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TRNSYS17: NEW FEATURES OF THE MULTIZONE BUILDING MODEL

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ABSTRACT

For the upcoming release of TRNSYS 17, one main focus is the improvement of the simulation of highly glazed large spaces such as multi-story atriums with respect to accuracy, user effort and error-proneness. Therefore, the existing multizone building model has been extended to a detailed modelling of 3-dimensional energy transport by radiation and thermal stratification.

This paper briefly describes the new model for long-wave and short-wave radiation handling within a thermal zone as well as the multiple airnode approach.

The new radiation model applies so-called Gebhart factors, which are based on view factors. The long-wave and short-wave diffuse radiation exchange between all surfaces of a thermal zone are calculated explicitly, including all possible paths. Point sources are treated similarly. To account for stratification effects or local conditions near the facade, multiple airnodes can be defined within each thermal zone.

In addition, external sunlit factors of solar radiation can be handled automatically and the incoming beam radiation is distributed depending on the sun's position, the external shading and the geometry of the thermal zone.

For convenient geometry input and visualisation a graphical interface will be available for TRNSYS 17. From the resulting geometric information the required inputs such as view factors, shading factors and distribution factors are calculated in a preprocessing step.

INTRODUCTION

For the upcoming release of TRNSYS 17 one main focus is the improvement of the simulation of highly glazed large spaces such as multi-story atriums with respect to accuracy, user effort and error-proneness. Therefore, the existing multizone building model has been extended to a detailed modelling of 3-dimensional energy transport by radiation and thermal stratification.

Figure 1 provides an overview of the newly integrated features. These new features are optional such that the user can adapt the level of detail according to the needs of the project.

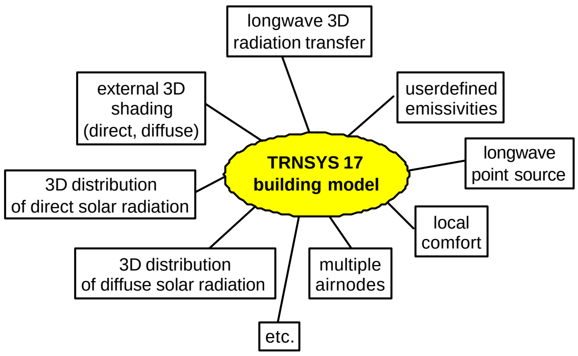

Figure 1 New features of the multizone building model

GEOMETRIC INPUT DATA

For TRNSYS 17, the standard building description file is extended by the addition of geometric information. This information is optional and is required only for radiative zones that make use of the new detailed radiation model.

Radiative zones are three-dimensional convex polyhedral solids. The zones can be disjoint or touching each other at a common vertex, edge or face, but zones are not allowed to penetrate one another. Obstructions are considered as two-dimensional planar polygons with zero transparency. All walls, windows and obstructions are considered as planar non-selfintersecting polygons without holes. Windows are subsurfaces of walls. The edges of a polygon are restricted to straight lines. The boundary of a polygon is represented by an ordered list of its vertices. Point heat sources and local comfort positions are represented by a vertex. The building and its obstructions are defined in a so-called world coordinate system.

For convenient geometry input and visualization, it is planed to extend existing interfaces such as the OpenStudio plugin for SketchUp 7 (Ellis, 2009) to write the new building description file.

PREPROCESSING

From the resulting geometric information, the additional required inputs of the multizone building model such as view factors, sunlit factors and distribution factors are calculated automatically in a preprocessing step.

Preprocessing offers various advantages over calculation of sunlit fraction and distribution factors during the course of the simulation with respect to flexibility, computing time and input effort. Instead of using the provided routines, users have the opportunity to use other external tools. For many simulations (such as optimization of active systems) the geometric factors are constant and calculating them only once saves significant time.

All preprocessing steps are integrated in an updated version of TRNBuild, the building input description manager of TRNSYS.

Solar sunlit factors of external windows

The integrated tool for calculating solar sunlit and distribution factors is based on TRNSHD (Hiller, 2000). The code has been completely revised and adapted to the needs of TRNSYS 17. The polygon clipping procedure, which calculates the shading effect of a set of arbitrary polygons on a receiving polygon is fundamentally improved with respect to stability and robustness. In addition, the beam radiation shading is no longer solved by hourly calculation for a given location but by discretisation of the half hemisphere. The approach has several advantages:

- pure geometric sunlit factors
- independent from building location
- only one calculation for both beam and diffuse radiation
- less data (even for 5° steps resulting in 1296 values compared to 8760 values)

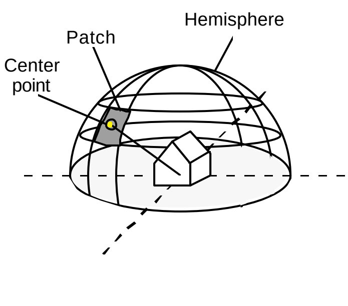

Figure 2 Discretization of the half hemisphere

The sky is represented by a half hemisphere where the building is placed in its center (see Figure 2). The half hemisphere is subdivided into patches. Each center point of a patch is defined as a sun position. The portion of external surfaces sunlit by beam radiation for each sun position is determined by projection and 2D polygon clipping.

