A comparison between four dynamic energy modeling tools for simulation of space heating demand of buildings

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Abstract. Different building energy modelling programs exist and are widely used to calculate energy balance of building in the context of energy renovation of existing buildings or in the design of energy performance of new buildings. The different tools have unique benefits and drawbacks for different conditions. In this study, four different types of building energy system modelling tools including TRNSYS, Energy Plus, IDA-Indoor Climate Energy (IDA-ICE) and VIP-Energy are used to calculate the energy balance of a recently built six-storey apartment building in Växjö, Sweden. The building is designed based on the current Swedish building code. The main outcomes of the software include hourly heating and cooling demands and indoor temperature profiles. We explore the general capabilities of the software and compare the results between them. For the studied building with similar input conditions such as weather climate data file, infiltration and ventilation ratio and internal heat gain, IDA-ICE modeled the highest space heating demand while the TRNSYS the lowest due to the simplification of thermal bridges. The main advance feature of VIP-Energy is the detail thermal bridge analysis while the main drawback is the complexity of using the model. EnergyPlus and TRNSYS can be used for energy supply system integration with the ability to add mathematical sub-modules to the models. .

Keywords: Building, Energy analysis, energy simulation tools, VIP energy, Energy plus, IDA, TRNSYS

1 Introduction

Buildings are large user of energy with a global final energy use of about 124 EJ, corresponding to 30% of the total global final energy use. Space heating and cooling dominate the final energy use in buildings and together accounted for 32% and 54% of total final energy use of residential and non-residential buildings in 2013, respectively [1]. Furthermore, the energy savings potential is large in the building sector compared to the industrial, transport and power generation sectors.

Analyses of buildings' energy saving potentials are often based on different Building Energy Modeling Programs (BEMPs). The accuracy of the programs is important when estimating potential energy savings of different measures and depends on a program's capacity to reflect the real energy flows in buildings. There are various static and dynamic energy simulation tools which can be used to analyze energy flow of buildings and several tools have been commercially introduced in the last decades such as DOE-2,E-Quest, Energy plus, TRNSYS, IES, Openstudio, Lesosai and Revit. Examples of Swedish commercial building energy simulation tools are Enorm, BV2, VIP-Energy and IDA-ICE. However, various benefits and draw backs are associated with different simulation tools.

1.1 Research aims and method

The aim of this paper is to compare the capabilities and outcomes of TRNSYS 16, IDA-ICE, EnergyPlus and VIP-Energy. The tools are used to model the energy flows of a building under cold climate conditions, to investigate how key parameters and energy balance results differ when modeling space heating demand. The analyzed building is located in Växjö, in the county of Kronoberg in southern Sweden. The energy balance of the building is modeled hourly with the same or similar criteria and conditions with all four BEMPs. The monthly and hourly heating demands as well as key parameters used in the building energy balance calculations for the proposed building are assessed. The hourly weather data for Växjö for the year 2013 is used for the analysis and is imported using data generated by the Meteonorm software. In this paper, the selected BEMPs are discussed and used to analyze a building. Input data and assumptions for modelling the energy balance with the BEMPs are described. Finally, the results are compared and the selected BEMPs are assessed regarding their key features.

2 Energy simulation tools

2.1 VIP Energy

VIP-Energy is a hourly based time-step and multi-zone dynamic energy simulation program developed by Strusoft [2] and increasingly used by researchers, consultants and construction companies in Nordic countries for analysis of energy balance of buildings. The program has been validated by the International Energy Agency's BESTEST and ANSI/ASHRAE Standard 140 and CEN 15265 as having reliable algorithms and calculation models [3]. VIP-Energy allows detailed analysis of thermal bridges of buildings. It models heat storage of buildings assuming the configurations of the building envelope as a series of thermal resistance and capacitance with finite difference in response to thermal, taking into account various thermophysical properties including thermal conductivity, density and heat capacity of materials. The program has a comprehensive materials and components catalogue and estimates solar radiation available to a building using the Hay-Davies-Klucher-Reindl model [4]. Mathematical descriptions of other key models used in the VIP-Energy program are described by Jóhannesson [5] and Nylund [6].

2.2 IDA-ICE

IDA-ICE is a dynamic whole building indoor climate and energy balance calculation program managed by Equa simulation AB [7]. The program is commonly used in European countries for research and consulting purposes. The program has multi-zone calculation feature and models indoor environment and energy performance of buildings in variable time-steps including hourly and minute time resolutions. It is based on a general system simulation platform with a modular system. The accuracy of the solution in IDA-ICE can be controlled by defining tolerances for calculations. The program is validated with ASHRAE 140-2004 [8] and EN 15255-2007 and 15265-2007 [9], showing that IDA-ICE can give accurate calculations of buildings' energy and indoor climate performances in comparison to other state-of-the art simulation programs. IDA-ICE has a BIM import extension function, allowing importation of 3D CAD objects in open or IFC format.

