BSim Modeler Report

Empirical Validation of Building Simulation Software

Technical Report

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Validation of Building Energy Simulation Tools

Subtask E

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by

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1. Introduction

Test cases DSF100_e and DSF200_e were simulated with the Danish Building simulating software BSim, version 4.7.1.18.

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http://www.bsim.dk (BSim homepage)

BSim (Building Simulation) is the integrated tool for projecting buildings and installations. The software consists of seven modules:

- SimView - Graphic user interface
- Tsbi5 - Indoor climate, thermal and moisture conditions
- Xsun - Sunlight and shadows
- SimLight - Daylight calculations
- BV98 - Danish Building regulations compliance checker
- SimDXF - Importing CAD drawings
- SimDB - Database with constructions and materials

Moreover there few advanced options available, these are:

- Advanced simulations of moisture transport in buildings and constructions
- Calculations of electrical energy yield from a building integrated solar cell (PV) system
- Simulation of indoor climate with natural ventilation in the building

2. Modelling approaches in BSim

Calculations in BSim performed in a steady state condition for the each time step. The software contains also accumulation of heat and moisture calculations. There are two or more time steps per hour.

Zones

A building consists of an arbitrary number of zones, which are limited by an arbitrary number of surfaces.

The zone air is represented in the building description as a nodal point, for which air temperature and water vapour content are calculated. It is assumed that the air in a zone is fully mixed. However, the temperature stratification in a zone can be modeled by means of Kappa-model, which is highly dependent on user assumptions/inputs.

External environment

This is so-called virtual zone, e.g. the outside air, the condition of which is not to be calculated, but is given by data from a file or a timetable, defined by user.

Transmission of solar radiation to the zone

XSun, which forms a part of the BSim software suite, can be used for the detailed analyses of the path of direct solar radiation through a building. It is possible to see where and when the sun strikes any face in the model. The direct solar radiation through the external and internal window will be distributed geometrically correct according to the solar path, while the diffuse solar radiation will be distributed according to surface area weighting.

Solar radiation

From the values given in the weather data file BSim is able to calculate the solar incidence on an arbitrarily orientated surface. Petersen's model is the default one for calculation of solar incidence in BSim. Available models for calculation of solar incidence in BSim are: Petersen's, Munier's, Lund's and Perez's.

Longwave radiation exchange between the model and ambient

Only the radiative exchange to the sky takes part in the simulation. There is thus no radiative exchange with eventual other buildings in the model and nor with eventual advanced parts of the building itself. The radiative heat exchange is thus only dependant on the temperature difference between any surface and the sky, respectively the ground and the tilt of the surface.

Internal longwave radiation exchange

It is only possible to simulate long-wave radiative exchange in tsbi5 in those rooms, which are convex, in order to enable calculation of view factors in BSim. When the internal longwave radiation exchange is to be calculated then the convective heat transfer coefficients are calculated separately for each surface, otherwise a combined value of convection and radiation is used.

The longwave radiation exchange from the surfaces of the glass and the surrounding surfaces with average emission coefficient (e = 0.94) is used for all surfaces made of glass.

Outdoor surface convection coefficient

Next to calculating the long wave radiation effects, the heat transfers coefficient between the outdoor air and the first node point on the exterior side of the construction is calculated as a function of wind speed.

Convective heat transfer coefficients

<u>For vertical surfaces:</u>

Laminar conditions, small surfaces ($\Delta T \leq 9.5/L^3$):

Equation 2-1

$$\alpha_c = 1.43\left(\frac{\Delta T}{L}\right)^{0.25} \text{ W/m}^2\text{K}$$

Turbulent conditions, large surfaces ($\Delta T > 9.5/L^3$):

Equation 2-2

$$\alpha_c = 1.31(\Delta T)^{0.33} \text{ W/m}^2\text{K}$$

<u>For horizontal surfaces with upward heat flow (warm floors or cold ceilings):</u>

Laminar conditions, small surfaces ($\Delta T \leq 0.19/L^3$):

Equation 2-3

$$\alpha_c = 1.32\left(\frac{\Delta T}{L}\right)^{0.25} \text{ W/m}^2\text{K}$$

Turbulent conditions, large surfaces ($\Delta T > 0.19/L^3$):

Equation 2-4

$$\alpha_c = 1.52(\Delta T)^{0.33} \text{ W/m}^2\text{K}$$

For horizontal surfaces with downward heat flow (cold floors or warm ceilings), only laminar conditions:

Equation 2-5

$$\alpha_c = 0.59\left(\frac{\Delta T}{L}\right)^{0.25} \text{ W/m}^2\text{K}$$

Glass temperature

In the model, different absorption and reflection at the two glass faces are used in the calculation of the absorbed amount of radiation in the glass. Then the temperature for the glass surfaces is calculated as a heat balance to the air temperature next to the glass surface, including the amount of absorbed energy in the glass face.

