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Testing and Validation of TEKNOSim: A Building Energy Simulation Program

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Abstract

TEKNOSim is a well-established software tool for simulation of thermal indoor climate. It is used for modelling and simulation of thermal loads, indoor temperatures and thermal comfort. TEKNOSim 5, a new version of the simulation tool has been launched with several new features and enhanced functionalities. This paper presents results of testing and validation of TEKNOSim 5 against two state-of-the-art building energy simulation tools, IDA-ICE and DesignBuilder. Comparisons with the reference tools have been made for a number of test cases. Simulation results indicate that, for realistic scenarios, there exists a very close agreement between TEKNOSim and the reference tools. The largest discrepancies between the simulation tools are observed for unrealistic scenarios. Besides this, the observed trends in discrepancies between the tools also suggest that the algorithms used in TEKNOSim 5 are correct.

Keywords – Validation; TEKNOSim; DesignBuilder; IDA-ICE; Thermal powers

1. Introduction

Thermal simulation and climate analysis tools have become indispensable for design and optimization in the building sector. There exists a number of tools [1] with contrasting capabilities, limitations and input data needs to perform building thermal and energy simulations. These tools, which range from simple spreadsheets to highly sophisticated simulation programs, are used for different purposes in different contexts. The simplest tools focus on a single aspect of building design, whereas more advanced tools simultaneously address several aspects. The advanced tools are expected to be more accurate, but have extensive input data requirements and are relatively complex to use.

TEKNOSim is a relatively simple yet accurate tool for indoor thermal climate simulations. It is developed by Lindab [2] – a leading supplier and manufacturer of building, ventilation and indoor climate related products and system solutions. It is used for calculation of heating and cooling effects, air

and operative temperatures, and predicted percentage of dissatisfied (PPD) index. Originally developed in 1985 for in-house use, TEKNOsim was made publicly available in 1995. Since then it has been used extensively in both industry and academia for selection and sizing of HVAC systems. At present, TEKNOsim has over 700 licenses in use in 17 different countries. As a license can be shared among multiple users across a network, the actual number of users is considerably higher. Academic studies that have used TEKNOsim in research settings include [3], [4], [5], [6], [7], [8] and [9], among others.

A new version of TEKNOsim has been launched in 2016. The new version, TEKNOsim 5, includes several new features. The most noticeable improvements since the previous release version include a 3D graphic modeller with AutoCAD compatibility, an improved dynamic simulator, updated building materials database, and a new result viewer.

The aim of this study is to test and validate TEKNOsim 5. It is also desired to identify characteristic trends and features of the tool and the implemented algorithms.

2. Previous Validation Studies

Two major studies to validate TEKNOsim have been previously undertaken. In the mid-nineties, TEKNOsim 3 was tested and compared [10] against BRIS [11], a then-popular and well-validated Swedish building energy simulation tool based on the heat balance method. The comparison was made for room construction types of Fig. 1 under following three scenarios.

Scenario 1: Ventilation air supplied to the room without any cooling. Resulting room temperature calculated.

Scenario 2: Ventilation air, 20 l/s, cooled to 19 °C. Resulting room temperature calculated.

Scenario 3: Room temperature maintained at a maximum of 25 °C. Required cooling power calculated.

The comparison results reproduced in Table 1 indicated very good agreement between TEKNOsim 3 and BRIS. The discrepancies between the two programs were less than 1 K for *Scenarios 1* and *2* and less than 3 % for *Scenario 3*.

Room 1A	<ul style="list-style-type: none"> - Standard office room. - Lightweight structure. - Typical internal loads. 	Room 1B	<ul style="list-style-type: none"> - Standard office room. - Heavyweight structure. - Typical internal loads.
Room 2	<ul style="list-style-type: none"> - Standard office room. - Heavyweight structure. - Two outer facades. - Large windows. - No internal loads. 	Room 3	<ul style="list-style-type: none"> - Standard office room. - Heavyweight structure. - 10 people for two daily periods.

