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Implementation of the TEB model as a new TRNSYS-TYPE for the Assessment of Urban Microclimate prior to Dynamic Building Thermal Simulation

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1. Introduction

Why Implementing TEB in TRNSYS? Standard climate data are usually used by building engineers and architects as boundary conditions in building energy modelling. However, urban microclimate effects are generally neglected. Typically used in Germany are e.g. the Test Reference Years TRY of the German Weather Services DWD. The main reason to this is lack of building energy tools including such urban microclimate-related calculations.

This paper addresses the necessity of coupling urban climate and building energy models prior to investigating the energy demand of urban buildings. It explains the implementation of the urban canyon model „"Town Energy Balance"“ TEB (Masson 2000, Lemonsu et al. 2004) - when used in offline mode - as new TRNSYS component named TYPE 201. This overcomes the lacking consideration of the microclimate changes like urban heat island effects, due to the surrounding built environment which constitutes the real boundary conditions of urban buildings.

The final outcome is to develop a model which simultaneously simulates outdoor and indoor climates dynamically with the necessary feedback between the two spaces at each time step.

2. Relevance of TEB for use in TRNSYS

TRNSYS is a modular designed simulation software, with a well-documented programming interface. It is possible to extend TRNSYS with self-developed modules. A module within TRNSYS is called Type. TRNSYS provides a Graphical User Interface (TRNSYS Studio) which allows the user to create simulation configurations in a graphical way. With the aid of TRNSYS Studio a user can easily build a complex simulation model, which consists of different Types connected to each other. Here, the outputs of one Type serve as inputs for other Types via user defined connections. Basically, no text based manipulations of configuration files are needed; instead all required information of a Type and global simulation properties like the simulation time step are configured within the TRNSYS Studio.

The Town Energy Balance model (TEB), parameterizes at local scale the energy and water exchanges at the urban structure with the atmosphere. The urban surface is simplified as repetitive 2D urban canyons composed of roads, walls and roofs (Masson 2000, Lemonsu et al. 2004). The model provides the urban air temperature as well as all terms of the energy balance from which the short-wave and long-wave radiation, turbulent sensible and latent heat fluxes, heat storage in the materials, etc.

The model TEB has some features which makes it favorable for a combination with TRNSYS: 1) Compatibility with TRNSYS: Simulation at hourly basis, for 1 year, e.g. with TRY standard climate data, 2) Short simulation time: 2-3 minutes per simulation and 3) Detailed description of urban canyon facets as multi-layered components for street, roof, and walls.

The new implementation of TEB in TRNSYS also solves a number of disadvantages of the original SURFEX tool (where TEB is embedded): 1) The low user friendly graphical interface under LINUX, 2) the time-consuming pre-processing and lack of consistency check of the inputs and the too large outputs files for each key metric and 3) The fragmented source code which is rather difficult to decrypt by an end-user and 4) the difficult installation requiring a Linux operating system.

3. Presentation of TEB as Type 201 for TRNSYS

Figure 1 shows an interface of a TRNSYS project using TEB as example of using the new implemented TEB model within TRNSYS Studio. Now, a user can build TEB simulations in a graphical way, write the desired simulation outputs into one output file using a file printer (Type 25) and displaying output during simulation with an online plotter (Type 65). The new TEB-Type can be configured like every Type in TRNSYS in a well-arranged way now, by simple double clicking on the Type and manipulating the values in the corresponding tabs as shown in Figure 2.