Heat balance for the zone air

The heat balance for the air in a zone does not make allowance for the heat capacity of the air which means that the air momentarily adjusts itself to alterations in the surroundings, includes:

-heat flows from adjoining constructions
-heat flows through windoors
-solar radiation through windoors (of which only a limited amount is assumed to be induced to the air)
-thermal contribution from various heat loads and systems
-air penetration from outdoor air (infiltration, venting)
-air supplied from ventilation systems
-air transferred by from other zones (mixing)

Heat transmission in the constructions

The constructions consist of one or more layers, which are assumed to be homogeneous, consisting of one material, which is characterized by thermal material values. The heat transmission internally in the constructions is described non-stationary, i.e. by making allowance for each individual layer's thermal capacity. Thick material layers are divided into several thinner layers (control volumes).

Heat transfer coefficients at the window surfaces are calculated in the same way as the heat transfer coefficients for the wall containing the window.

Air mass balance

If an un-balanced air-stream is introduced in any thermal zone, this will automatically be balanced with in- or exfiltration of air from the outdoors in the tsbi5 simulations. This happens even if the thermal zone has no direct connection (faces) to the outdoors.

Control

All systems in BSim are controlled on the basis of an operative temperature in the thermal zone to which they are attached. However, it is possible to adjust the control system for application of the air temperature instead for the operative air temperature.

3. Modelling assumptions

General

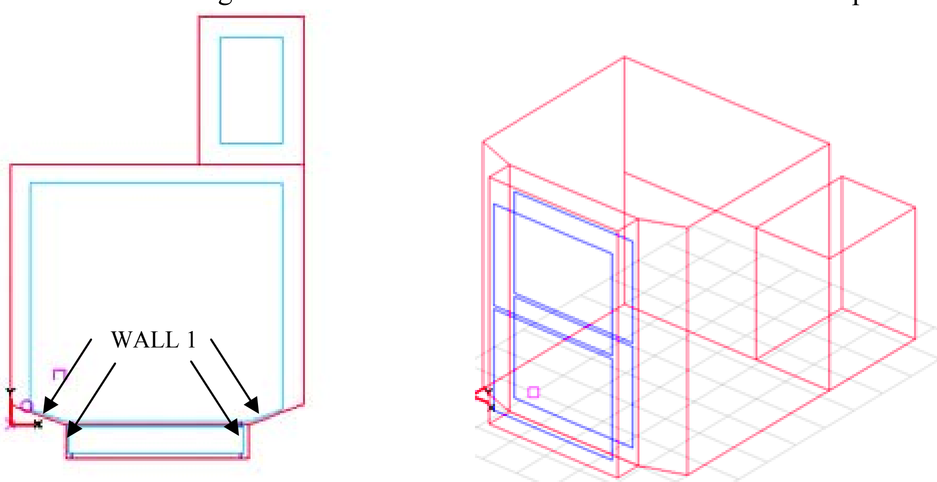
Weather data

The climate data is provided together with the specification, where it is advised to use global and diffuse solar radiation on the horizontal surface as input parameters. BSim is not able to use these parameters as inputs; therefore the Normal direct solar radiation and diffuse solar radiation were used instead for. Normal direct solar radiation was calculated manually on the basis of provided climate data.

Model geometry

Thermal zones in the model are defined according to the specification, thus zone 1 represents the DSF and zone 2 represents the room adjacent to the DSF.

WALL 1, shared by zone 1 and zone 2 was modeled as an adiabatic and relatively thin wall for each of the zones, see Figure 1a. The internal dimensions of the zone 1were kept unchanged according to the specification. Internal dimensions and shape of the zone 2 were changed, as following: left and right WALL 1 in the zone 2 was given a slope in order to activate the longwave radiation calculations (BSim limitation for the concave spaces). The length of the WALL 2 was changed to attain the same internal zone volume as in the specification (Figure 1) .



a. b.

Figure 1. Geometry of BSim model. Plan (a). Model in 3D (b).

