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energy resources and building performance

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Contents

PART 3
Energy Saving Strategies

Building Simulations and Modelling: Energy

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ABSTRACT **The quest to achieve high standards in energy efficiency has resulted in the development of complex simulation tools that aim for a precise calculation of energy performance, thus supporting building design as well as the management process.**

Common questions regarding the simulation of performance address several issues: during what stage is simulation being conducted (preliminary design, main design, dimensioning of the systems, certification), how complex is the procedure, what resources are needed (data and computational) etc.

In everyday practice we are confronted with a variety of available software options, each of which is advertised as the right choice for building energy performance simulation. With regard to the approach towards modelling, complexity, and simulation processes, we can distinguish several application levels, each having certain advantages and disadvantages.

The starting point for an adequate simulation procedure relies on the available legislation and professional standards, calculation procedures, and computational logic. Depending on the desired outcome or goal of the process, an adequate simulation strategy must be applied.

A comparison between the two most commonly used pieces of simulation software in Serbia, *KnaufTerm2* and *Ecotect*, has been conducted, illustrating the differences in procedure and the results gained.

KEYWORDS simulation, modelling, energy performance

1 Introduction – Building Simulations and Modelling

To address the expected performance of buildings, whether in terms of occupancy comfort or energy consumption issues, it is necessary to make some predictions as they relate to more or less accurate assumptions. Since the energy performance of buildings depends on many factors, our assumptions rest on many limitations and generalisations. This is the case especially when addressing the complex issue of occupancy behaviour, which significantly influences energy consumption. When dealing only with energy demand, the greatest field of assumptions are found in the choice of elements within the complex nature of heat transfer taken into account.

The definition of the *thermal simulation* of a building, as given by Bahar, Pere, Landrieu, and Nicolle (2013), represents a dynamic analysis of building's energy performance by using computer models and simulation tools. Bahar et al. (2013), state that there are currently over 400 applications that can be used for analysing building energy and thermal simulation. Among these, we vary simulation tools with visual communication (so called *frontend*), such as *DesignBuilder*, *Ecotect,* and *IES Virtual*, where, through creation of a 3D building model and assigning relevant properties to modelled elements, all relevant parameters are defined, and simulation-calculation tools, where all necessary data are entered in textual/numerical format (simulation tools such as *EnergyPlus*, *DOE*, *HTB*, etc.). For the latter, this means that all preceding analyses of geometry and thermal zoning are done using some other modelling software, or frontend simulation software. The interoperation of both types of simulation tools with existing 3D modelling programs (such as *ArhiCAD*, *Revit*, *SketchUp,* etc.) represents a developing field, with the purpose of integrating energy modelling with the design process as early as possible in the design development. Standardising the format of the necessary data extracted from the modelling software for the easier input and recognition by the simulation tools is also a developing issue (*Green Building Studio - gbXML* file format is an example).

Gado and Mohamed (n.d.) claim that the benefits of simulation in predicting the performance of the design at both early and detailed design stages outweigh the cost of simulation in the majority of cases. They also indicate the practice of widespread use of software like Ecotect or IES in architectural firms, for checking the performance of their designs even before consulting specialised engineering consultants in this field.

It should be emphasised that most of the software that is widely used for whole building energy modelling is not designed for specific uses, such as the dimensioning of HVAC systems, or identifying problems that occur in the thermal envelope of a building (moisture content, thermal bridging etc.). Specific software exists for each of these uses, such as numerous software types dealing with thermal bridging, as stated by Tilmans and Orshoven (2010). The main use of energy modelling is the comparison of several design options in terms of energy performance, and the certification of a particular design when compared to a determined base case model. In addition, thermal simulations can be used for various research and practical purposes. The authors, Rajčić, Radivojević, and Elezović (2015), used thermal simulations (IES software) in a study to test the thermal influence of unconditioned staircases to heated zones, in order to determine more precise parameters used in energy performance calculations.

Depending on the specific purpose of thermal simulation (certification, comparisons between designs, research, examination of building components etc.) different tools can be used. This chapter aims not only to give an overview of possible uses and adequate tools, but also to illustrate differences that can occur when using two different simulation tools for the same purpose. Further discussion of the results clarifies the details of the tools used, which influence the results and thus their adequate use.