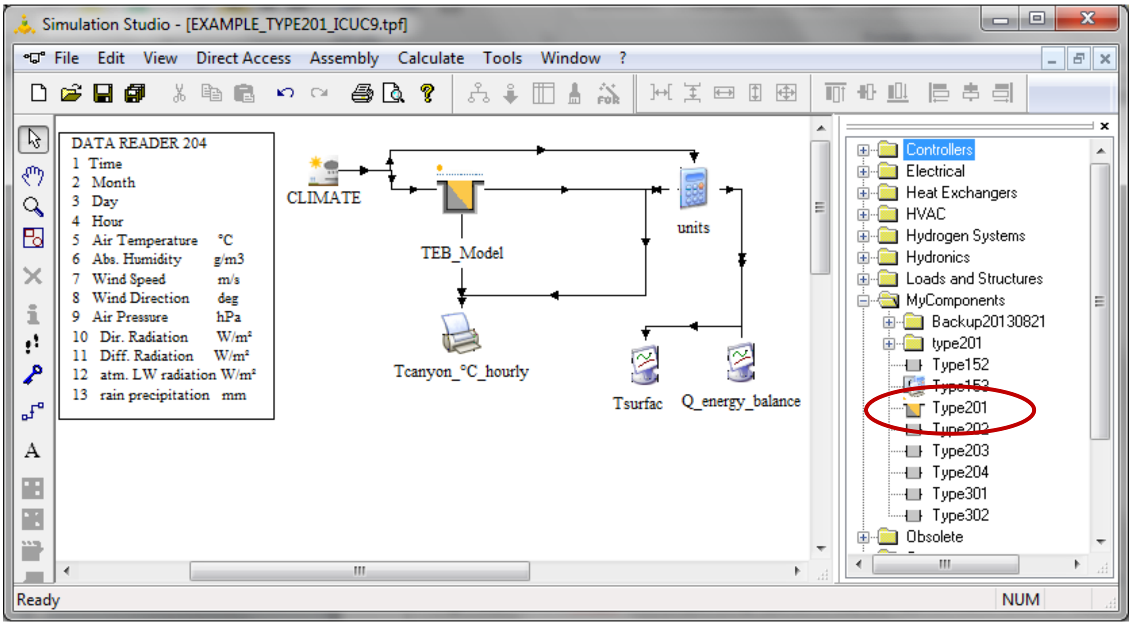


Fig. 1 Interface of a TRNSYS-Studio project using Type 201 (TEB) and Type 204 (climate data reader for TEB)

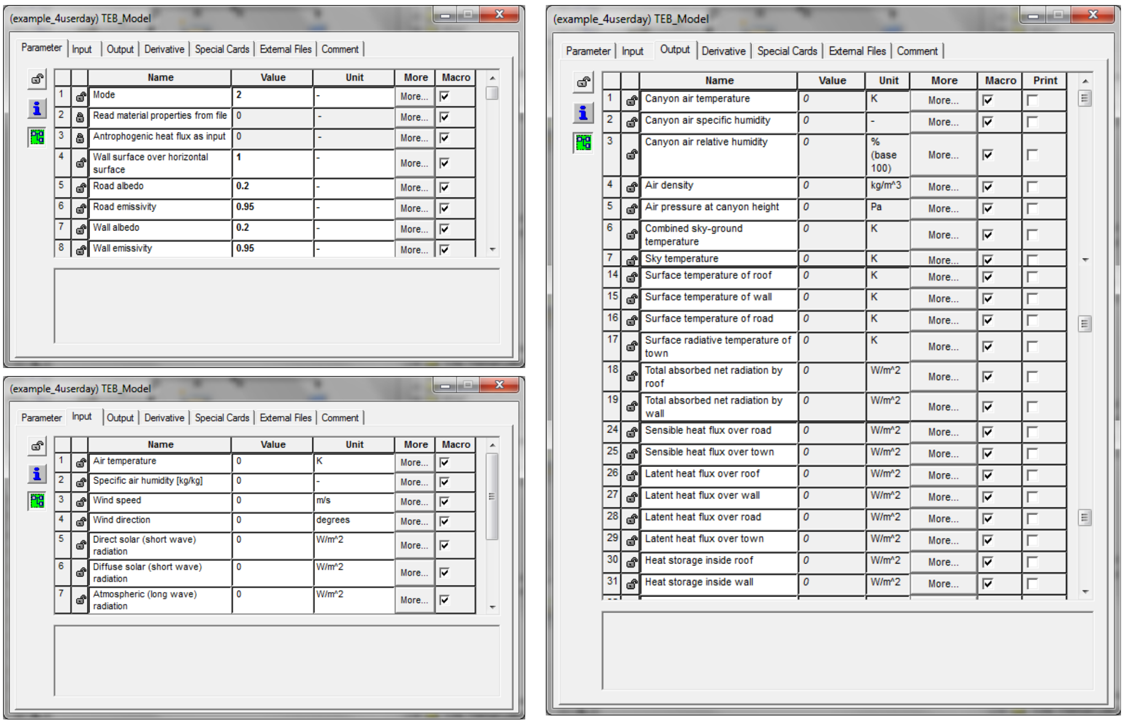


Fig. 2 Tabs of Type 201 showing the inputs, parameters and outputs

INPUTS 10	
6,7	Air temperature
6,8	Specific air humidity [kg/kg]
6,9	Wind speed
6,10	Wind direction
6,12	Direct solar (short wave) radiation
6,13	Diffuse solar (short wave) radiation
6,14	Atmospheric (long wave) radiation
6,15	Rain precipitation
0,0	Snow precipitation
6,11	Atmospheric surface pressure