2.3 Energy Plus

DOE-2 is one of the most known building energy use and cost analysis software with a 25 years history. EnergyPlus is a new generation simulation program built upon the best features of DOE-2 and BLAST although new modeling features are developed in this software beyond the two programs. Sub-hourly time step calculation and dynamic integration of loads and system performance for building energy balance calculations is the most advantages of EnergyPlus over the DOE-2 although it causes much slower processing compared with other DOE-2 based software [2, 3]. The EnergyPlus is an engine for thermal simulation that uses text as an input therefore a "Graphical User Interface" (GUI) such as SKETCH UP or Design Builder can be used together with EnergyPlus in order to have a visual interface for the building models.

2.4 TRNSYS

TRNSYS is a transient system simulation software tool with a modular structure that is designed to develop an energy system with wide range of simple to complex systems [3]. TRNSYS has special module to model the thermal behavior of a building called TRNBuild or Type 56 (subroutine component in the TRNSYS library). The building description is read by this component from a set of external files generated based on user supplied information and generates its own set of monthly and hourly summary output files. The required input data for this subroutine is supplied by the weather data component. The user supplied information to TRNBuild includes e.g. geometric, physical and thermal properties of the building. The simulation in this software can be performed from time interval of 0.1 second [4].

3 Building energy models

To assess the features and capabilities of the selected BEMPs, a building is modelled with input data and assumptions described as follows.

3.1 Modelled building

The modelled building is a 6-storey Swedish multi-family building constructed in 2014 in Växjö, Sweden (lat. 56º 87′ 37″ N; lon. 14º 48′ 33″ E). The concrete-frame building contains 24 apartments and has a total heated floor area of 1686 m^2. The foundation is made up of layers of 200 mm crushed stone, 300 mm Styrofoam insulation and a 100 mm concrete ground floor slab. The external walls consist of 100 mm and 230 mm concrete on the outside and inside respectively, with a 100 mm layer of cellplast insulation material between them. The roof is made up of 250 mm concrete slab and 500 mm loose fill rock wool insulation with wooden trusses and a roof covering over layers of asphalt-impregnated felt and plywood. Figure 3 and 4 shows a ground floor plan and façades of the building respectively and Table 2 gives key envelope characteristics of the building. The window area on each floor is 6.55, 26.87, 12.42 and 6.55m^2 on south, west, east and north, respectively. The corresponding values for exterior wall area are 205, 329, 353 and 205 m^2.

Table 1. Key envelope properties of the modelled building

Description	U-value (W/m^{2}K)					Air leakage at 50 Pa (l /s m^2)
	Ground floor	External walls	Windows	Doors	Roof	
Values	0.11	0.32	1.2	1.2	0.08	0.6

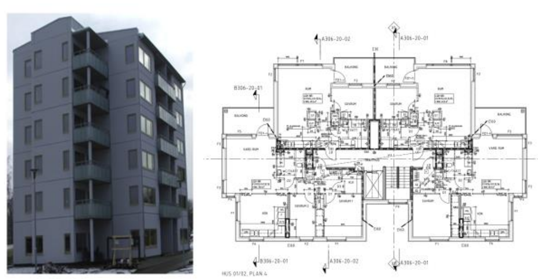

Fig. 1. Photograph (left) and typical floor plan (right) of the modelled building.

Fig. 2. West (a) East (b) North (c) and South (d) façades of the modelled building

The main materials which are used for the building construction are wood pine, concrete, cell plast, loose wool and drained gravel. The properties of these materials are given in table 3.

Table 2. Building construction material properties

Type of material	Thermal conductivity (kJ/hmK)	Heat capacity (kJ/kgK)	Density (kg/m^3)
Drained Gravel	5.04	1	1800
Cell Plast	0.1296	1.4	25
Concrete normal RH	6.12	0.8	2300
Wood Pine	0.504	2.3	500
Loose Wool	0.1512	0.8	40

3.2 Input data and assumption

The daily variation and monthly mean values for outdoor air temperature, daily global radiation as well as sunshine hours for the generated and imported 2013 weather file for Växjö are shown in Figure 1.