2 Simulation and Modelling

There are two basic principles for heat transfer simulation in the quantitative analysis of building energy performance through calculation of energy demand:

– quasi-stationary method, where heat transfer is determined for a longer time period (monthly or seasonally) and in which the dynamic effects of heat transfer are taken into account through the empirically determined utilisation factors of heat gains and the influence of heat loss;
– dynamic method, in which heat transfer is determined for shorter periods of time (hourly) and which takes into account the heat that is stored and released through the thermal mass of the building.

International standard EN ISO 13790 defines three different approaches to the methodology of calculation of energy need for heating and cooling in buildings:

– a fully prescribed monthly quasi-steady-state calculation method (or, optionally, a seasonal method)
– a fully prescribed simple hourly dynamic calculation method,
– calculation procedures for detailed (e.g. hourly) dynamic simulation methods.

In the quasi-steady-state methods, the dynamic effects are taken into account by introducing correlation factors (utilisation factors for gains and losses).

A dynamic method models thermal transmission characteristics, heat flow by ventilation, thermal storage, and internal and solar heat gains for every defined building zone. The EN ISO 13790 standard gives full specification for a three-node hourly method. A monthly calculation method gives adequate results on a yearly level, but values for specific months near the beginning or the end of the heating season might significantly differ from the real ones. The hourly method is introduced to include the influence of different regimes in the calculations. In addition, the hourly method takes into account the influence of insolation in a much more precise way, which is more significant for the assessment of energy need for cooling than monthly/seasonal methods. The dynamic model gives the most precise results, but also requires a large set of input data and parameters that significantly influence the results if not addressed properly.

One of the aspects that significantly influences the results of the dynamic simulation is the modelling of occupant behaviour. This may not be a crucial issue when comparing several designs based on the same occupancy behaviour pattern, but it may be very significant if we are trying to predict future energy consumption or comparing the model and the real building, in the case of refurbishment of the existing buildings. The influence of occupant behaviour on energy consumption is an elaborately studied field, and authors, such as Gram-Hanssen (2013), conclude that identical buildings can differ in terms of energy consumption for heating by up to 2-3 times, depending on occupancy behaviour. The behaviour of building users is taken into consideration during a computer simulation by specifying properties such as the number of occupants, their clothing level, metabolic rate, the appliances on/off patterns, and even the open/close patterns of windows and doors. It is possible to set these levels in the model that are similar to the values used in calculation procedures, but it is not so easy because a thermal model consists of multiple *thermal zones* and these values need to be set for each zone, rather than for the entire building.

Thermal zoning is also the reason why it is impossible to directly use a 3D model of the building used for the purpose of visualisations, or generated through BIM software. Zoning of the model is a specific principle in building energy simulation, where every part of the building that has different thermal comfort bands, occupancy profiles, orientation and influence of adjoining components, needs to be defined as a different thermal zone. This type of information is specific for thermal modelling and this is why it is very difficult to integrate thermal modelling into regular BIM models used in design and construction purposes.

Another crucial set of data is the climate data for thermal simulations. These are provided through a *weather file*, with statistically weighed climate data for a chosen location. These files differ, based on the source, since the relevant data for a typical meteorological year are usually not publicly available.

An overview of the most commonly used tools is given in literature by Bahar et al. (2013), with the emphasis on its interoperability through the BIM Platforms. Crawley, Jon, Kummert and Griffith (2008) conducted a comprehensive comparative survey of twenty major building energy simulation programs based on 14 categories. These categories depict the complexity of the thermal simulation issues:

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- Zone Loads;
- Building Envelope and Daylighting;
- Infiltration, Ventilation and Multi zone Airflow;
- Renewable Energy Systems, Electrical Systems and Equipment;
- HVAC Systems;
- HVAC Equipment;
- Environmental Emissions; and
- Economic Evaluation.

The most complex tools can address all of the listed issues, while others deal only with the first three.

3 Simulation in the National Context

Methods of energy performance calculations and simulations are introduced into international and national legislation for the purpose of building design verification and certification based on energy performance level. Thus, all methods that are prescribed as part of legislation must be fully defined, in terms of parameters and procedures, and can be considered as *verification methods*. Since they are used for rating and comparing different building designs, their actual accuracy is not of utmost importance, but rather the straightforwardness and clarity of the prescribed procedures, in order to avoid different interpretations, is imperative. Defined in this way, verification methods are usually characterised with more limitations than simulation methods. Also, simulation methods are not related to any specific regulation, but are free to be used internationally.

