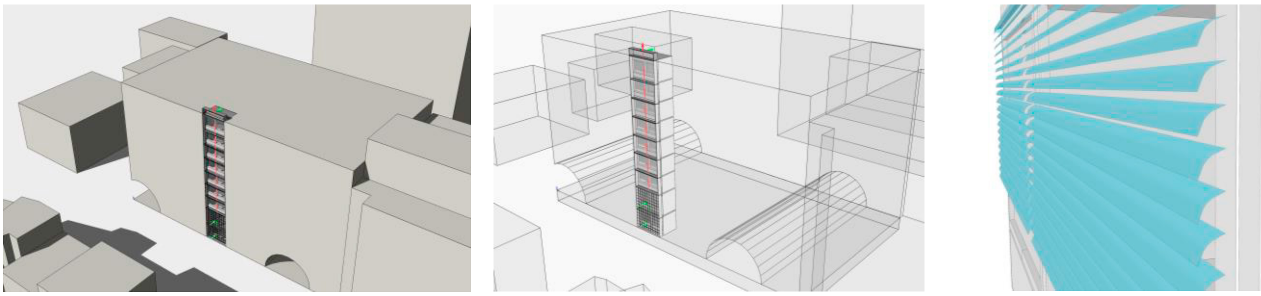

Fig. 4: Visualisations of the 3D-model in IDA-ICE.

2.4. Three Dimensional Computational Fluid Dynamic Simulation (3D-CFD) with StarCCM+

The flow in the façade cavity was calculated using a 3D-CFD model of a segment of the façade, including the relevant features. The climatic conditions (temperature, wind) were taken into account, as well as the aerodynamic influence of openings, constrictions, grids, deflections, shading louvers, etc. These features lead to deflection, deceleration and / or turbulence that altogether influence the convective heat exchange and the mixing of layers with different temperatures. The calculations were carried out on a finite volume mesh, that accurately reproduces the façade geometry with variable cell size and boundary layer refinement by solving the Reynolds-Averaged formulation of the Navier-Stokes equations (RANS). A common k-epsilon turbulence closure and blended wall functions for precise boundary layer flow computations are employed, yielding the convective heat transfer at the surface boundaries. The shading louvers were modeled by an increased roughness depth. Whereas, obstacles such as, walkway grids were modeled as porous media with oriented viscous and inertial influence. The buoyancy is a result the consideration of differences in density and of gravity terms in the momentum conservation equations, as well as the application of the height-dependent atmospheric pressure at the openings (breathable joints in the bottom floors and upper outlet).

3. Results

3.1. Velocity and Temperatures of the Cavity Flow

Fig. 5 shows the air temperatures resulting from the CFD simulations for 15:00. The metal and glass surfaces of the façade heated by the solar radiation lead to a heating of the air in the vicinity of these surfaces. Significantly higher temperatures occur close to the inner façade as opposed to the outer façade (see left in Fig. 5). The thermal buoyancy of the heated air induces an upward flow that is faster when close to the hot surface, showing the pronounced three-dimensionality of the flow conditions. The average upward flow velocity amounts to 0.6 m/s. Due to the suction of this flow, air is continuously sucked in from the surrounding area through the breathable joints (see right in Fig. 5). From the lowest, largest joint, air flows with up to 1.7 m/s impinging on the opposite inner glazing. On the lower floors, the incoming flow contributes to the lower temperatures on the inner glazing. On the way upward, the air passing the hot surfaces heats up from 34.3 °C to 42.7 °C.