The calculations are based on hourly time step in all simulation tools. The ground temperature for all developed models is considered to be 10^{o}C. The internal heat gains for all models consist of occupancy, lighting system, electrical devices and hot water circulation. The annual average values for all internal heat gains are assumed to be 4.95 W/m^2 and 0.21 W/m^2 for the analyzed building's living and common areas, respectively. The indoor set-point temperatures are 21^{o}C and 18^{o}C in the living and common areas, respectively.

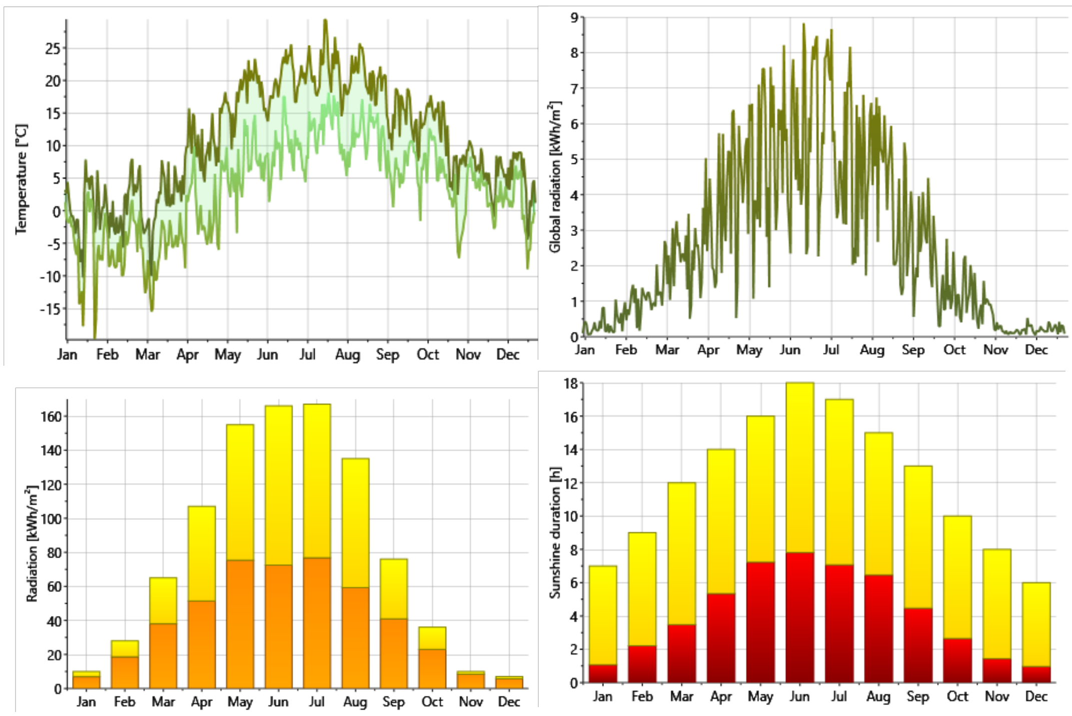

Fig. 3. Climatic key parameters for Växjö based on the meteorological data for 2013 obtained from Meteonorm software

3.3 Zone definition

The main differences between the models are the zones definitions. VIP-Energy and TRNSYS have two attached zones: Living area and common areas for each floor and all internal walls are considered in the models. In IDA-ICE, the whole building is divided into 25 zones while 4 attached zones represent each single flat for each floor and one single zone for common area for the whole building. EnergyPlus consists of 24 attached zones including 3 living areas and one common area for each floor. The main simplification in EnergyPlus is the balcony, which is assumed to be an exterior part of the building and is not considered in the annual space heating demand analysis but the effect of balcony windows are considered in the simulation. Figure 2 shows the different zones configurations for the building models.

In TRNSYS 16, CAD files or geometry cannot be imported but there is a special module in called TRNBUILD that is used to design a building including almost all details except doors. Therefore, in this study, the effects of doors are just considered in the infiltration section and thermal conductivity of the doors are neglected in the simulation.

