

## INTEGRATION OF CAAD, THERMAL BUILDING SIMULATION AND CFD BY USING THE IFC DATA EXCHANGE FORMAT

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### ABSTRACT

This paper describes the results of a German research project, where a CAAD-program (Computer Architectural Aided Design) was integrated with two energetic building simulation programs to a software package for calculating and optimising the energy demand of CAAD-constructed buildings. The used key technology to transfer the huge number of geometrical, topological and physical building parameters was the IFC data exchange format. For realising the project task, the CAAD-program was extended for the use with energetic building simulation and the building simulation tools were coupled. Furthermore a simulation user interface was implemented to improve the usability of such complex simulation tools. Different possibilities of a graphical and statistical postprocessing allow the user a better understanding of the simulation results. The software package was used successfully to analyse some testcases of 3D digital building constructions.

### INTRODUCTION

Applications for the building simulation are often used within the planning process to improve the energy efficiency of the building. For the realisation of such simulation calculations the used building simulation tools have to be configured and parameterised for each building in an individual way. Often this is a time-consuming and error-prone process, because the necessary geometrical, topological and physical parameters aren't available in a common database, which could be used directly by the building simulation tools.

The desired geometrical and topological parameters are usually contained in the digital three-dimensional building model, which is constructed by the architect using a CAAD-program. Many of the actual CAAD-tools moreover support the hierarchical structure of buildings (building → zones → building elements) by using object oriented methods. Since a few years furthermore suitable data exchange formats are available (e.g. the IFC-format from the International Alliance for Interoperability,

<http://iaiweb.lbl.gov/>), which allows the transfer of object oriented structured building models from CAAD to energetic building simulation tools.

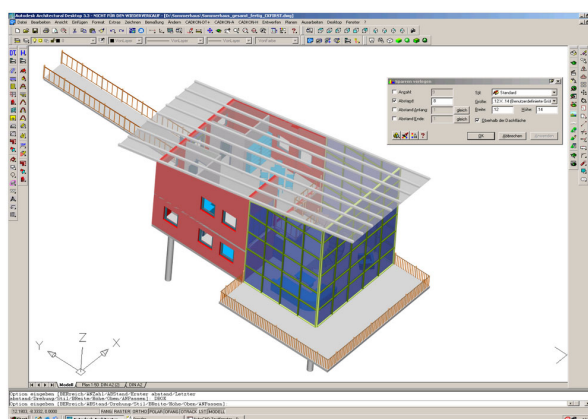


Figure 1: CAAD-program CADKON-DT

Within the research project, which was sponsored by the Deutsche Bundesstiftung Umwelt, the above-mentioned approaches and methods were used to realise an automatic data flow from a CAAD-program to two energetic simulation programs - one for thermal building simulation and one for airflow simulation. The Autodesk ADT3.3-based CAAD-program CADKON-DT (AutoCAD Magazin, 1998, see figure 1), an object oriented multizone thermal building model, based on the simulation environment SMILE (Ernst et.al., 2000) and a CFD-code, based on the FEM-tool KASKADE (Beck et.al., 1995) were combined with the help of the IFC data exchange format to a common energetic planning tool for buildings. At this the data exchange is realised by using the IFC format in version 1.5.1 and 2x.

### CAAD-PROGRAM CADKON-DT

CADKON-DT is an enhancement of the CAAD-program Architectural Desktop (ADT) from Autodesk (<http://www.autodesk.com>), which includes a lot of additional important construction functions, which aren't included in the standard software. Within the research project the following features were added to CADKON-DT by using

the VBA/OMF API:

- Creating thermal zones: After the user has selected the ADT-object 'room' he can add a number of building element objects like walls, windows, doors, slabs and roofslabs to this object. Roofs and some other AEC-objects are not supported in the current ADT3.3/IFC-interface. The room object and the building element objects compose a thermal zone. Further new functions were implemented for linking several rooms to one virtual thermal zone and for detaching building element objects from zones. All connections between the objects are realised with the ADT property-sets.

CADKON-DT got two new functions for visible information about thermal zones and the appropriate objects. On the one hand the user can pick an object and CADKON-DT shows the attached zone and all other connected objects. On the other hand the user can select a thermal zone and CADKON-DT shows all linked zones from the virtual zone, if one does exist.

