Using the PASSYS cell for model-to-model comparison of hygrothermal building envelope simulation tools

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ABSTRACT
IEA-EBC Annex 68 "Indoor Air Quality Design and Control in Low Energy Residential Buildings" is an international collaborative project to provide new insight into methods and strategies for ensuring high indoor air quality in dwellings during both design and operation phase of their life cycle. Within the Annex 68 work, we defined a common exercise, which focusses on model-to-model comparison of different simulation tools to assess their modelling abilities with respect to combined heat, moisture and pollution transfer.
As basis of the common exercise, we selected a model of the PASSYS cell (originally used as a common European outdoor test facility for thermal and solar building research). The PASSYS cell is modelled by using several simulation tools with different modelling capabilities (e.g. 2D hygrothermal building envelope models vs. 3D building energy models). Model comparisons are done at stepwise increased level of complexity starting at simple thermal analysis (heat transfer through walls, internal heat sources, internal long wave radiation, etc.) and ending at pollution emission analysis under operation of HVAC systems (demand controlled ventilation, heating and cooling).
This paper introduces results from the first part of the exercise covering simulations carried out by using following 2D tools CHAMPS-BES, DELPHIN5 and DELPHIN6.

KEYWORDS
Hygrothermal simulation, building envelope, building energy performance simulation, quality assurance, common exercise.

INTRODUCTION

Focus of Subtask 3 of the IEA-EBC Annex 68 project is the development of quality assurance criteria for optimal use of building performance simulation tools. Therefore, the main target is a review, gap analysis and categorization of existing models and standards. The gap analysis will reveal missing or incomplete model features while the categorization delivers information on usability of the different tools. The strategy includes supporting actions as common exercises and a collaborative development towards a fully Coupled Heat Air Moisture and Pollutant Simulation (CHAMPS) platform.
The common exercise is based on the PASSYS Cells Project (Wouters, Vandaele et al., 1990). Figure 1 shows a sectional view of the construction. The exercise starts with a 2D thermal analysis by using the hygrothermal building envelope models CHAMPS-BES[1], DELPHIN5[2] and DELPHIN6[2]. A gradual buildup of model complexity is implemented by consideration of additional variants of heat, air, moisture and VOC flows.

[1] http://champs.syr.edu/software/champs_bes.html
[2] http://www.bauklimatik-dresden.de/index.php?aLa=en

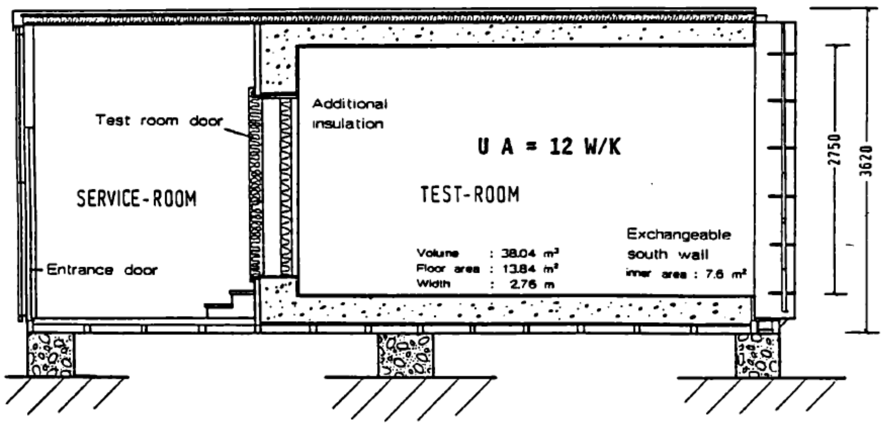

Figure 1. Sectional view of the PASSYS cell (Wouters, Vandaele et al., 1990).

The sectional view of the PASSYS cell in Figure 1 shows that it consists of two rooms: a test room and a service room, separated by a partition wall. The test room is equipped with an exchangeable external wall at its front side. The original purpose was to test the performance of different wall constructions and their influence on indoor climate.