Verification tools are mostly used for checking the achieved performance of the whole building at the end of the design process, while simulation tools are more often used for optimising design decisions during the design process. While some parameters, such as U-values of components, shading coefficients etc., can also be altered during the calculations to see how they affect the overall energy performance, there is usually a missing link to building geometry that prevents calculation methods being used more as energy performance oriented design development tools.

In Serbia, the national standard for calculation and certification of building energy performance is regulated by the Rulebook on energy efficiency in buildings (2011). This rulebook is entirely in line with EN ISO 13790, and the calculation procedure is based on the fully prescribed monthly quasi-steady-state calculation method. Currently, the calculation of energy need is based on the energy requirement for heating, which is also used for expressing a building energy level. It is planned to include all other energy uses (cooling, ventilation, lighting, appliances), as well as energy from renewable sources in the calculations, upon the adoption of a national software for this purpose. The energy need for heating is determined for a defined heating season for several locations in Serbia based on a heating degree day method.

Climate data used in calculations consist of the number of heating days and outside temperatures determined for representative locations in Serbia. Solar radiation is addressed based on the average values for the entire territory of Serbia.

A comprehensive overview of the methodology for energy performance calculations in Serbia, based on current legislation, is given by Rajčić and Ignjatović (2012) in the case study of one typical multifamily housing building. Several commercial tools have been developed in the market for calculation and certification of energy performance of buildings, mostly by companies that produce thermal insulation materials (*Ursa*, *Knauf Insulation*, etc.).

Energy modelling in the context of national standards is sometimes necessary in order to achieve certain incentives targeted at improving energy efficiency. Ignjatović, Jovanović Popović, and Kavran (2015) used thermal simulation to validate the energy savings achieved by applying sunspaces in the design of a residential building in Belgrade. This kind of validation was needed for obtaining fiscal incentives for the developer, since the area of the sunspace can be excluded for the calculation of the net useful area upon which the tax is paid, but only if the energy savings achieved by a sunspace are validated through energy modelling software. In this way, the benefits of energy modelling outweigh its cost.

4 Simple vs. Complex Simulation

In order to illustrate the differences between various calculation and simulation tools, a case study is presented, on a typical single family, single storey house. The calculation tool in use is *KnaufTerm2 pro V27* and the simulation tool used is *Ecotect Analysis.*

The method of calculation is actually a verification method based on the national legislation, and uses the fully prescribed monthly quasi-steady-state calculation method using the degree-day method, while the simulation tool uses the simplified dynamic simulation on an hourly basis using the admission method.

4.1 Calculation Tool: KnaufTerm pro V27

KnaufTerm is one of the most widely used calculation tools in Serbian practice for the verification of the energy performance of buildings. The author of the software is Dr Aleksandar Rajčić. The software is available for free use with registration on the website of KnaufInsulation company. The version of the software used in this case study is *KnaufTerm2Sv27.13*.

The method of calculation is based on the determination of the annual energy requirement for heating, through energy balance calculation, which includes transmission and ventilation heat losses, and solar and internal energy gains. The influence of thermal mass is taken into account through the *dimensionless gain utilisation factor for heating* ($h_{H, gn}$).

The procedure for calculation in the software starts with the input of data about the building's geometry: net heated area, gross heated volume, surface area of all the elements of thermal envelope, net ventilated volume etc. Then details about the structural characteristics of the thermal envelope are filled in, together with all the relevant parameters that are set according to the current legislation (Rulebook, 2011). The data on the building geometry can be taken from the technical drawings by measurement, but it is recommended that a 3D CAD model is built, as illustrated in the example given by Rajčić and Ignjatović (2012). The work environment in the software illustration is presented in Fig. 4.1.