Fig. 1 Room types used for TEKNOsim 3 and BRIS comparison.

Table 1. Results of TEKNOSim 3 and BRIS comparison.

Room	Scenario 1		Scenario 2		Scenario 3	
	TS	BRIS	TS	BRIS	TS	BRIS
1A	35.6 °C	35.6 °C	31.6 °C	31.3 °C	707 W	696 W
1B	29.7 °C	29.9 °C	27.1 °C	27.2 °C	494 W	503 W
2	33.6 °C	32.9 °C	31.2 °C	30.5 °C	828 W	851 W
3	27.8 °C	28.2 °C	25.8 °C	26.2 °C	448 W	449 W

In 2007, TEKNOSim 4 was compared [12] to a test case from the German Standard VDI 2078 [13]. The comparison was performed for the “Drawing Office” case shown in Fig. 2, using the provided construction characteristics, occupancy schedule, thermal loads, and other room features. Simulations were performed with and without internal sun shading. Room temperatures without any cooling were simulated using TEKNOSim 4. The results were compared to other simulation tools presented in VDI 2078. Fig. 2 reproduces the comparison results with one of the tools, whose results are representative of three out of five simulation tools used in VDI 2078. As obvious from the figure, TEKNOSim 4 results were found to be highly satisfactory. The few minor discrepancies were attributed to slightly different settings used for TEKNOSim 4 simulations.

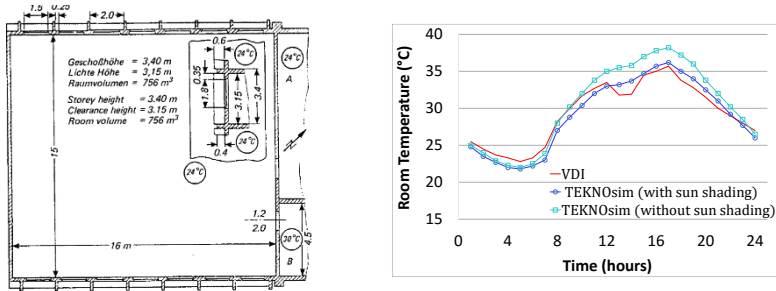


Fig. 2 Comparison of TEKNOSim 4 and VDI 2078 comparison – Plan view of office room and simulated air temperatures.

3. Methodology

In this paper, we have validated TEKNOSim 5 using a comparative validation approach. In the comparative approach, a simulation tool is validated by comparing its results to the outputs of other state-of-the-art simulation tools under identical settings. The ANSI/ASHRAE Standard 140 [14], which contains simulation results from 8 prominent simulation tools for 39 test cases, has frequently been used for the comparative validation. On the other hand, user-developed non-standard test cases, ranging from simple box rooms to actual buildings, have also been used quite frequently.

We have performed TEKNOsim 5 validation against two state-of-the-art building thermal and energy simulation tools, IDA-ICE [15] and DesignBuilder [16], using non-standard and customized test-cases. IDA-ICE is a 3D energy modelling software and has been verified using a number of established standards [17]. DesignBuilder is an extensive 3D energy modelling software and a modified user interface for EnergyPlus [18], one of the oldest and most developed set of building simulation algorithms.

The study has been carried out in two different parts. The first part is aimed at identifying the impact of certain building components and other simulation properties. Investigated parameters in this part include for instance thermal mass, heat transfer surfaces, as well as window properties. This part of the study has been performed using simple box rooms. Detailed information on the first part of the validation is presented in Section 3.1. The second part of the study is aimed at establishing simulation results based on more realistic situations, for which a more complex room has been modelled and simulated. More detailed information on the room and the second part of the validation is presented in Section 3.2.

3.1 Box room study

The simulated object for the first part of this study is a simple box room with standardized internal dimensions. Four different construction types of the box room have been considered, see Fig. 3. *Box Room 1* has no thermal mass and consists of only a 100 mm mineral wool insulation layer. *Box Room 2* consists of a 100 mm interior concrete layer and a 100 mm exterior mineral wool insulation layer. *Box Room 3* is similar to *Box Room 2* but has a window on the south-facing façade. *Box room 4* is also similar to *Box Room 2* but has a window on the north-facing façade.