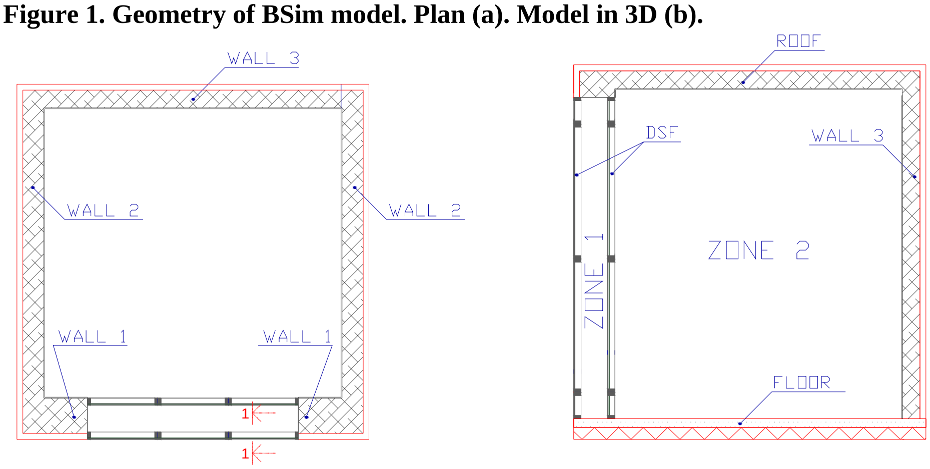


Figure 2. Definition of zones and walls in the specification. Plan (left) and section1-1 (right).

Opaque constructions

U-values for the constructions are calculated by BSim when the material properties of the constructions are defined by user. The U-value is calculated according to the Danish Norms DS 418. Material properties were defined according to the specification.

Transparent constructions (Windoors)

Following Figure 3 is included in the report to explain the modelling procedure for the DSF. Figure 3a corresponds to the original geometry definition in the test specification. First, all windows and wall of the external façade are replaced by a separate construction with the U-value equal to the U-value of the window frame (U= 3.86 W/m^2, Figure 3b). Then windows are added to the new construction (Figure 3c). Six sections of the external windows are replaced by 2 sections with the corresponding area of glazing.

It is necessary to leave some distance between the window frame and the edge of the construction in BSim. In the Figure 3c is shown area of 1.236 m^2, left around the windows (blue color), this area has the same U-value as the window frame. Total frame area of windows is 3.216 m^2.
Remaining frame area will be:
A=3.216-1.236=1.98 m^2
This area 1.98m^2 was equally distributed between 2 windows (Figure 3c.)

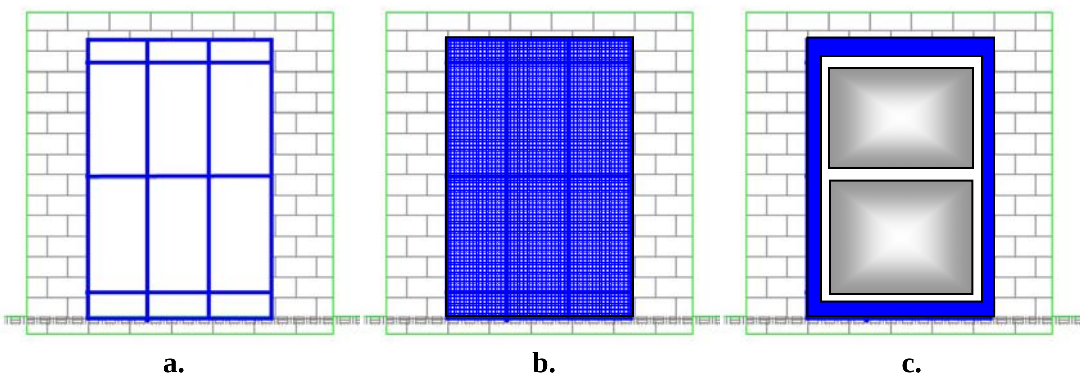


Figure 3. South façade, defined in the test case specification and in the model

Same steps were repeated for the internal window sections.

These changes require adjustments in U-value of the windows, to fulfill a condition:

Equation 3-1

$$A_w \cdot U_w \cdot 6 \approx A_c \cdot U_f + A_w^* \cdot U_w^* \cdot 2$$

A_w – area of window section defined in the specification, m^2
U_w – U-value of the window section defined in the specification, W/m^2
6 – number of window sections
A_c – area (of new construction) left around the window, m^2
U_f – U-value of the frame defined in the specification, W/m^2
A_w^* – area of 1 out of 2 window sections (Figure 3c), m^2
U_w^* – adjusted U-value of window sections in Figure 3c, m^2
2 – number of window sections (Figure 3c)

Incident solar radiation

Perez model was used for the calculations

Transmission of solar radiation

The transmission of solar radiation as a function of angle of incidence is estimated on the basis of a default function in BSim:

Incident angle	Transmission of external window pane	Transmission of internal window panes
0	0.76	0.53
10	0.75	0.53
20	0.75	0.53
30	0.75	0.53
40	0.74	0.52
50	0.72	0.50
60	0.65	0.45
70	0.52	0.35
80	0.30	0.19
90	0.00	0.00

Solar heat transmittance (g-value) for the solar radiation normal to the glass surface is calculated f by BSim on the basis of glazing transmittance properties. Values used in simulations are according to the WIS calculations given in specification.