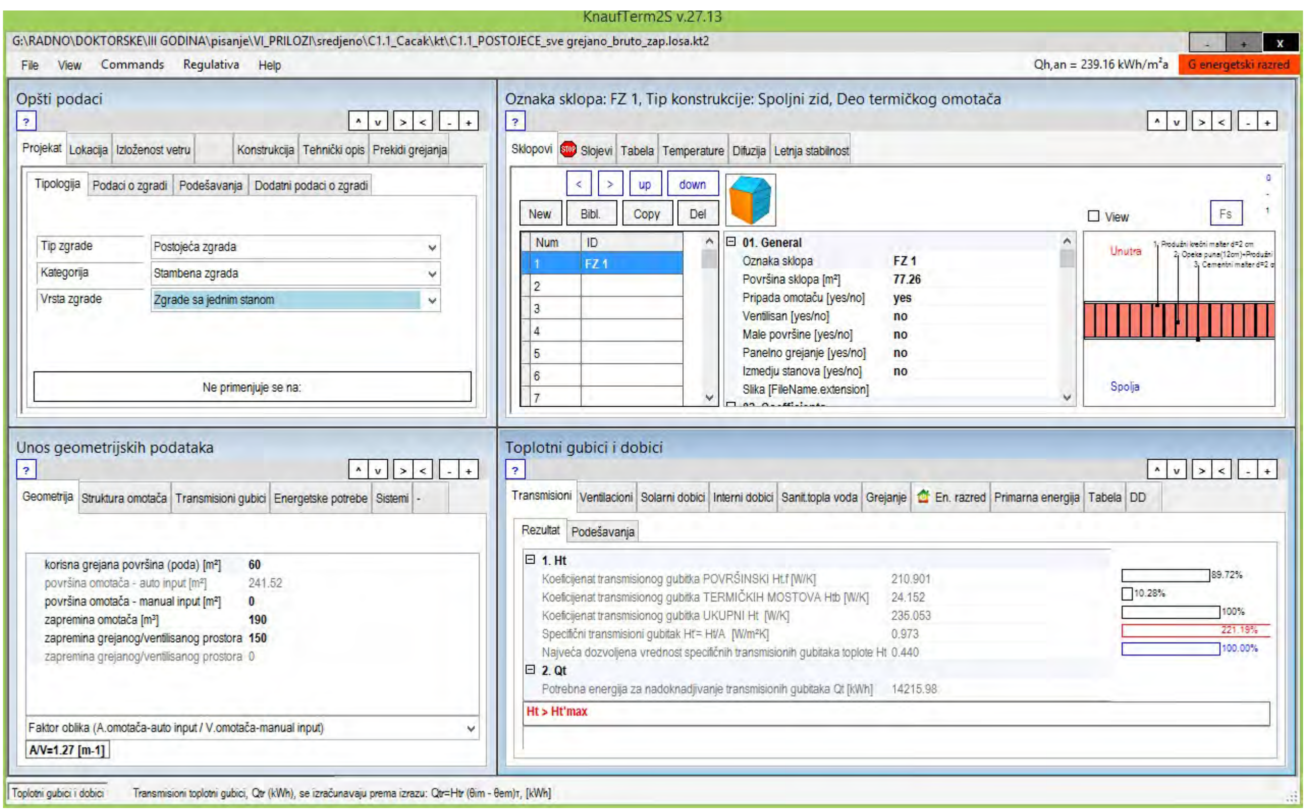

FIG. 4.1 Working environment in the *KnaufTerm2* software

The method defined in standard EN ISO 13370 is used for the calculation of floors and walls in contact with ground, and it takes into account the geometry of the floor, through the value of the characteristic floor dimension (B' [m]) and equivalent floor thickness, as well as the thermal properties of the soil. By using this method, the floors on the ground of the same structural composition can have significantly different U-values, depending on their shape and size.

Besides the widespread use of verification of energy performance of buildings in domestic practice as a part of the documentation for obtaining a building permit, *KnaufTerm2* was excessively used in the research field. All calculations of energy need for heating and improvement levels in the *National typology of Residential Buildings of Serbia* by the group of authors: Jovanović-Popović, Ignjatović, Radivojević, Rajčić, Ćuković Ignjatović, Đukanović and Nedić (2013), were performed using this software. Also, it was used for the assessment of the energy efficiency improvement of the traditional housing type by the authors Radivojević, Roter-Blagojević, and Rajčić (2012). It was also used in the case study of possibilities for energy rehabilitation of a typical single-family house in Belgrade by application of some complex improvement measures by the authors: Ćuković Ignjatović, Ignjatović, and Stanković (2016).

4.2 Simulation Tool: Ecotect Analysis

Ecotect Analysis is one of the most widely used programs for the simulation of building energy performance as stated by Crawley, Jon, and Griffith (2008). Its greatest advantage in comparison to other simulation software is its user-friendly interface for model building and its possibility to perform different types of analysis (solar gains, shadows, daylight, energy performance, acoustic performance) in the early phases of the project. Because of this ease of use, many architectural offices are using it as a tool in the design phase, as stated by Gado and Mohamed (n.d.). The program was developed by Dr. Andrew Marsh and *Square One Research Ltd.* in 1996, and in 2008 it was taken over by *Autodesk*. Within *Autodesk* three more standalone versions were developed (2009, 2010, and 2011), and since March 2015, the functionalities of this software were merged with *Autodesk Revit*. Since then, it works as a plug-in in this widespread BIM tool, and is being developed together with Green Building Studio simulation tool known as *Project Vasari*. The version of the software used in this case study is the stand-alone version *Autodesk EcotectAnalysis2011*. The work environment in the software illustration is presented in Fig. 4.2.