Each box room has been simulated in four different settings, see Fig. 3. In *Setting 1*, all box room elements are adiabatic elements except the external floor. In *Setting 2*, all box room elements are adiabatic elements except the external roof. In *Setting 3*, the box room has adiabatic ceiling and floor but non-adiabatic external walls. In *Setting 4*, all box room elements are external and non-adiabatic. Fig. 4 shows screenshots of *Box Room 3* modelled in each simulation tool under *Setting 4*.

<p><u>Box Room 1</u></p> <ul style="list-style-type: none"> - No thermal mass. - 100 mm insulation. - No window. 	<p><u>Box Room 2</u></p> <ul style="list-style-type: none"> - 100 mm concrete - 100 mm insulation. - No window. 	<p><u>Setting 1</u></p> <ul style="list-style-type: none"> ▪ External floor. ▪ Adiabatic roof. ▪ Adiabatic walls. 	<p><u>Setting 2</u></p> <ul style="list-style-type: none"> ▪ External roof. ▪ Adiabatic floor. ▪ Adiabatic walls.
<p><u>Box Room 3</u></p> <ul style="list-style-type: none"> - 100 mm concrete. - 100 mm insulation. - South window. 	<p><u>Box Room 4</u></p> <ul style="list-style-type: none"> - 100 mm concrete. - 100 mm insulation. - North window. 	<p><u>Setting 3</u></p> <ul style="list-style-type: none"> ▪ External walls. ▪ Adiabatic floor. ▪ Adiabatic roof. 	<p><u>Setting 4</u></p> <ul style="list-style-type: none"> ▪ External floor. ▪ External roof. ▪ External walls.

Fig. 3 Room construction types and settings used for validation of TEKNOsim 5.

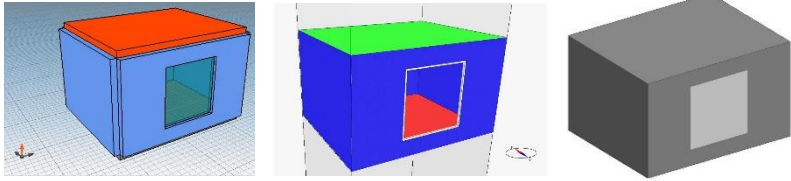


Fig. 4 3D images of *Box Room 3* under *Setting 4* from TEKNOsim (left), IDA-ICE (middle), and DesignBuilder (right).

The simulations have been carried out using a 5 m x 4 m x 3 m box room. No ventilation or infiltration is considered. The room is assumed unoccupied and unfurnished but with a fixed load of 1000 W. Space temperatures during winter and summer are set to be 21 °C and 25 °C, respectively. The mineral wool insulation used has a thermal conductivity of 0.035 W/(m-K), a thermal capacity of 100 J/(kg-K) and a density of 0.01 kg/m³. The concrete used has a thermal conductivity of 2.0 W/(m-K), a thermal capacity of 879 J/(kg-K) and a density of 2300 kg/m³. The windows are assumed to be unshaded. Each window has a gross area of 4 m² and a glass to frame ratio of 0.92. The used glazing has a U -value of 2.66 W/(m²-K) and a g -value of 0.70. The window frame has a U -value of 2.66 W/(m²-K).

3.2 Complex office room study

The simulated object for the second part of the study is a real office room with a floor area of 411 m² and a ceiling height of 2.8 m. The room consists of all external facades and has several windows in all directions. The construction consists of a 100 mm interior layer of concrete and a 100 mm exterior layer of mineral wool insulation. The total gross window area is 110 m². The room is assumed to be occupied by 30 people with 1.0 clo and 1.0 met. The internal load for devices and lighting is 5,940 W, between 8:00 and 17:00 hrs. The ventilation rate is 0.35 l/(s-m²) and 7.0 l/(s-person) with a supply temperature of 16 °C and a heat recovery efficiency of 70 %. The external infiltration rate is 0.10 ACH. The conditioned temperatures during winter and summer are set to be 21 °C and 25 °C, respectively. The materials used for the construction of the complex room have the same properties as the ones used for the box room in Section 3.1. Fig. 5 shows the screenshots of the room modelled in each simulation tool.