OUTPUTS

with i = roof, j = wall, k = road, l = canyon

- Total absorbed short-wave radiation for urban facet i, j, k (W/m2)
- Long-wave absorbed radiation for urban facet i, j, k (W/m2)
- Total absorbed net radiation by urban facet i, j, k (W/m2)

- Sensible heat flux over urban facet i, j, k (W/m2)
- Latent heat flux over urban facet i, j, k (W/m2)
- Heat storage inside urban facet i, j, k (W/m2)
- Flux through the urban facet i, j, k (W/m2)
- Anthropogenic heat fux from urban facet i, j, k (W/m2)

- Tsurface of urban facet i, j, k (°C)
- Tsurface canyon (°C)
- Ta canyon °C
- Ta input °C

Fig. 3 List of inputs (climate data) and outputs (energy balance and temperatures) of Type 201

Type 201 reads the inputs from a data reader named Type 204 conceived for specific use with Type 201 and provides all terms of the energy balance at each surface (street, roof, wall) so that the physical processes prevailing in the formation of a specific urban microclimate can be explained. The outputs include for each urban facet and as sum for the canyon (wall + road) and for the “town” (road + walls + roof): The total received and absorbed short-wave radiation, long-wave radiation, total net radiation, the sensible and latent heat fluxes, the heat storage, the anthropogenic heat fluxes, as well as the single surface temperatures, and the air canyon temperature (Figure 3).

4. Application Example

Exemplarily, an application of the Type 201 is given below. A parametric set of 54 runs was undertaken where different constructions were systematically compared including 3-steps variation of thermal insulation levels (weak, medium, high), thermal inertia (massive and light-weighted) and urban density (shallow, unity-like and deep urban canyons) for a mid-latitude location as listed in Table 1. The plot in Figure 4 is a snapshot of a running simulation in TRNedit which shows the input air temperature against the urban canyon air temperature as well as the surface temperatures of the 3 facets road, wall and roof instantaneously during the simulation run. This plot gives the possibility of real time control of user self-defined outputs.

As an example of results, Figure 5 shows the maximum daily course of the deviation of the urban air temperature for the 52 runs differentiated according to density (H/W) and inertia (light-weighted vs. massive). The error bars show the range resulting from varying the thermal insulation. The results confirm that the canyon is mostly warmer and the daily air temperature patterns are influenced by each of the investigated parameters. Increasing the urban density revealed to be decisive in enhancing the intensity of the urban heat island. Light-weighted constructions lead to warmer street canyons in the daytime and massive constructions in the night-time which is in phase with the heat storage and release processes. Thermal insulation also shows large impact. This advocates for a systematic prior consideration of microclimate changes in building energy modelling.

Table 1 TEB simulation Canyon geometry and construction settings

urban & building variables		steps	-1	0	1
canyon	vertical profile		H/W = 0.2	H/W = 1	H/W = 1.8
Building	window ratio		30 %: perforated facade	60 %: row facade	90 %: glass facade
	thermal insulation (mean of opaque and transparent parts)	-1	1.44	2.23	3.03
		0	0.92	1.43	1.95
		1	0.39	0.63	0.87
	thermal inertia		light-weighted construction	-	massive construction
Climate	climate		Mannheim: 49.52°N		