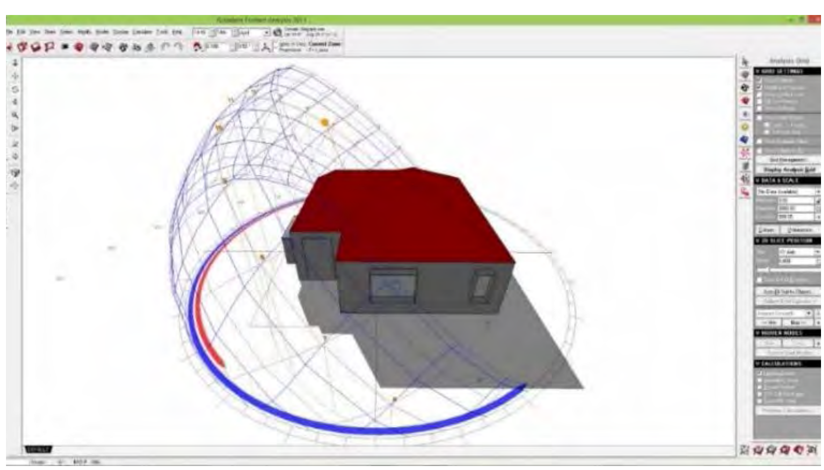

FIG. 4.2 Working environment in the *Ecotect* software and model appearance

The greatest advantage of simulations in *Ecotect,* in comparison to the calculation made using the monthly method, lies in the accurate calculation of solar heat gains, through real sun tracing and mapping of solar radiation on the building facades, taking into account real shadow geometry, instead of median sums of solar radiation and correction factors for shading used in calculations according to standards.

The greatest difference between simulations and quasi-steady-state calculations is the method of taking into account the dynamic effects of heat transfer. The way a simulation program treats this problem depends on its *simulation engine*, which is essentially a calculation tool based on sets of thermodynamic equations. *Ecotect* software uses a dynamic method known as *CIBSE Admittance Method.* This method was developed in the '50s, driven by the need to address the problem of overheating in buildings that had a high percentage of glazing, and calculate maximum temperatures in natural and mechanically ventilated buildings. Rees, Davies, Spitler, and Haves (2000) explain that, unlike ASHRAE, whose methods were directed towards the creation of a constant internal temperature, so that the internal mass had only a second order effect, CIBSE's primary aim was to demonstrate the role of internal mass in modifying room temperature. This method is defined in CIBSE (Chartered Institute of Building Services Engineers) *Guide A - Environmental design* (CIBSE 1999), by using methods for calculation of temperature profiles defined by Steve Szokolay in his seminal book *The Thermal Design of Buildings* (1987). CIBSE differentiates two types of dynamic simulations: *cyclic* and *transient*. Cyclic simulations are those in which it is supposed that boundary conditions (temperature, solar radiation) affect the construction in regular sinusoidal cycles during a 24-hour period, while in transient models, boundary conditions are more sensitive to external and internal influences. Cyclic models, like the admission method, are adequate for the assessment of thermal characteristics and related energy performance in cases of constant usage regimes and exterior conditions, and are less accurate in intermittent heating or cooling, large thermal inertia, or sudden changes in outside temperature or internal gains (CIBSE, 2006).

Using this method, the energy requirement for compensation of energy gains/losses is determined similarly to the quasi-steady-state calculations, through the difference in outside and inside temperatures multiplied by the heat gains/losses. The data on median outside temperatures are generated from the weather file. The determination of internal temperatures that define the comfort band is where differences between methods occur. Comfort temperature (Tc) is defined as the temperature that depends on the set point air temperature in the room (Ta), and environmental room temperature (Te), which depends on the temperature of all room surfaces, in the following ratio:

Tc=0.25Ta + 0.75Te (Rees et al., 2000).