The fraction of each patch sunlit by beam radiation is given by:

$$f_{beam,ex} = \frac{A_{sunlit}}{A_{total}}$$

where A_{sunlit} is the sunlit area and A_{total} is the total area of an external window.

For solving the diffuse radiation shading it is assumed that the patches are rather small and far away. Thus, the diffuse radiation leaving each patch can be treated as parallel radiation with the direction from its center point to the center of the hemisphere. In the current version the diffuse radiation is assumed to be isotropic. Therefore, the diffuse fraction of an external window can be determined by:

$$f_{dfu,ex} = \frac{\sum_{k=1}^{n} \cos\alpha_k \cdot \Delta\omega_k \cdot f_{beam,k}}{\sum_{k=1}^{n} \cos\alpha_k \cdot \Delta\omega_k}$$

$$\Delta\omega_k = \sin\theta_{Z,k} \cdot \Delta\theta_Z \cdot \Delta\gamma$$

where n is the number of patches where the external window is sunlit, α_k is the angle between the surface normal vector and the sun vector of patch k, $\theta_{Z,k}$ is the zenith angle of patch k, $f_{beam,k}$ is the "beam" sunlit fraction of patch k, $\Delta\omega_k$ is the increment of the solid angle of patch k, $\Delta\gamma_k$ is the increment of the solar azimuth angle, $\Delta\theta_Z$ is the increment of the solar zenith angle of patch.

All calculated sunlit fractions are written to an external file (*.SHM) which is read in by the multizone building model at the start of the simulation.

Solar beam distribution factors of external windows

In addition to sunlit fractions of external windows, TRNSHD can calculate the beam sunlit fractions of the window that strike each inside surface of the radiative zone. The performed calculation steps are similar those for external shading. All sunlit inside surfaces are projected onto the plane of the window and clipped against the remaining sunlit parts of the window obtained from the external shading calculations. In the current version the beam distribution factor calculation is restricted to external windows only.

The calculated distributions factors are also written to an external file (*.ISM) which is read in by the multizone building model at the start of the simulation.

Solar beam radiation of comfort positions

For local comfort evaluation it is planned to account for beam radiation as well. Therefore, TRNSHD has been extended to determine if a given point is sunlit (depending on external shading), and from which external windows it receives sunlight, for each patch of the half hemisphere.

The determined window IDs are written to an external file (*.IPM) which is read in by the multizone building model at the start of the simulation.

View factors

The view factor is a key factor of the new radiation model. The view factor $F_{A®B}$ is defined as the part of diffuse radiation, that leaves surface A and strikes surface B on the direct path (Siegel et al., 2002). The view factor is a pure geometrical factor and does not include any optical properties. In general, it is not possible to determine the view factor for an arbitrary geometrical configuration by an analytical solution. Therefore, mainly numerical methods are applied (Cohen et. al., 1993) which may have a negative impact on the accuracy and require significant computational effort.

For TRNSYS 17, two methods have been tested for the radiation exchange between surfaces (polygon↔polygon): A numerical method proposed by Walton, 2002 and an analytical approach according to Schröder et al., 1993. The strength of Walton's method is the ability to handle obstructed views, but the geometric input generation is more laborious. Complex polygons have to be generated by a combination of planar triangles or convex quadrilaterals. The algorithm of Schröder et al., 1993 provides a closed form solution of the form factor integral between two general (planar, convex or concave, possibly containing holes) polygons in 3D. Obstructed views cannot be handled by this approach. For local comfort evaluation and longwave radiation point sources (differential sphere↔polygon) an analytical method is applied.

With regard to energy conservation it is important to check the accuracy of the resulting view factors and to apply special smoothing procedures if necessary. The applied method is developed by Lawson, 1995.

The calculated view factors are also written to an external file (*.vfm) which is read in by the multizone building model at the start of the simulation.

THE NEW 3D RADIATION MODEL

For a detailed treatment of shortwave beam radiation shading and distribution the multizone building model reads in the sunlit factor matrices generated by the preprocessing at the beginning of the simulation. For each time step the actual sunlit fraction of surfaces are determined by a bilinear interpolation of the four nearest center points with respect to the sun's actual position.