METHODS

2D model of the PASSYS cell

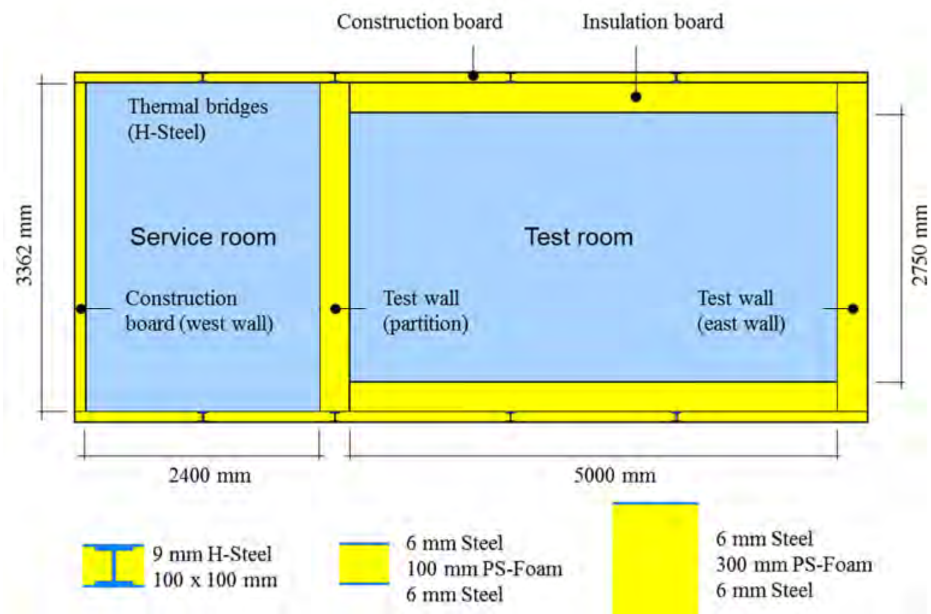

Figure 2. 2D simulation model of the PASSYS cell. The orientation of cells in this model is east (right) to west (left).

For the purpose of this common exercise, the original construction of the PASSYS cell was simplified. Construction boards consisting of rigid PS-foam insulation material and steel covering were used, see Figure 2. The cell was put up using 100 mm thick insulation panels reinforced by H-steel beams. Additional 300 mm thick insulation boards were used as a partition to separate the test room. Concrete foundation and support construction were neglected.

Boundary conditions, climate data and initial conditions
Climate data for the city of Essen, Germany - hourly values for temperature, relative humidity, direct and diffuse solar radiation, atmospheric counter radiation, wind velocity and direction, and rain provided by the German weather service (DWD) were used.
The simulation tools used the climate data and additional parameters as surface heat transfer and moisture absorption coefficients to calculate the heat and moisture flows at the boundaries of the construction. The orientation of the construction elements (west wall, flat roof and east wall) had to be taken into account by the tools. Input files containing aforementioned parameters were generated for each particular tool.
Placement of the PASSYS cell directly on the ground was assumed. Therefore a constant ground temperature of 8 °C was used as a boundary condition at the bottom side. The initial conditions are the same for all test cases: 20 °C and 80 % R.H. The total simulation time was 365 days.

Used simulation tools
For the 2D simulation variants of the exercise, CHAMPS-BES, DELPHIN5 and DELPHIN6 have been used. The advantage of these tools over 3D building energy simulation tools is that they can consider transient heat, air, moisture and VOC flows and use a fully discretized construction. Disadvantages include a longer simulation time due to a large equation systems to be solved and a relatively simple airflow model.