- Material database for wall layers: A material database for parameterizing different wall constructions, realised as a simple MS-DAO 3.6 database, includes material data (density, heat capacity and heat conductivity) from German and European standards (DIN 4108-4 and EN 12524). The user can attach values from the database to the layer objects of the wall object.
- Data export by IFC 1.5.1 and 2x: At the beginning of the research project the ADT 3.3 didn't support the IFC 2x format. Since autumn 2002 a beta version of an external developed (G.E.M. Team Solutions) IFC 2x interface can be used in the project. Both interfaces are limited, e.g. only a part of the properties from the structural members are exported and 3rd party development isn't possible. This problem was handled in CADKON-DT by an extensive use of the ADT property-sets.

## IFC DATA TRANSFER

The data transfer from the CAAD to the simulation software uses the IFC data format. Building objects from the drawing are converted to the IFC data model and written to an exchange file. An IFC reader module parses and analyses the exchange file. After some consistency checks and enhancements the data is used to configure both simulation models (see figure 2).

The project had to deal with the conversion between four different types of views at building structures. All three tools use different object models,

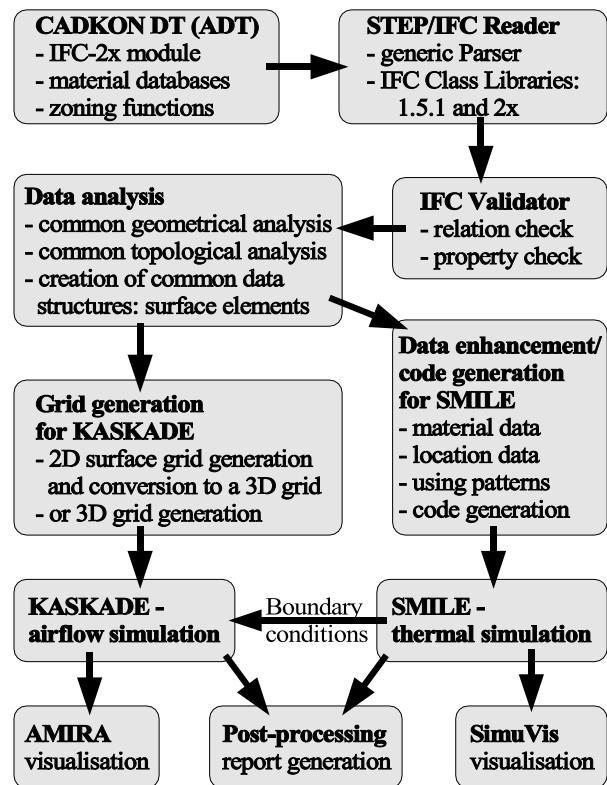


Figure 2: Information Flow Plan

and IFC introduces a fourth one. Because of differences between these models a lot of conversion has to be done, which is time-consuming and potentiates loss of information. The imported data may be more or less complete regarding material data, geometrical consistency, topological integrity and other items. The IFC standard usually offers more than one way to store a specific information, but not all of the ways are sufficiently bound to CAAD applications. Here is an example: A 'thermal zone', which may cover one or more rooms, is an important basic structure for thermal simulation. IFC offers an appropriate entity called IfcZone. But because the CAAD application doesn't bind this entity to objects, a lot of workaround-code had to be implemented to misuse special room objects as zones. The generic properties and property-sets of some IFC entities turned out to be a very helpful feature to transfer additional information which is either not covered by the standard or not bound by the application.

Furthermore the quality of the connection of different CAAD-programs to IFC was analysed. While IFC provides a clear object oriented specification for the building domain, the connection to the individual object models of the different CAAD-programs is not satisfying until today. A result was that parts of needed information may be lost or transformed irreversible even if the information is contained in the CAAD model. To set an example: One of the tested applications stored each layer of one wall as a separate IfcWall, which will obviously screw up the

data model.

An analysis and a preprocessing of the transferred IFC data were needed for the parameterisation and configuration of both simulation programs. The object oriented IFC data model and an additional IFC-Validator are used for analysing and preparing the specific elements of the building like zones, walls, doors and windows and their relations among each other. Therefore the imported IFC data is the basis for the creation of surface data structures representing a face. These common data structures (surface objects) are the base for the coupling between the simulation programs. As the view points from the models of both simulation programs are quite different (see figure 3) the construction of the list of the surface objects requires non trivial methods. For standard geometry cases it could be implemented.