Program assumes heat transmittance for diffuse solar radiation (reflected from surroundings, i.e. neighbor buildings, ground, clouds etc.) equal to the transmittance for direct radiation at an angle of incidence of 60°.

Surface finishes

Solar radiation sticking the opaque external surfaces is absorbed according to the defined surface absorption property, however solar radiation sticking on the opaque internal surfaces is fully absorbed by the surface.

Glazing Surface temperatures

In BSim the model for calculation of the glazing surface temperatures is simplified, it accounts for the absorbed solar radiation in the glazing pan and the air temperature in the neighboring zones. However there it has a limitation: it is assumed that there are always two layers of glass and this model is not applicable for the glass with coatings. And therefore it can not be directly applied for the constructions defined in the specification.

Glazing emissivity

This is the default value in the BSim and equals 0.84

Air flow modelling

The airflow model for the case defined in the specification is described as 'Single Sided in Different Levels'**.** It is used when several pairs of openings in one face are located in different vertical levels with the uniform temperature distribution in the thermal zone. The airflow through the zone is described by general expression in Equation 3-2.

Equation 3-2

$$q = \left| \pm q_v^2 \pm q_t^2 \right|^{1/2} = \left| \frac{c_v}{|c_v|} \cdot \left(c_v \cdot V_{10}\right)^2 + \frac{\Delta T}{|\Delta T|} \cdot \left(c_t \cdot |\Delta T|\right)^2 \right|^{1/2}$$

Equation 3-3

$$c_t = \sum_{j=1}^{n} c_{D,j} \cdot A_j \cdot \left(\frac{2 \cdot \left(H_o - H_j\right) \cdot g}{T_i} \right)^{1/2}$$

Equation 3-4

$$c_v = 0.03 \cdot A$$

q	- air flow rate in the zone
q_v, q_t	- airflow rate caused by wind forces and buoyancy correspondingly
c_v, c_t	- coefficient for the wind force and buoyancy correspondingly
V_{10}	- the reference wind velocity at the height 10m
ΔT	- temperature difference between two environments
n	- number of openings
j	- opening number
c_D	- the discharge coefficient
A_j	- area of the opening 'j'
H_o	- height of the neutral plan
H_j	- height of the opening 'j'
g	- gravity force

Wind pressure coefficients

In BSim the wind pressure coefficients are the default values, determined as average values for the surfaces at the different wind incidence angles. BSim chooses the Cp-values from these standards based on the geometry of the building model. Comparison of the Cp values given in the specification and BSim-values is performed in Figure 4.
However, the BSim approach means that every surface is given only 1 value independently on number of openings in the surface and as consequence there is no pressure difference between the openings on the same surface caused by wind.

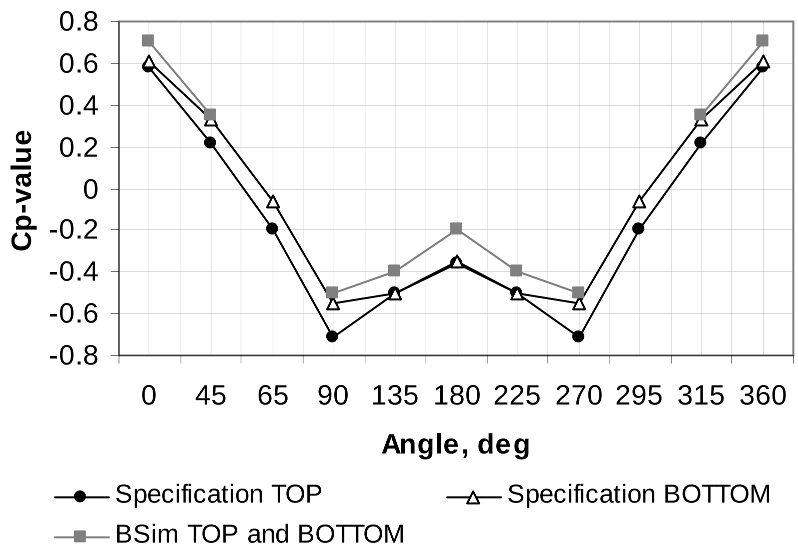


Figure 4. Comparison between Cp -values in the specification and BSim default.