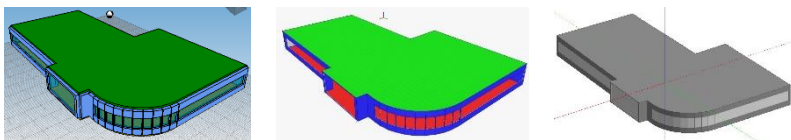


Fig. 5 3D images of the complex office room from TEKNOsim (left), IDA-ICE (middle), and DesignBuilder (right).

4 Results

This section presents validation results of TEKNOsim 5 against IDA-ICE and DesignBuilder for test cases of Section 3. All simulations were performed for Gothenburg, Sweden using similar weather and geographical inputs to all three simulation tools. It should be noted that eight consecutive design days were considered when calculating peak cooling loads from TEKNOsim 5.

Fig. 6 presents peak cooling loads determined from simulation tools TEKNOsim, IDA-ICE and DesignBuilder for the *Box Rooms* of Fig. 3 under *Settings* 1–4. It can be readily observed that the peak cooling loads calculations from the three tools are, in general, quite similar to each other. Let us first consider *Box Rooms* 1 and 2. The maximum discrepancy in results of TEKNOsim and IDA-ICE for these two rooms under *Settings* 1 and 2 is -5% and 7% , respectively. Under these two settings, the simulated room only has one external element. The difference between the two tools increases marginally with introduction of additional external elements under *Settings* 3 and 4. The maximum discrepancy, however, still remains fairly reasonable and does not exceed 20% . The comparison of TEKNOsim with DesignBuilder, on the other hand, exhibits slightly larger discrepancies than IDA-ICE for all four settings of *Box Rooms* 1 and 2.

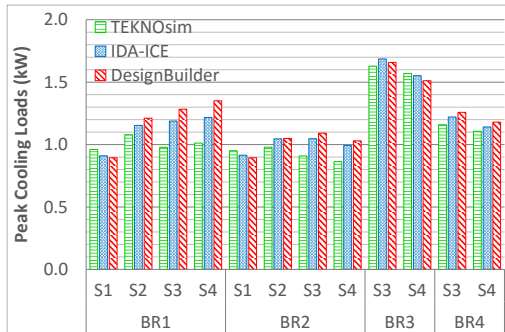


Fig. 6 Peak cooling loads for box room (BR) study.

Let us now consider *Box Rooms* 3 and 4. Due to the presence of non-adiabatic external walls, it is not possible to apply *Settings* 1 and 2 to these rooms. For *Settings* 3 and 4, the results from the three simulation tools are in very good agreement. The maximum difference between TEKNOsim and IDA-ICE results is 5% and 3% under *Settings* 3 and 4, respectively. On the other hand, the maximum discrepancy between TEKNOsim and DesignBuilder results is approximately 8% under both *Settings* 3 and 4.

Fig. 7 presents peak heating loads determined from simulation tools TEKNOsim, IDA-ICE, and DesignBuilder for *Box Rooms* of Fig. 3 under *Settings* 1–4. It can be seen from the figure that the peak heating loads from

the three tools are largely comparable in all cases. Like earlier, let us again first consider *Box Rooms 1* and *2*. For these two rooms, the largest discrepancy between the three simulation tools is for *Setting 1*. The maximum difference between TEKNOsim and IDA-ICE results for this case is approximately -40% . The maximum difference between the results of TEKNOsim and DesignBuilder is around -35% . However, it must be noted that the magnitude of peak heating loads under *Setting 1* is quite small, and the effect of slight differences is magnified when considering the percentage differences. For all other settings of *Box Rooms 1* and *2*, the difference between three simulation tools is smaller than -10% . The maximum differences in results under *Setting 2*, *Setting 3* and *Setting 4* are 2% , -2% , and -6% , respectively, for IDA-ICE and 7% , -4% , and -9% , respectively, for DesignBuilder.