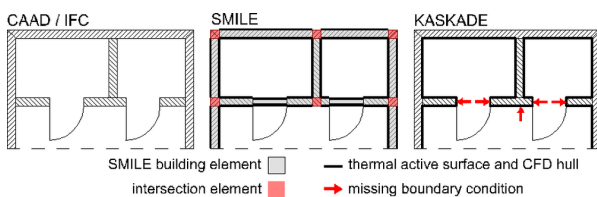


Figure 3: Different modelling aspects on the geometry from CAAD, thermal simulation and CFD

Anyway it could be shown that some of the missing IFC-information can be reconstructed from the transmitted information with the help of validation algorithms.

## SIMULATION PROGRAM SMILE

The generic simulation environment SMILE (<http://www.smilenet.de>) has been developed by the University of Technology Berlin and the Fraunhofer FIRST since 1990 (Ernst et.al., 2000). SMILE contains a simulation kernel (several numerical solvers and a runtime system) and an object oriented modeling language for describing time continuous and discrete (hybrid) systems. Starting with the SMILE model description a model compiler and a C-compiler generate model libraries for simulation experiments.

In the last years an object oriented model library for thermal building simulation was developed on the base of SMILE (Nytsch-Geusen et.al., 2001). The model library contains a set of basic model classes for building elements (walls, windows, roofs etc.), airvolumes, thermal zones and some specialized classes for shadowing and the conditions of use. The basic models of this library allows the configuration of very complex and hierarchical structured multizone building models by an extensive use of the three object oriented paradigms: encapsulation, inheritance and aggregation. Beside the well-known physical effects of thermal building simulation the building model can calculate the interzonal

airchange through a pressure network. This feature is the assumption to get nontrivial boundary conditions for the airflow simulation.

## CFD CODE KASKADE

The finite element code KASKADE (Beck et.al., 1995) has been developed by the ZIB for the solution of partial differential equations in one, two or three dimensions. The toolkit KASKADE (<http://www.zib.de/SciSoft/kaskade>) has an object-oriented structure based on C++. It possesses adaptive finite element techniques to provide procedures of optimal computational complexity, with a posteriori error estimator, local mesh refinement and multilevel preconditioning. KASKADE was designed as a platform for further developments of adaptive multilevel codes. So it was further developed at the ZIB to tackle the three dimensional problem of the stationary, laminar and thermal induced flow. The partial differential equations are resulting from the mass, momentum and energy conservation with the specified simplifications and the assumption that the motion of flow results from an hydrostatic equilibrium perturbed by a temperature dependent density variation. For the boussinesq equations validity see Gray et.al., 1975.

The CFD-grid generation uses the list of generated surface objects (see chapter IFC DATA TRANSFER). All the surface objects compose a closed volume, which represents the inner surface of one or several rooms. Each surface object contains a polygon, which is triangulated in consideration of the inlying, overlapping and neighbour polygons. During the triangulation of the surface hull the boundary identifications are saved. With a triangulated surface hull the tetrahedron based FEM-grid is automatically generated with AMIRA (<http://www.amiravis.com>).

The results of the CFD simulation are visualized using the scripting facilities of the Tcl-command interface of AMIRA. AMIRA allows to compute iso-surfaces and direct volume rendering and uses advanced vector field visualization algorithms.

## PROGRAM COUPLING

The SMILE multizone model for the thermal building simulation delivers the boundary conditions for the CFD-code in terms of temperatures of all surfaces and flow velocities in the openings of a thermal zone. As the CFD-code calculates stationary and the result of the CFD simulation doesn't enter the thermal building simulation, the coupling can work without a back coupling from CFD to thermal simulation.

The coupling of the two simulation programs is realised by the use of the same identification names

on the surfaces of the related boundary conditions. As the thermal simulation model is based on a more abstract geometry, the CFD geometry input has to be generated starting with the common surfaces (compare figure 3).

These common surfaces, interface between the two simulation programs stay invariant while the two simulation models are build and the FEM grid is generated. This isn't as trivial, as it appears to be, because of the difficult task of an automated three dimensional grid generation. The SMILE program writes the desired data (temperatures and velocities) to a special file at fixed intervals. Because of the efficiency and ability to store and describe structured information the NetCDF file format was chosen for that purpose. Furthermore NetCDF allows concurrent read and write access, which enables the airflow simulation to run before the thermal simulation has finished.