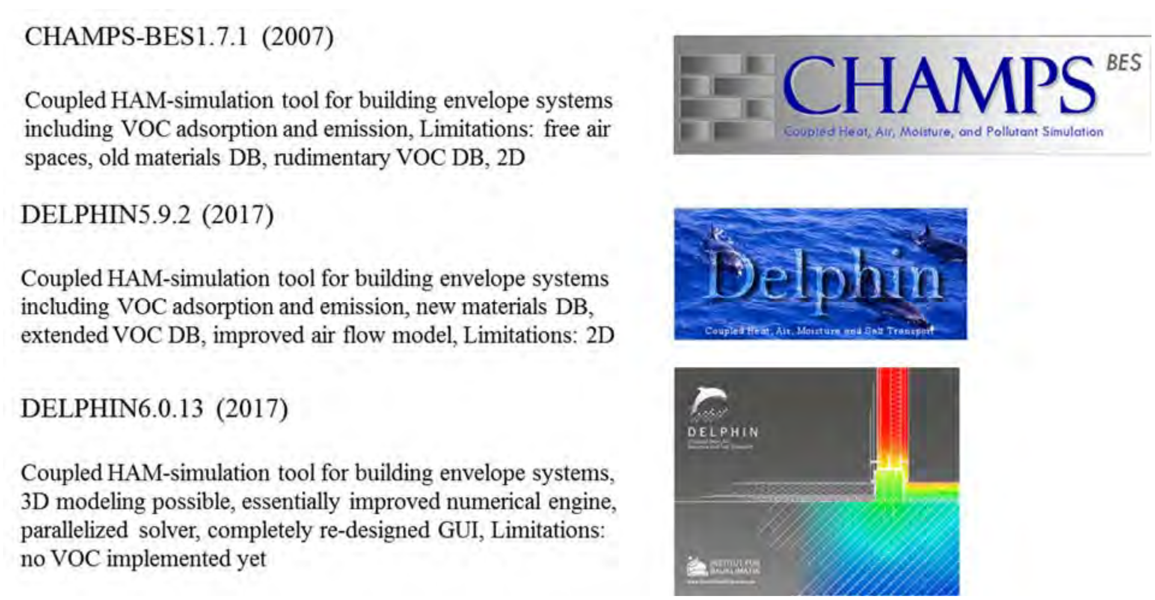

Figure 3. Simulation tools used for calculation of the PASSYS cell.

Based on the former DELPHIN versions (1987-2006), CHAMPS-BES has been developed at Syracuse University in 2006-2007. DELPHIN5 is the result of a continuation of the development at the TU Dresden during 2007-2017. The first DELPHIN6 version has been released in 2017. It is in large parts a major upgrade of the code, e.g. it comes with a completely re-designed simulation engine in order to resolve simulation time issues for problems with large number of equations.

Simulation variants
The assumption is that simulation tools used by the participants offer very different modelling features. The target of the exercise is to research and document how accurately and efficiently the different models solve given tasks. Therefore, the task description should leave room for flexible adaptation while being precise enough to provide clear information.
The modelling complexity is gradually increased in five steps. The simplest test case represents solely a thermal analysis. Hygrothermal analysis without and with airflow follows next. Finally, emission analysis without and with HVAC is built upon the previous test cases. Each of the test cases includes sub-cases as shown in the (not complete) list below, which will be extended according to the individual modelling capabilities of the tested tools.
The present paper reports results of the test cases 1b), 2a), 2b), 3a) and 3b), which are indicated by bold text. These cases are considered most relevant and were solved first. The remaining test cases are in preparation. Additional VOC data must be collected before emission analysis can be started.

<u>Test cases to increase the complexity of the exercise:</u>
1) Thermal analysis (H)
    a. Free-running building, just heat transfer through walls
    b. External long wave and short wave radiation
    c. Internal heat sources, internal long wave radiation
2) Hygrothermal analysis (HM)
    a. Moisture fluctuation in rooms
    b. Rain load, capillary action and moisture buffering in walls
    c. Internal moisture sources
3) Hygrothermal analysis with air flows (HAM)
    a. Air exchange with external air in zones
    b. Air permeable construction elements, air flow between zones
    c. Air flow within zones, buoyancy effects
4) Emission analysis (HMP)
    a. Internal VOC sources in zones
    b. Absorption and emission of VOC by construction materials
    c. Combination of internal VOC sources, absorption and emission
5) Emission analysis with action of HVAC systems (HAMP)
    a. Scheduled ventilation
    b. Demand-controlled ventilation
    c. Influence of heating and cooling, energy optimized HVAC operation

Following output data (hourly values) were analyzed: air temperature in test and service room and temperatures in the walls measured at three locations (inside, middle, outside).