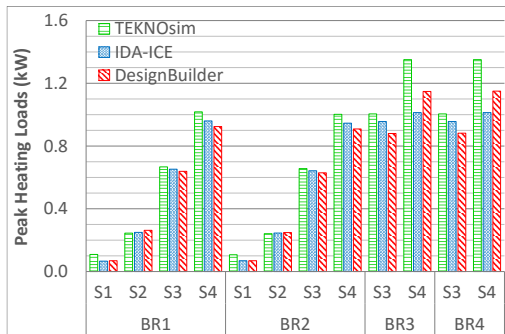


Fig. 7 Peak heating loads for box room (BR) study.

Let us now consider *Box Rooms 3* and *4*. As explained previously, it is not possible to apply *Settings 1* and *2* to these rooms because of non-adiabatic external walls. Under *Setting 3*, the maximum difference between TEKNOsim and IDA-ICE results is -5% and between TEKNOsim and DesignBuilder results is -12% . Under *Setting 4*, the maximum discrepancy for IDA-ICE and DesignBuilder is -25% and -15% , respectively.

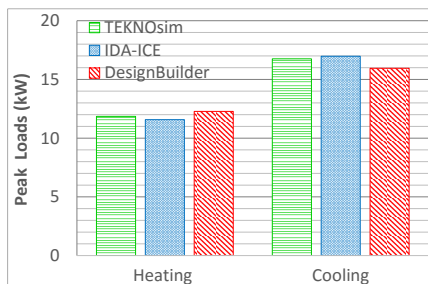


Fig. 8 Heating and cooling peak loads for the complex office room study.

Fig. 8 presents peak heating and cooling loads determined from simulation tools TEKNOsim 5, IDA-ICE, and DesignBuilder for the complex office room of Fig. 5. It can be seen from the figure that both peak heating and peak cooling loads obtained from the three simulation tools are very similar. The difference in peak heating loads between TEKNOsim and IDA-ICE is -3% and between TEKNOsim and DesignBuilder is 4% . On the other hand, the difference in peak heating loads between TEKNOsim and IDA-ICE is 2% and between TEKNOsim and DesignBuilder is -5% .

5 Discussion

A general set of conclusions that can be drawn from the analysis of simulation data of box rooms and complex office room is that in comparison to the reference tools IDA-ICE and DesignBuilder, TEKNOsim, in general, simulates somewhat lower peak cooling loads and slightly higher peak heating loads. To further investigate this intriguing observation we have looked into the comparison of IDA-ICE and DesignBuilder with other simulation tools. Both IDA-ICE and DesignBuilder have previously been tested [18, 19] against ASHRAE Standard 140 [14] for low- and high-thermal mass cases of Fig. 9. The results of peak heating and peak cooling loads from IDA-ICE and DesignBuilder for low-mass and high-mass test cases of ASHRAE Standard 140 test are shown in Fig. 10 and Fig. 11, respectively. Since TEKNOsim's scope is limited to the calculation of peak heating and cooling loads only, we have only shown results of IDA-ICE and DesignBuilder comparisons with ASHRAE Standard 10 for peak powers and not energies.

Low-mass	<ul style="list-style-type: none"> ▪ Case 600: Base Case ▪ Case 610: South Shading ▪ Case 620: E/W Window Orientation ▪ Case 630: E/W Shading ▪ Case 640: Thermostat Setback ▪ Case 650: Night Ventilation 	High-mass	<ul style="list-style-type: none"> ▪ Case 900: Base Case ▪ Case 910: South Shading ▪ Case 920: E/W Window Orientation ▪ Case 930: E/W Shading ▪ Case 940: Thermostat Setback ▪ Case 950: Night Ventilation ▪ Case 960: Sunspace
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Fig. 9 ASHRAE Standard 140 [14] test cases.