## SIMULATION USER INTERFACE

A graphical simulation user interface allows the import of IFC Files, modifications and additions on the building model, its 2D and 3D-visualization, the control of the simulation experiments and a post-processing of the simulation results (figure 4). The simulation user interface guides the simulation engineer step by step through the simulation project:

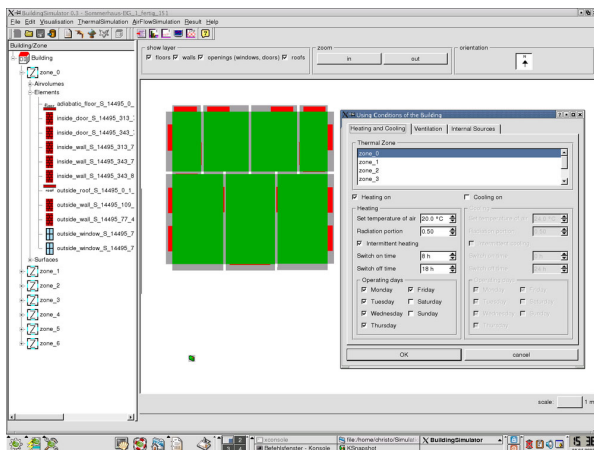


Figure 4: Simulation User Interface

- Import of IFC Files: Currently it is possible to import data files from a CAAD-program in the IFC 1.5.1 and 2x format.
- Control of the building geometry and topology: After the import of an IFC file the user can check the correctness of the imported building model in a different manner. On the one hand he gets the building topology (building → zones → elements) as a tree structure. On the other hand he can see the 2D-floor plan and a 3D-visualization of the building model if required.

- Modification and addition of building parameters: Normally the building parameter set coming from the CAAD-program by IFC is incomplete for a building simulation. The architect may have drawn the building construction without wall layers. In that case the simulation user interface sets a default value (one layer for each wall with a standard material). The user can edit the wall construction by using an wall editor under the restriction of the total wall thickness. Further on all physical building parameters except the building geometry and topology may be amended within the simulation user interface.
- Definition of building location and weather data: The building model needs furthermore specifications for the external boundary conditions like the building environment and orientation and the building location. To this the user selects a weather data set, which was generated by Meteonorm (Meteonorm, 2000) in this project.
- Definition of the using conditions: In the next step the user has to define the using conditions for each thermal zone. These are the set temperatures and time profiles for heating and cooling and also the time profiles for internal heating and moisture sources and ventilation.
- Starting and controlling the thermal building simulation: After that the user has to configure and starts the thermal building simulation. He can control the simulation experiment in two different ways: A monitor shows for the most important state variables like air temperatures and air moisture, heating and cooling rates time continuous trajectories (figure 5).

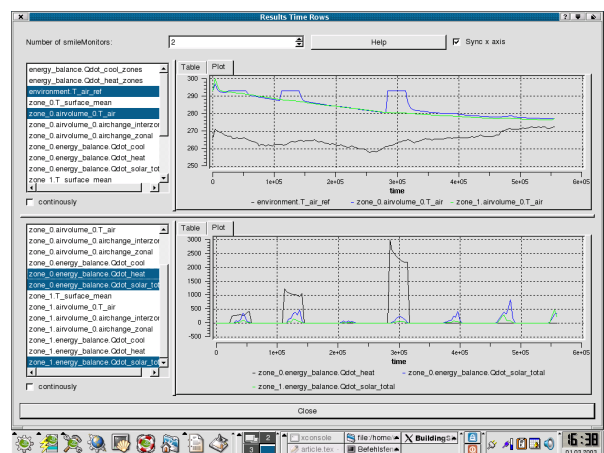


Figure 5: Monitor for controlling thermal building simulation

Complementary further state variables as surface temperatures, air mass flows between the zones and the building environment are visu-



alized within the 3D-building model (see the example in the next section).

- Starting and controlling the air flow simulation: After the thermal simulation has finished, the user can choose a time point within the simulated time period for the steady state CFD simulation. The result of the CFD calculation, the three dimensional temperature and velocity fields, is visualized with the tool AMIRA.
- Postprocessing for the simulation results: The great quantity of model parameter and simulation results is summarized by a postprocessing and is figured on a set of generated PDF-pages. These pages contain tables of input parameters, graphics of daily and monthly energy balances and temperature and air velocity statistics and snapshots on well-choosen planecuts for the estimation of comfortableness.