RESULTS AND DISCUSSION

Thermal analysis: Test case 1b)
Considered conditions:
- External air temperature, short wave solar radiation, long wave radiation
- Free-running building, heat transfer through walls, no ventilation

The simulation tools should be capable to capture at least two main effects. First is temperature amplitude damping in the walls from outside to inside and second is the temperature fluctuation in the rooms, which is influenced by the insulation. The results are depicted in Figures 4 and 5. The temperature field shows clearly the effect of thermal bridges by the H-steel beams. In Figure 5, the results from the service room calculated by CHAMPS-BES, DELPHIN5 and DELPHN6 can be compared in detail. Room and wall temperatures for all tools are in a good agreement.

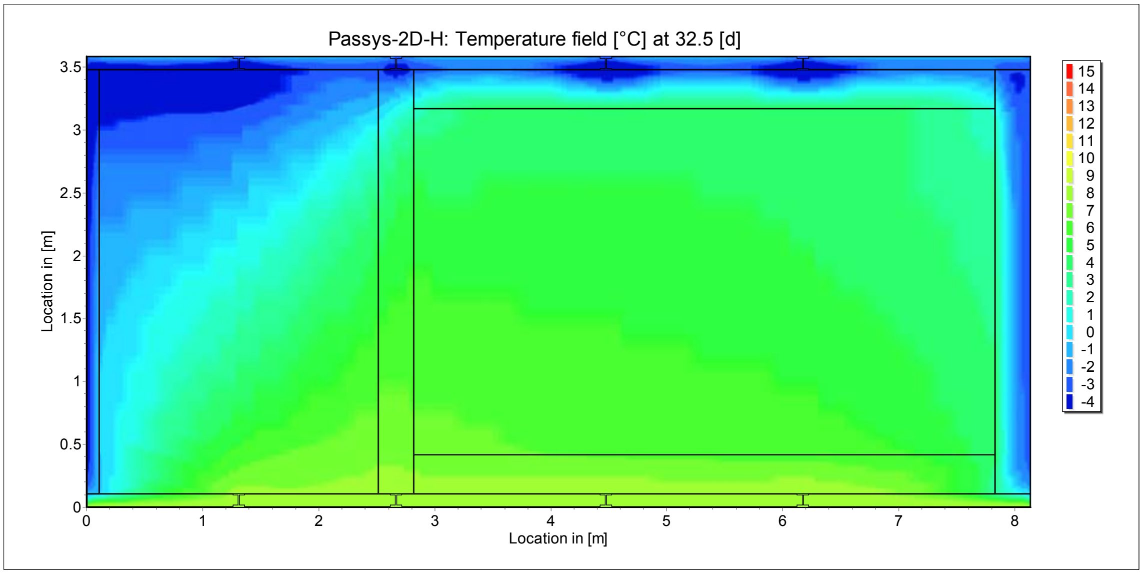

Figure 4. Temperature field of the PASSYS Cell at a cold day (Feb-02), calculated by CHAMPS-BES.