Wind profile

The default function is used to describe the wind velocity profile. A function for the scattered wind breaks was used in the calculations and can be described as in Figure 5.

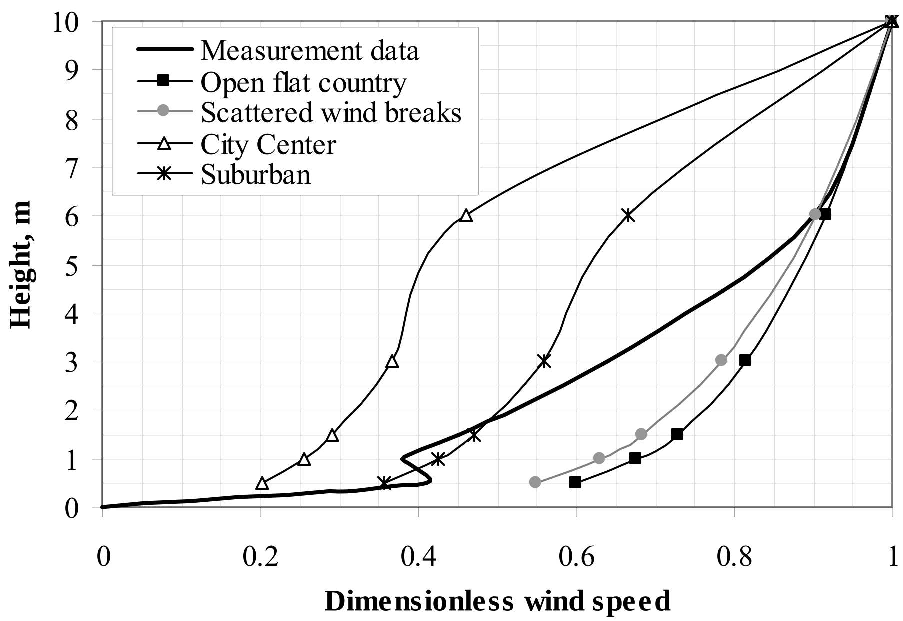


Figure 5. Wind profiles available in BSim.

$V_h = V_{10} k h^{\alpha}$

V_h is the wind velocity in height h [m/s]

V_{10} is the measured wind velocity 10 meters above the free terrain [m/s]

h is the actual height above terrain [m]

k is a factor dependant on the terrain

α is an exponent, dependant in the terrain

For the terrain with the scattered wind breaks the k and α coefficients are as following
$k=0.52$
$\alpha=0.20$
Thus the wind speed reduction coefficient for the height of 6m (roof of the building) is 0.744

Discharge coefficient

The discharge coefficient in BSim is used 0.65 and 0.72 for the bottom and top openings correspondingly to the specification.

Thermal bridges

Thermal bridges were included into the calculations by modification of the constructions in correspondence with the heat loss measurement, described in the specification.

Infiltration

Infiltration is not included into the calculations

Control and air temperature

In BSim systems are controlled according to the operative air temperature, however in the specification the control is performed true the air temperature only. I order to follow the requirements in the specification the longwave radiation contribution on the calculations of the operative air temperature were deactivated.

Remaining parameters

Remaining parameters were modeled according to the test case specification

DSF100_e

Heating/cooling

Heating/Cooling system is introduced to *Zone 2*. The set point temperature for cooling is set to 21.8°C and 21.7°C for heating.
The proportion of the cooling output that is reckoned to be given off to the room air by convection is equal to 1. Heating/Cooling power provided to the *Zone 2* is unlimited to maintain the set point temperature of the room.

DSF200_e

Heating/cooling

Heating/Cooling system is introduced to *Zone 2*. The set point temperature for cooling is set to 21.8°C and 21.7°C for heating.
The proportion of the cooling output that is reckoned to be given off to the room air by convection is equal to 1. Heating/Cooling power provided to the *Zone 2* is unlimited to maintain the set point temperature of the room.

Natural ventilation

The natural ventilation is activated and calculated as described above

4. Results

All results are given in tables:
Output results DSF100_e.xls
Output results DSF200_e.xls

5. Remarks

Glass surface temperature needs investigations

6. Corrected errors

Calculation of view factors for the large opposing glazed surfaces on a short distance from each other.

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