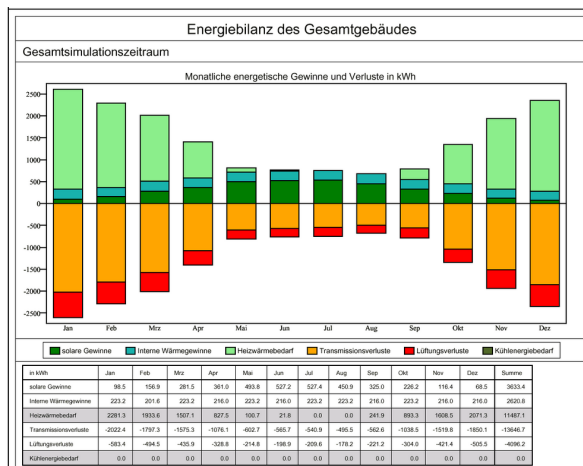


Figure 6: Simulation results: Monthly energy balances of a building

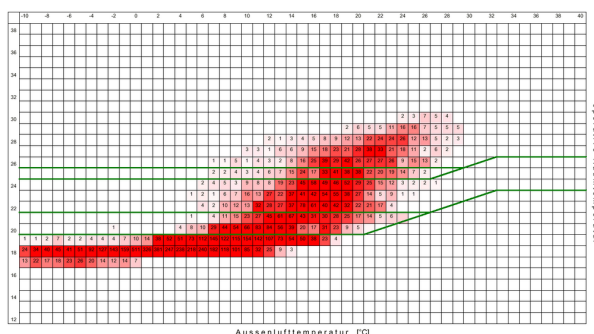


Figure 7: Simulation results: Temperature statistics for a single zone - outdoor temperature versus operative room temperature

For example figure 6 shows the monthly energy balances for a building and figure 7 a temperature statistic for a single zone.

## TESTCASES

The software package of CAAD, thermal building simulation and CFD was used successfully in the project for analysing simple and more complex testcases. The following example demonstrates by means of a building with seven thermal zones the CAAD input and possible results of the simulation tools. The simulation experiment was specified in a way that the thermal simulation program calculates the energy balances and the airchange for each single zone and the CFD program the temperature and velocity fields over a region, which extends over all zones. Figure 8 shows the digital construction in CADKON-DT.

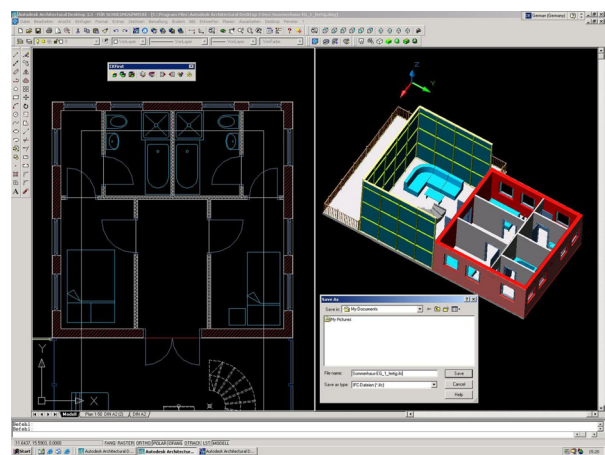


Figure 8: Digital building construction in CADKON-DT

After importing and parameterizing the building construction by the simulation user interface the thermal building simulation can be started.

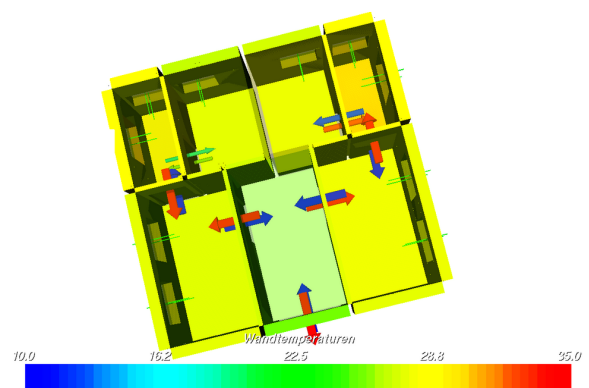


Figure 9: Thermal Simulation: Inside surface temperatures and air mass flows between the zones and to the environment

During the simulation process or as a postprocessing the 3D-visualization program SimuVis (<http://www.dezentral.de/soft/SimuVis>) visualizes the time dependend state of important building model parameters, like surface temperatures, heat fluxes and air mass flows (figure 9).