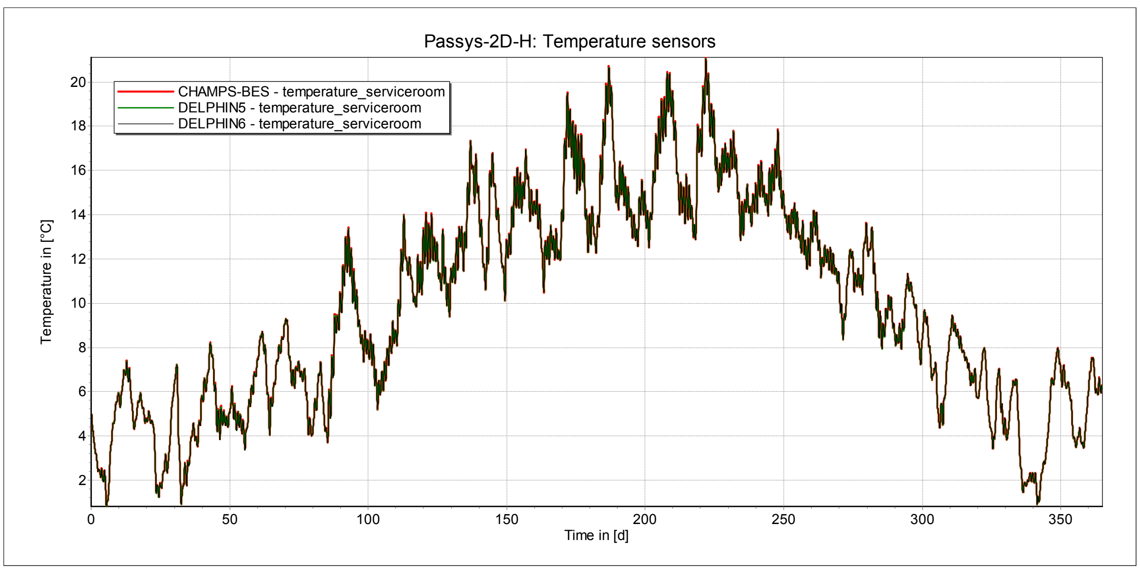

Figure 5. Comparison of the temperatures in the service room, calculated by CHAMPS-BES, DELPHIN5 and DELPHIN6.

Hygrothermal analysis: Test case 2a)

Additional conditions (with respect to 1b): Humidity + Rain + Wind

The room air temperatures and relative humidity values should fluctuate inversely in this test case since the construction board consists of steel-covered insulation, which is vapor permeable. The simulation tools should be able to set flux from the humidity and rain boundary conditions

to zero. Consequently, the total moisture mass in the construction should remain constant throughout the year, which was correctly calculated by DELPHIN5 and DELPHIN6.
While DELPHIN5 and DELPHIN6 results agree very well, CHAMPS-BES shows considerable deviations in relative humidity, which led to convergence problems and stop of the simulation after 1.2 days. This problem was caused by a programming bug, which was fixed in one of the later DELPHIN5 versions. In conclusion, CHAMPS-BES cannot be recommended for hygrothermal simulation problems with air volumes.

Hygrothermal analysis: Test case 2b)
Additional conditions (with respect to 2a): Capillary-active construction (brick masonry) for east wall and partition.
Change of the construction from moisture-tight to diffusion-open and capillary-active should increase the moisture content in the east wall by rain water absorption and lead to higher relative humidity values in the test room. This was correctly calculated by DELPHIN5 and DELPHIN6. CHAMPS-BES was excluded from the further analysis.
While DELPHIN6 completed the simulation well after approximately two hours, DELPHIN5 must have been stopped at 152nd day because the simulation took longer than two days, which was set as maximum time limit. This shows the advantage of DELPHIN6 over DELPHIN6 in simulation speed. Another remarkable fact is that there are deviations of maximum 15 % between DELPHIN5 and DELPHIN6 in integral moisture contents. DELPHIN5 and DELPHIN6 use different wind driven rain models: DELPHIN5 uses an internal model, and DELPHIN6 uses a model after the European standard (DIN EN ISO 15927-3, 2009).

Hygrothermal analysis and air flow: Test cases 3a) and 3b)
Additional conditions (with respect to 2b): Air change rate in zones, air permeable construction. Since DELPHIN5 could not finish the previous case within two days, the original model was replaced with a downscaled version of the PASSYS Cell was used which decreased the number of used volume elements from 23940 to 5670. Air change was modeled in two ways 3a) direct air change with external air at 1 h^{-1} and 3b) infiltration through air gaps, inlets at the east wall and outlets at the west wall providing air change of 2.5 h^{-1}.
The results from DELPHIN5 and DELPHIN6 were almost identical for the room air conditions. However, small deviations could be observed in total moisture mass, even without rain boundary condition. Therefore, further exploration and bug fixing is needed to find the reason for that.

CONCLUSIONS
This exercise laid the corner stone of a comparative test series of simulation tools for hygrothermal building envelope and building energy performance problems. First results are encouraging and further participation of different working groups will deliver more results. In the consequence, this will lead hopefully to higher quality results in building simulation.

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