It can be seen that barring a few exceptions, both IDA-ICE and DesignBuilder compute the peak heating and cooling loads within minimum and maximum bounds of the ASHRAE Standard 140 results. However, in comparison to mean values of ASHRAE Standard 140 data, IDA-ICE calculates lower-than-average values of peak heating loads and higher-than-average values of peak cooling loads. DesignBuilder, on the other hand, shows more variations, but in general calculates higher-than-average values of peak cooling loads for low-mass cases, lower-than-average values of peak cooling loads for high-mass cases, and lower-than-average values of peak heating cooling loads for all cases.

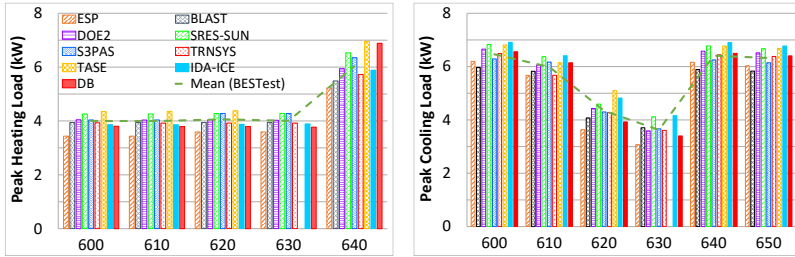


Fig. 10 ASHRAE Standard 140 [14] test cases – Low mass peak heating and cooling.

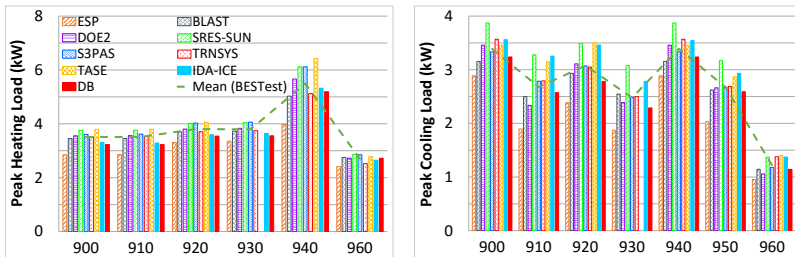


Fig. 11 ASHRAE Standard 140 [14] test cases – High mass peak heating and cooling.

The comparison of IDA-ICE and DesignBuilder results against ASHRAE Standard 140 data shows similar trends to those which have been observed from their comparison with TEKNOsim 5 in Section 4. This, in turn, also confirms the ability of TEKNOsim 5 to calculate the peak heating and cooling loads in good correspondence with well-established building thermal and energy simulation tools. What is also interesting to note here is that the largest discrepancies between TEKNOsim and the reference tools occur for the simplest, and for that reason, almost non-existent, hypothetical cases. The discrepancies between the tools seem to decrease with increasing model complexity. For more realistic cases the differences between TEKNOsim 5 and the state-of-the-art simulation tools tend to be fairly modest. Furthermore, no suspicious or unexplainable scattering of results was identified.

As a logical next step to this work, it is recommended to validate TEKNOsim 5 against ASHRAE Standard 140 and other relevant European and international standards. Such a validation would further enhance the utility of TEKNOsim as an effective and valuable design tool for thermal climate simulations.

6 Conclusion

This paper validated the precision and accuracy of TEKNOsim 5 for performing indoor thermal climate simulations. The validation was performed by comparing TEKNOsim 5 with two state-of-the-art building thermal and energy simulation tools IDA-ICE and DesignBuilder. Peak heating and

cooling loads were calculated and compared for several test cases ranging from simple box rooms to an actual office building. TEKNOSim gave reliable results compared to both IDA-ICE and DesignBuilder simulations. The trends of the discrepancies between TEKNOSim and the reference simulation tools were found to be very consistent, leading to the conclusion that the algorithms used in TEKNOSim are error-free.

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