The results of the CFD simulation are visualized by the program AMIRA. Figure 10 shows a horizontal cut through the 3D-velocity and temperature field. Close to the window surfaces the air temperatures are significantly higher than the values in the middle of the rooms. Figure 11 shows four horizontal cuts through the 3D-velocity field close to a large opening - an open door - of the building envelope. The picture illustrates the typical reversal of the air flow direction subject to the altitude.

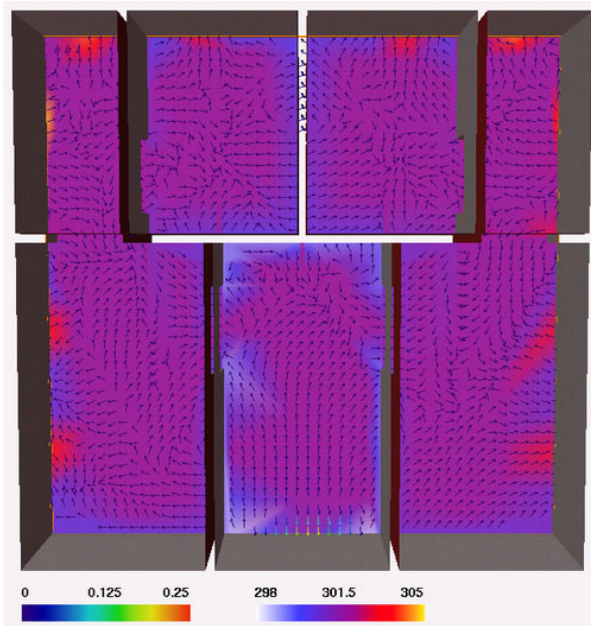


Figure 10: Airflow simulation: Velocity and temperature field (horizontal cut)

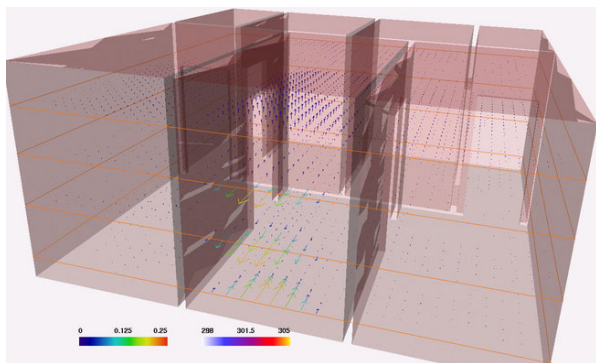


Figure 11: Air flow simulation: Velocity field close to a large opening (four horizontal cuts)

## OUTLOOK

A lot of refinements and improvements have to be done to create a working application ready for the end-user.

Despite the platform issues (ADT3.3/CADKON-DT runs on Windows, SMILE and KASKADE runs

on LINUX/UNIX) the integration of the tools has to be enhanced.

For now only simple geometries are covered by the software package, the IFC classes, which are recognized by the simulation tools, need to be extended for more complex geometries, e.g. building elements with a curved shape or buildings with tilted roofs.

It would make sense to show a part of the simulation results directly in CADKON-DT for detecting thermal weakness of building elements within the 3D-building construction.

The physical models for the thermal building simulation and the airflow simulation should be improved. For example a cell model for the airvolume within a thermal zone would give the CFD-Code more detailed boundary conditions. Another important enhancement would be the implementation of a boundary layer model and a turbulence model in the CFD-code. If the CFD-code would be extended from a stationary to a dynamically model a back coupling from CFD to thermal simulation would make sense.

## CONCLUSIONS

- The IFC data exchange format has made it possible to integrate CAAD-programs and simulation tools for energetic building simulation. The data flow incl. the data reconstruction from the CAAD-program to the simulation programs could be implemented successfully for defined test cases.
- The implementation of the IFC 1.5.1 and IFC 2x interface for the ADT3.3 should be strongly improved.
- The coupling of thermal multizone building simulation program with a CFD-program for airflow simulation allows different detailed energy analyses in dependence from the simulation question.
- The time demand for parameterizing simulation tools for thermal building simulation and airflow simulation could be reduced drastically compared to the data input and grid generation by hand. It is better to have more time for calculating variants of the building model than wasting the time for collecting the model parameters.
- The simulation user interface offers an easy access and usability to both sophisticated simulation tools.

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