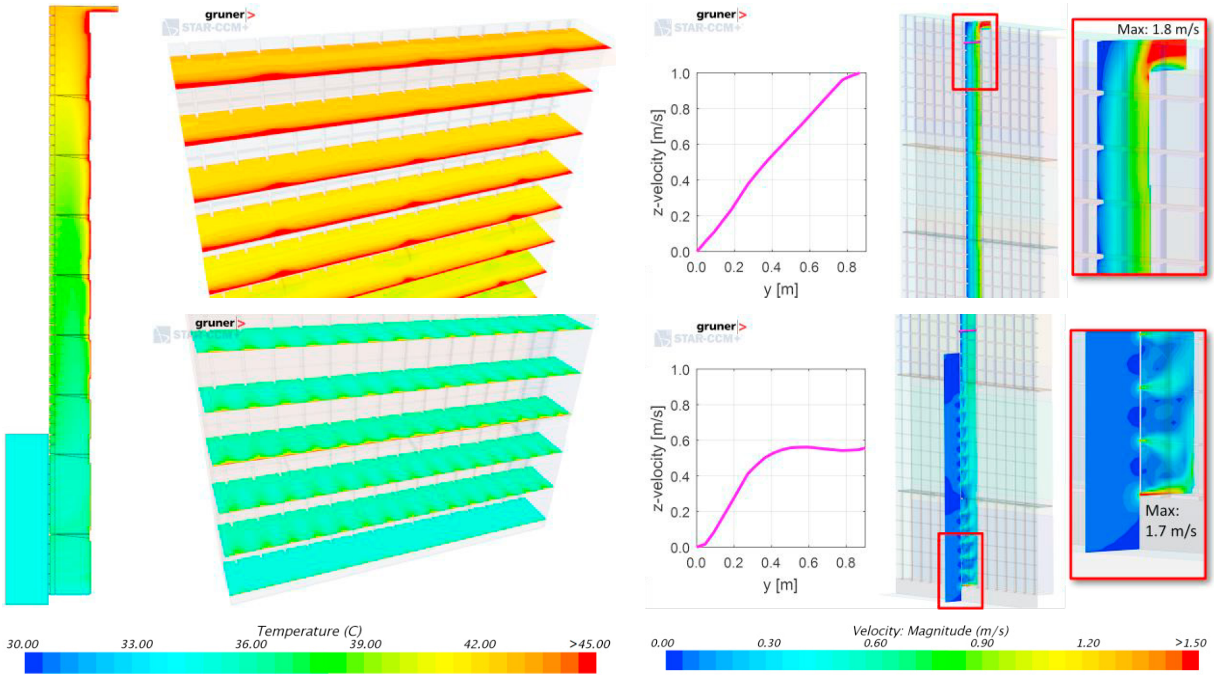

Fig. 5: Results of the 3D-CFD Simulation for 15:00, temperatures (left) and flow velocities (right).

3.2. Surface Temperatures and Heat Gains

The graph in the center of Fig. 6 shows the resulting mean temperatures of the façade surfaces representatively for the time 15:00. The surface temperatures increase from the lower to the upper floors. Average temperatures from 58 to 69 °C are determined on the aluminum façade and 54 to 63 °C on the shading louvers. The average interior glass temperatures on the top floors reach 31 °C. The high surface temperatures show the effects of high solar radiation on the southwestern façade for the presented case with high-transmissivity glazing. The graph to the right of Fig. 6 shows the solar irradiation over the day and the heat gains computed by the BPS, first for the whole façade, then the breakdown for only the 7th floor and then the breakdown for only the room behind the façade on the 7th floor. The peak of the heat gains occurs during afternoon solar radiation with shallow elevation. The effectiveness of the shading louvers is reflected by the lower heat gains into the room. These results are relevant for sizing the climatization devices.

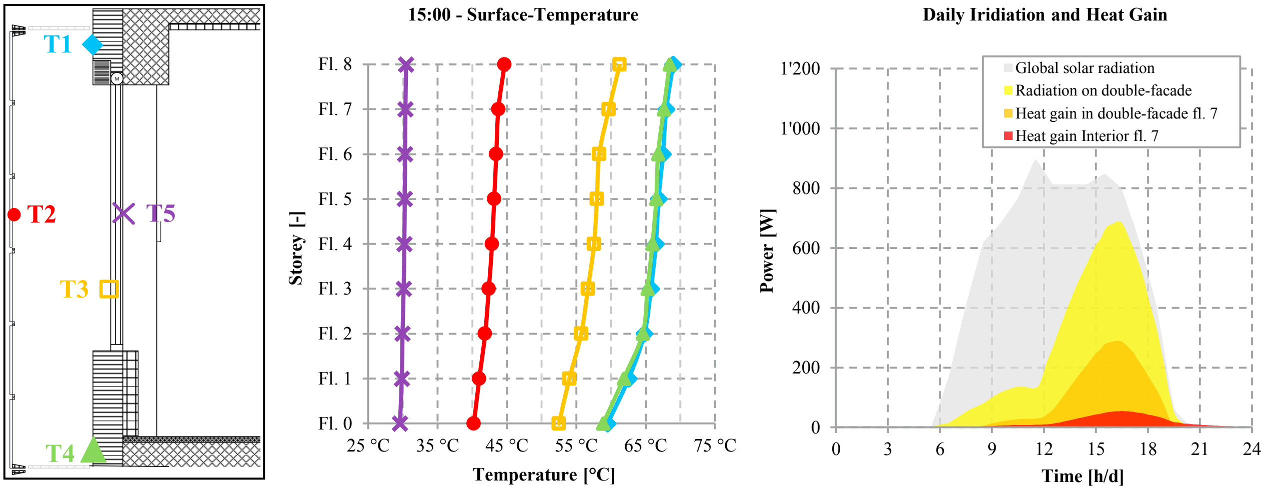

Fig. 6: (a) Surface naming, (b) average surface temperatures at 15:00, (c) day's course of solar irradiation and heat gains.

4. Conclusions

For the considered façade configuration, surface temperatures of up to 70 °C were determined. As the calculations show, such high temperatures are effective only for a limited time, however they could damage façade components (such as louver motors) if they are not designed for this purpose. In the lowest floor, intake speeds of up to 1.6 m/s were determined at the breathable joints, which could lead to noise and the ingress of dust. The presented results represent an upper limit, since they are based on a façade configuration with high transmissivity of the outer glazing and narrow openings at the breathable joints located only on the first two floors. The presented model now serves for an optimization with regards to the energy balance of the glazing parameters, the area and position of the openings, as well as the interaction with the planned HVAC systems.

The strong variation of the flow velocities and the related convective heat transfer between the outer and the inner glazing show the necessity of three-dimensional flow simulation. By coupling the flow simulation (CFD) with the building performance simulation, a flexible method for simulating the conditions in double façades was implemented. The application areas are manifold: the planer can mature his façade concept at an early stage, the plant builder can check the function and the regulation of the HVAC systems and the louver shadings can be optimized with regard to the effect on the energy balance and comfort.

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