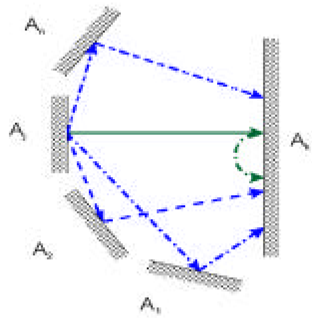

Figure 3 Impact of surface A_j on surface A_k by longwave radiation Weber, R. et al., 1999

For a detailed treatment of longwave radiation and shortwave diffuse radiation, the new radiation model applies so-called Gebhart factors. The Gebhart factor is defined as the part of the emission of a surface A_j that reaches surface A_k and is absorbed including all possible paths (multi-reflection). Thus, besides the geometric configuration represented by the view factor optical (wavelength dependent) properties of the surfaces are considered.

TRNSYS divides the electromagnetic radiation spectrum mainly into two bands: longwave and shortwave radiation which are treated separately. Weber, R. et al., 1999 showed that Gebhart factors can be used for all spectral bands.

Table 11

*Heat flux for different radiation source determined by the modified Gebhart matrix G**

Radiation source	**Heat flux**
longwave – surface source	$\dot{Q}_{ir} = G^*_{ir} T^4$
longwave – point source	$\dot{Q}_{ps} = G^*_{ps} \dot{Q}^\circ$
shortwave – diffuse	$\dot{Q}_{difsol} = G^*_{difsol} I_{difsol}$

Variable and abbreviation declaration:
T ... surface temperatur
$\dot{Q}^\circ$ ... longwave radiative power of point source
I_{difsol} ... transmitted diffuse solar radiation
ir ... longwave
ps ... point source
difsol ... diffuse (shortwave) solar radiation

In order to calculate heat fluxes, the Gebhart factors for n surfaces are written in an n by n matrix G and then algebraically transformed into a G* format. Thus, the radiation induced heat flux can be determined for different radiation sources by a simple multiplication with the "driving forces" $T^4, \dot{Q}^{\circ}$ and I_{difsol} as shown in Table 1. The assumptions and validity range of the method are discussed by Weber, R. et al., 1999.

If the optical properties are constant over the simulation period, the Gebhart matrices only have to be calculated once, at the beginning of simulation. However, an operable internal shading device may change the optical properties and thus the Gebhart matrix for longwave radiation has to be recalculated each iteration step.

The calculated heat fluxes are applied on the inside surfaces of each radiative zone. The equivalent resistance of each surface to the star node of the existing building model is set to a pure convective resistance. In addition, the star node resistance is set to a very low value such that the star node is essentially equal to the air node for the new explicit radiation model.

The internal iterative solver of the building model determines a converged solution with respect to temperatures and heat fluxes of the entire building.

Simulations show that for simple rooms with an ordinary facade of punched windows, the increased level of detail has a low impact on the results but increases input effort and computing time. Therefore, the level of detail of the radiation model can be defined for each zone. Two modes exist for beam radiation distribution: user-defined factors, or reading in precalculated distribution matrices from an external file. The diffuse radiation distribution can be calculated using aborption-transmission weighted areas or using Gebhart factors. Three modes are offered for longwave radiation: a simple one-node model, the common starnode model and the previously described detailed model based on Gebhart factors.

MULTIPLE AIRNODES

Due to the integration of the new detailed model a radiative zone may consist of more than one airnode as shown in Figure 4. Thereby, the convective modelling of stratification is improved significantly.

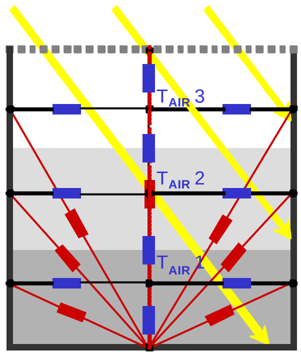

Figure 4 Radiative zone with 3 airnodes

Building surfaces and regime data (heating, cooling, infiltration, ventilation, etc.) are assigned to an airnode. The heat exchange between building surfaces and the airnode is based on convection only whereas the shortwave radiation distribution and the longwave radiation exchange is performed over the whole radiative zone. Airnodes of one radiative zone may have a convective coupling to two other airnodes of the same zone.

Also, TRNFLOW, the integrated air flow network model (Weber 2006), can be used in conjunction with the multiple airnode approach.

VALIDATION

The new features of the TRNSYS17 building model are implemented in a beta version undergoing in-house testing now. Simulations show that the models are integrated successfully and deliver the expected results. The validation process with standardized test procedures such as ASHRAE Standard 140, BESTEST and DIN EN ISO 13791 is in progress but not finalized yet. The preliminary results are presented below.