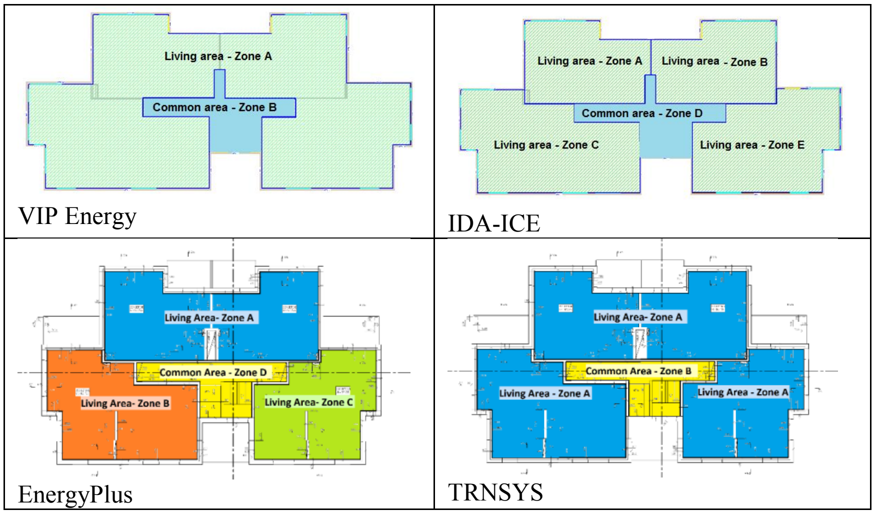

Fig. 4. Configuration of thermal zones at a typical floor level in the models

4 Result and discussion

The profiles of the calculated indoor operative temperatures for living and common area zones of the building are shown in Figure 5.

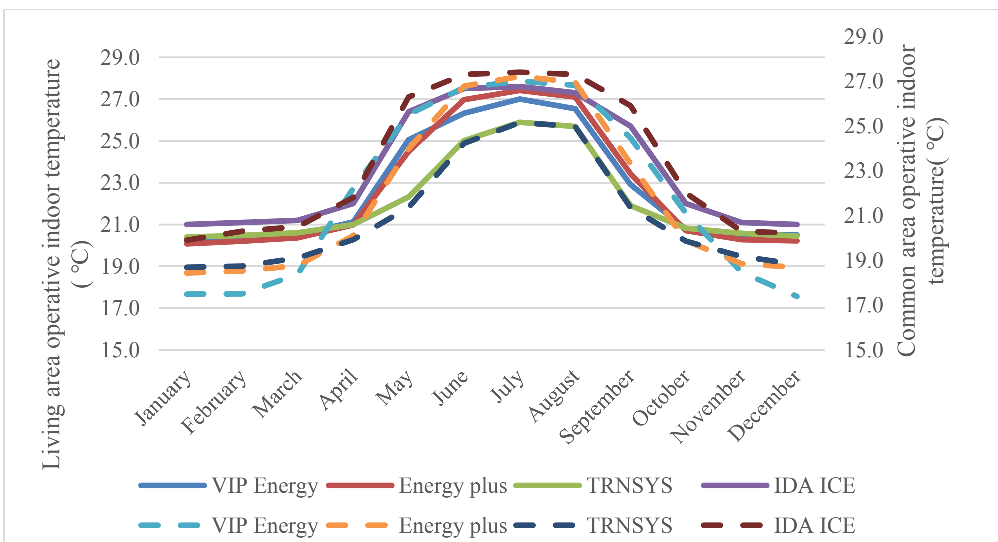

Fig. 5. Operative indoor temperature variation for living area (left axis-solid lines) and common area (right axis-dash lines) for the modeled building

Table 3 shows average annual operative temperature values for both zones, calculated based on hourly profile for an average day of each simulated month. The annual minimum and maximum operative temperatures for the zones are also given in the table.

Table 3. Annual average, maximum and minimum operative temperatures for living and common areas for the studied models. The value with the highest difference from average for the four models are given in bold.

	VIP Energy	Energy plus	TRNSYS	IDA-ICE	Average of four models	Average for three models*
	Operative living area temperature					
Average	22.7	22.7	22.1	23.7	22.8	22.5
max	27.0	27.4	25.9	27.6	27.0	26.8
min	20.4	20.1	20.4	21.0	20.5	20.3
	Operative common area temperature					
Average	21.5	21.9	21.4	22.9	21.9	21.6
max	27.0	27.4	25.9	27.6	27.0	27.3
min	17.4	18.4	18.7	19.9	18.6	18.2

* Average of three models excluding the model with largest difference with average of four models
Note: The values with the largest differences with the average of four models are highlighted.

IDA-ICE gives the largest difference in all average, maximum and minimum operative living area temperature compared with the average results of the four models while TRANSYS give the largest difference for maximum operative living area temperature. If the model gives the largest difference compared to average for all four models is not included in the average, the difference is small between the three remaining models and the average of them. The pattern for operative common area temperature is about the same as for living areas. IDA-ICE gives the largest differences in both average and minimum operative common area temperature compared with other models while the TRNSYS gives the largest differences in maximum operative temperature compare to other models. The main reason for these differences is the different definition of common area zone and the boundary conditions. For example, in IDA-ICE the common area is a single zone for the whole building and there is not any inter floor/ ceiling through the common area. Thus, the effect of internal thermal mass of the inter floors and ceiling in the common area is not considered. The different considered equations for heat transfer convections inside the building and heat losses in each simulation tools may also contribute to these differences.