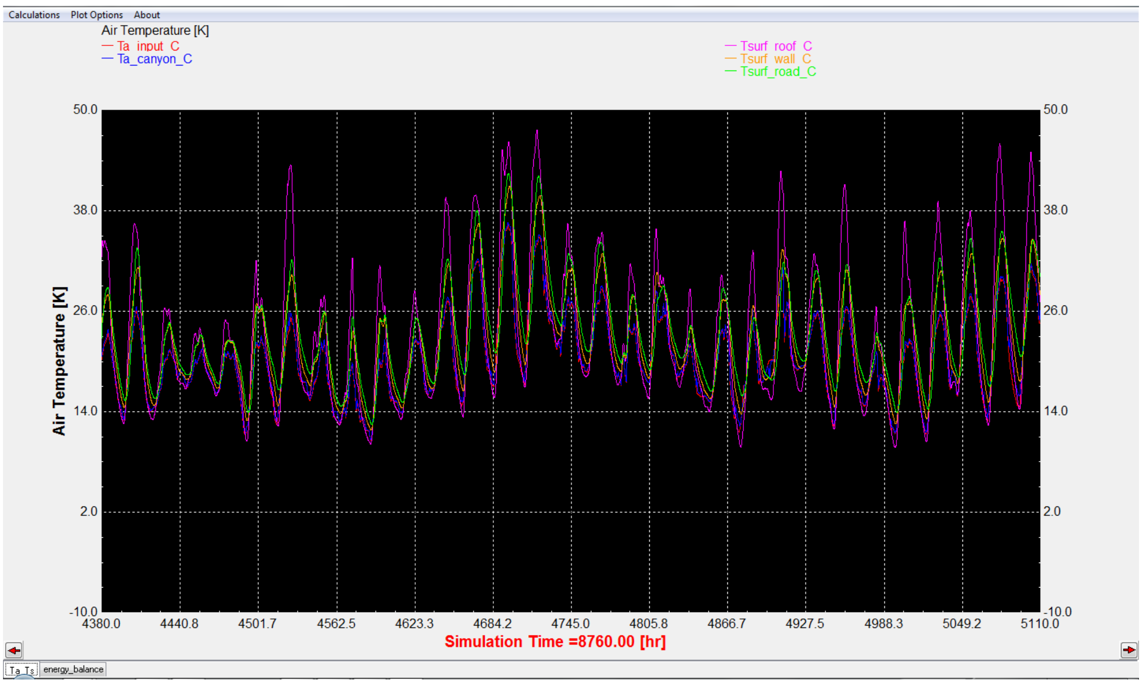
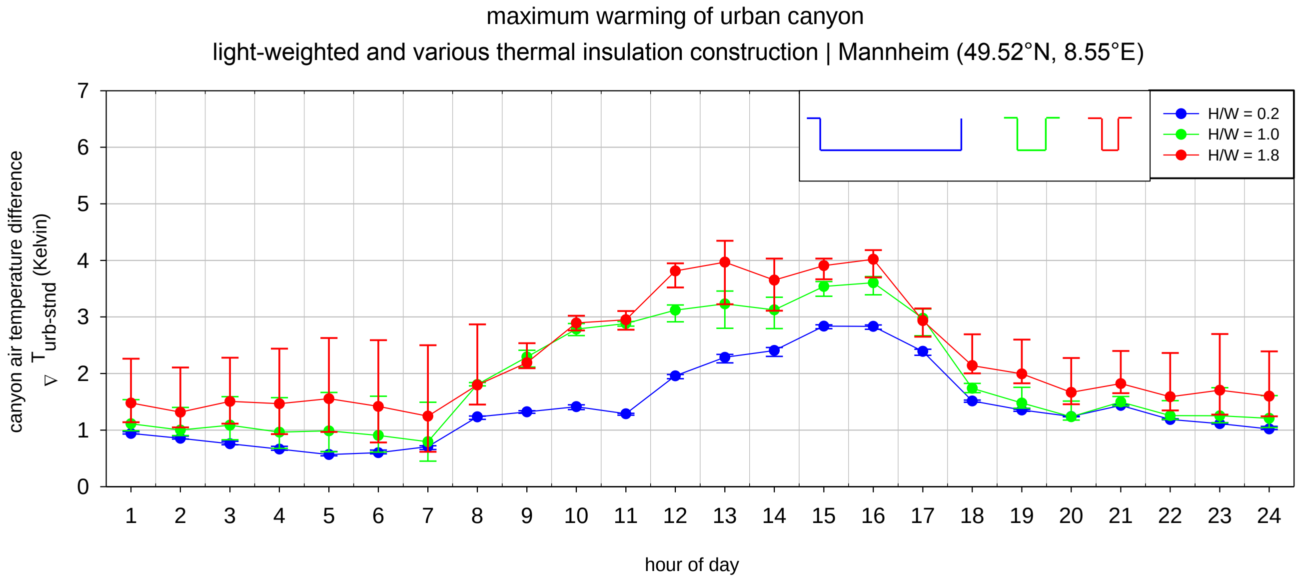