Beam radiation shading

For validating the beam radiation shading approach, the six tests according to DIN EN ISO 13791, Section 7.2.4 have been carried out (see figure 5). These tests include overhang and wingwall shading as well as an opposing obstruction for two different orientations and eleven sun positions. The tests were run with a 5 degree angular discretization of the half hemisphere (azimuth and zenith angle). The validation procedure allows a deviation of ± 0.05 for each value.

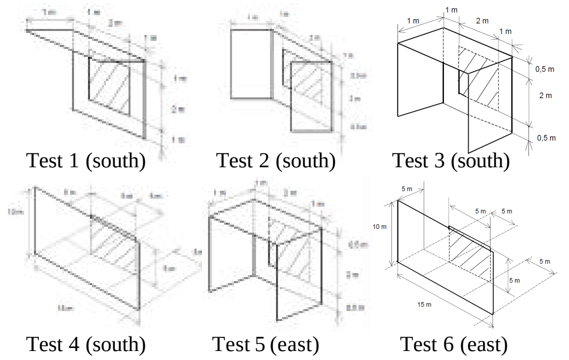

Figure 5 Test cases acc. to DIN EN ISO 13791- 7.2.4

The resulting deviations between given values according to DIN EN ISO 13791- 7.2.4 and calculated values by TRNSYS17 are shown in Table 2. It can be seen that good agreement of the results is obtained and that TRNSYS 17 meets the requirements.

The number and location of the patches on the half hemisphere is not yet optimized. Further simulations are required to save computing time.

Table 2

Deviation between given values acc. to DIN EN ISO 13791- 7.2.4 and calculated values by TRNSYS 17

Time	case 1	case 2	case 3	case 4	case 5	case 6
[h]	[-]	[-]	[-]	[-]	[-]	[-]
07:00	0.00	0.00	0.00	0.00	0.01	0.00
07:30	0.00	0.00	0.00	0.00	0.00	0.00
08:00	0.00	0.00	0.00	0.00	0.00	0.00
08:30	0.00	0.00	0.00	0.00	0.00	0.00
09:00	-0.01	0.00	-0.01	0.00	0.00	-0.01
09:30	-0.01	0.00	-0.01	0.00	0.00	-0.01
10:00	0.00	0.00	0.00	0.02	0.00	0.00
10:30	0.00	0.00	0.00	0.04	-0.01	0.01
11:00	0.01	0.00	0.01	0.048	0.00	0.00
11:30	0.01	0.00	0.01	-0.01	0.00	0.00
12:00	0.01	0.00	0.01	-0.01	0.00	0.00

Diffuse sky radiation shading

For validation, the results of the diffuse radiation shading procedure are compared to those of TRNSYS 16 standard shading model TYPE 34 (overhang and wingwall shading). Type 34 uses a different approach. It calculates the view factor from the receiver surface to the sky by subtracting the view factor from the window to the overhang and wingwalls from the view factor of an unshaded vertical surface to the to the sky. For determining the view factors from the receiver surface, Type 34 integrates over the receiver area. As with the beta version of the new shading methodology, Type34 assumes an isotropic sky. In order to obtain comparable results, view factors of Type 34 are converted into sunlit fractions by division with the view factor of the unshaded receiver area to the sky. Similar to the validation of beam radiation shading, the test cases of DIN EN ISO 13791- 7.2.4 are used. Due to the restrictions of Type 34 to overhang and wingwalls case 4 and 6 cannot performed. For the simulation a 5 degree angular discretization of the half hemisphere (azimuth and zenith angle) is used.

Table 3

Deviation between calculated diffuse sunlit fractions of TRNSYS Type 34 and the new building model

case 1	case 2	case 3	case 4	case 5	case 6
0.000	0.001	0.001	N.A.	0.001	N.A.

The results show a good agreement (see Table 3). As previously mentioned, the discretization of the half hemisphere is not optimized yet. Further simulations are required to save computing time.

CONCLUSION

The new features of the multizone building model greatly improve the detailed simulation of atria and double facades with TRNSYS. The integration of pure geometric calculation procedures in a preprocessing step offers various advantages with respect to flexibility, computing time and input effort.

Simulations show that the models are integrated successfully and deliver the expected results. For simple rooms with an ordinary facade of punched windows, the increased level of detail has a low impact on the results. The validation process with standardized tests is in progress but not finalized yet. The presented preliminary results show good agreement.

The number and location of the patches on the half hemisphere is not yet optimized. Further simulations are required in order to appropriately balance calculation accuracy with calculation speed. Also, further work concerning optimizing computing time and stability has to be performed. The release of TRNSYS 17 including the enhanced multizone building model is scheduled for summer 2009.

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