Figure 6 shows the total monthly space heating demand for the studied building as calculated by the different simulation tools. The annual space heating demand for the studied building is estimated to be 40, 44, 38 and 42 kWh/m^2 by VIP-Energy, EnergyPlus, TRNSYS 16 and IDA-ICE, respectively, giving an average of 41 kWh/m^2.

Compared to the average, EnergyPlus gives the largest difference of the models. Excluding the EnergyPlus will give an average of 40 kWh/m^2 as calculated by VIP-Energy.

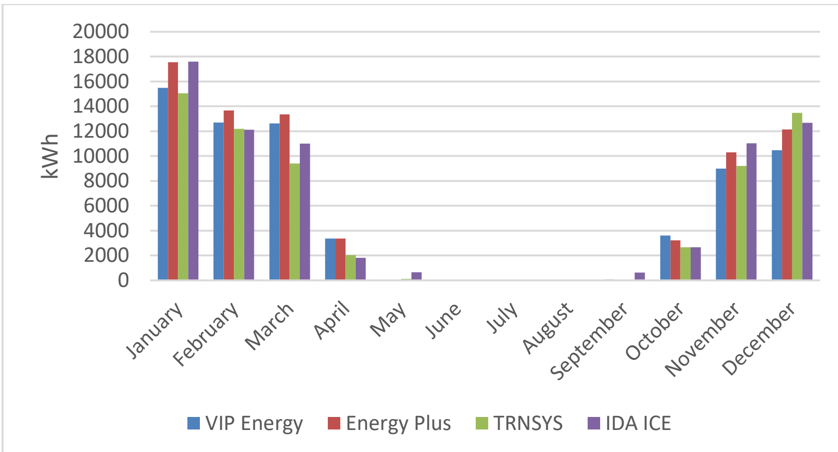

Fig. 6. Space heating demand for the modelled building in the four simulation tools

Eventually, the main features of the four BEMPs are compared and summarized in Table 4.

Table 4. Summary of key features of the four BEMPs

Description/ Feature	VIP-energy	IDA-ICE	EnergyPlus	TRNSYS 16
Multi-zone simulation	✓	✓	✓	✓
Hourly time step	✓	✓	✓	✓
Sub-hourly time-step	✗	✓	✓	✓
BIM or drawing import	✗	✓	✓	✗ (✓ ver.17-18)
3D Visualization of model	✗	✓	✗	✗ (✓ ver.17-18)
Material library	✓	✓	✓	✓
Thermal bridge modelling	Detailed	Simplified	Indirect method	Simplified
Visual interface	✓	✓	✗	✓
Incorporate with other tools e.g. (MATLAB, CFD tools, EES,VBA)	✗	✗	✗	✓
Open source code	✗	✗	✗	✓
Ability to add mathematical sub-modules to the model	✗	✗	✗	✓

5 Conclusion

In this study we have compared the calculated space heating demand and operative temperatures of a recently built multi-store residential building when modelled with VIP-Energy, IDA-ICE, EnergyPlus and TRNSYS. The calculations are based on the same or similar specified input data including hourly weather data for the Swedish city of Växjö. The results show that the annual space heating demand calculated by the different tools ranges between 38 to 44 kWh/m^2, indicating about 14-16% differences in the extremes of values calculated by the tools. TRNSYS resulted in the lowest while Energyplus resulted in the highest simulated space heating for the analyzed building. A calculated lower space heating demand by 5% can be caused by simplification of the thermal bridge in these two programs and by different correlations used for estimating the heat transfer coefficient and simulation algorithm for the calculations. For the operative temperature estimation, IDA-ICE has the largest differences of the studied tools with a 4% difference in annual average value for the living area of the building analyzed. The main advance feature of VIP-Energy is the detail thermal bridge analysis while the main drawback of this software is the level of complexity to use the software. EnergyPlus and TRNSYS can be used for energy supply system integration. The main difference between these two programs compared to other two models is the ability to add mathematical sub-modules to the models by adding correlations and equations to modify the inputs or outputs, incorporation with other software's such as MATLAB, component's programming modification due to the open source code and graphic visual interface which motivate the use of TRNSYS.

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