Fig. 4 Type 201 running in TRNSYS under TRNedit showing air and surface temperatures for a time sequence



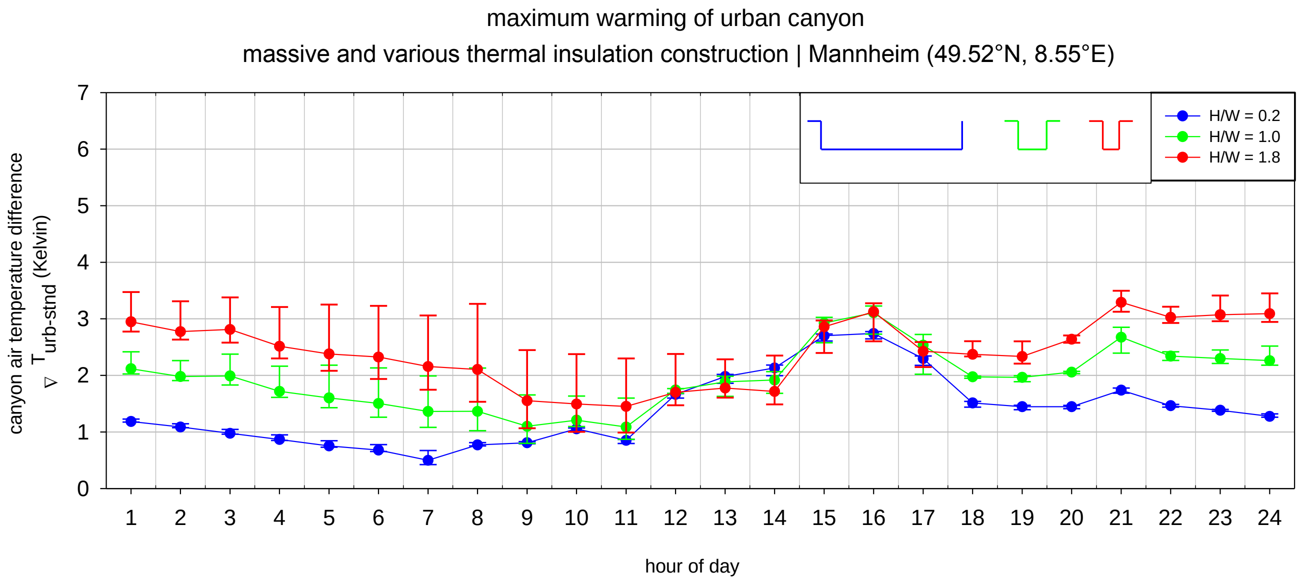


Fig 5 Maximum warming of the urban canyon for different urban densities and building constructions for Mannheim

5. Conclusion and Outlook

TEB model has been successfully implemented in TRNSYS as Type 201. It partly solves the methodological problem of lacking connection between building climate and urban climate simulations. Systematic parameter runs showed that the urban canyon geometry as well as the construction of the urban facets have clear impacts on the formation of a microclimate different from the input standard data.

So far, TEB can be executed from the TRNSYS simulation studio. However, a simultaneous coupling of the TEB model and the TRNSYS building model (TRNBuild, Type 56) is not yet possible. At the moment the TEB model includes a very simple internal building model, which will be removed and replaced by the more sophisticated TRNSYS building model in a next step.

The outlook of this work is the further development of a more extensive coupled urban canopy and building energy model for synchronized dynamic simulation of outdoor and indoor energy balances and climates, i.e. including their interactions at each time step and a cyclic information feedback, e.g. of the anthropogenic heat. This coupling requires eliminating the redundancy in calculating the energy budget at the urban facets which are the shared surfaces between the two entities, in TRNSYS and TEB with different methods. This further development is set as next research step.

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