When calculating transmission heat losses/gains, set point internal air temperatures are weighed against a daily level, depending on the internal surfaces temperatures, which are determined based on the structure's admission value. Admittance value (Y), in contrast to transmittance, describes the capacity of the material to exchange heat with its surroundings in cyclic temperature swings. As explained by Hall and Allinson (2008), it is this non-steady-state parameter that positively indicates the ability of the fabric to absorb (and store) heat energy from the environmental node, i.e. fabric energy storage, or thermal mass. Three additional parameters need to be defined for each structure in order to determine this ability, which define the non-stationary heat flow: admittance value [W/m^{2}K], degree of roughness and thermal decrement (f). The values of admission and thermal decrement are calculated using characteristics of thermal conductivity, thickness, density, and specific heat of the material and its position in the thermal envelope. The values for time dependency (v, or f - time lag [h]) are determined based on tabular values, given in literature by De Saulles (2009).

In this way, the factor of thermal inertia of a building (its thermal mass) is taken into account. Evangelisti, Battista, Guattari, Basilicata, and de Lieto Vollaro (2014) found that these factors significantly deviate from values that are taken into account in stationary calculations through gain utilisation factors. Detailed explanation of the calculation procedure, with the following set of matrix equations is given in the CIBSE manual, as well as throughout literature, for example, in studies by Hall and Allinson (2008), and Rees, Spitler, Davies, and Haves (2000).

This method proved to be accurate in assessing the influence of passive design measures on building energy performance. Stoios, Bougiatioti, and Oikonomou (2006) proved the adequacy of this software application in the case of sunspace influence assessment on winter and summer comfort, by comparison of modelled and measured temperature profiles. The author of the software, Dr Marsh (2005), also recommends it as a fine tool for comparative analysis of different designs, but for obtaining precise data recommends the data output to some other simulation engine based on more detailed dynamic simulations.

4.3 Case Study

The case study of comparative calculation and simulation is conducted for a typical Serbian single family house, built during the period 1950-1970. The model of the building is seen in Fig. 4.2.

Three models were tested through the calculation and simulation method:

- M0 – the original state of the house;
- M1 – first level of refurbishment;
- M2 – second level of refurbishment.

Relevant parameters for calculations in *KnaufTerm2* software, for all three models, are given in Table 4.1.

BUILDING GEOMETRY		**M0**	**M1**	**M2**
Net heated area [m^2]		60		
Gross heated volume [m^3]		190		
Net heated volume [m^3]		150		
Gross area of thermal envelope [m^2]		241.5		
Shape factor [m^{-1}]		1.27		
Envelope characteristics				
Mean U value [W/m^{2}K]		1.02	0.40	0.25
Specific transmission heat loss - $\mathbf{H_t}$, [W/m^{2}K]		0.957	0.414	0.283
Maximum allowed transmission heat loss $\mathbf{H_t}$, **max** [W/m^{2}K]		0.44		
Windows	**U** [W/m^{2}K]	3.5	1.5	0.8
	g [%]	0.8	0.6	0.4
Air tightness – air changes per hour (**n**) [h^{-1}]		1	0.6	0.5
Location				
Wind exposure		Moderately shielded		
Sun exposure (Shade factor)		Unshielded position (0.9)		
Location		Belgrade		
Heating days (HD)		175		
Heating degree days (HDD)		2520		
Internal set point temperature		20°C		
Hours of operation		Non stop		

TABLE 4.1 Relevant parameters for calculations in *KnaufTerm2* software for all three models

For simulations in *Ecotect* software climate, the data for Belgrade were used, from the *EnergyPlus Weather Data* file (Energy Plus, n.d.). Thermal model was created in the software, with two defined thermal zones, one conditioned (the entire ground floor, without subdivision into rooms, matches with the net heated area from *KnaufTerm2*) and one unconditioned, thermal buffer attic zone. The basic parameters for creation of the model are given in Table 4.2 and zone management area with these settings is shown in Fig. 4.3.

WIND EXPOSURE	MODERATELY SHIELDED
Terrain	Suburban
Air tightness – air changes per hour (**n**) [h^{-1}]	**M0:** n = 1 h^{-1} for conditioned thermal zone, and n = 2 h^{-1} for unconditioned attic zone
	M1: n = 0.6 h^{-1} for conditioned thermal zone, and n = 2 h^{-1} for unconditioned attic zone
	M2: n = 0.5 h^{-1} for conditioned thermal zone, and n = 1 h^{-1} for unconditioned attic zone
Location	Belgrade
Lower Thermostat Band	20°C
Upper Thermostat Band	26°C
Hours of operation	Non stop
Type of HVAC system	Full Air Conditioning

TABLE 4.2 Relevant parameters for simulations in *Ecotect* software

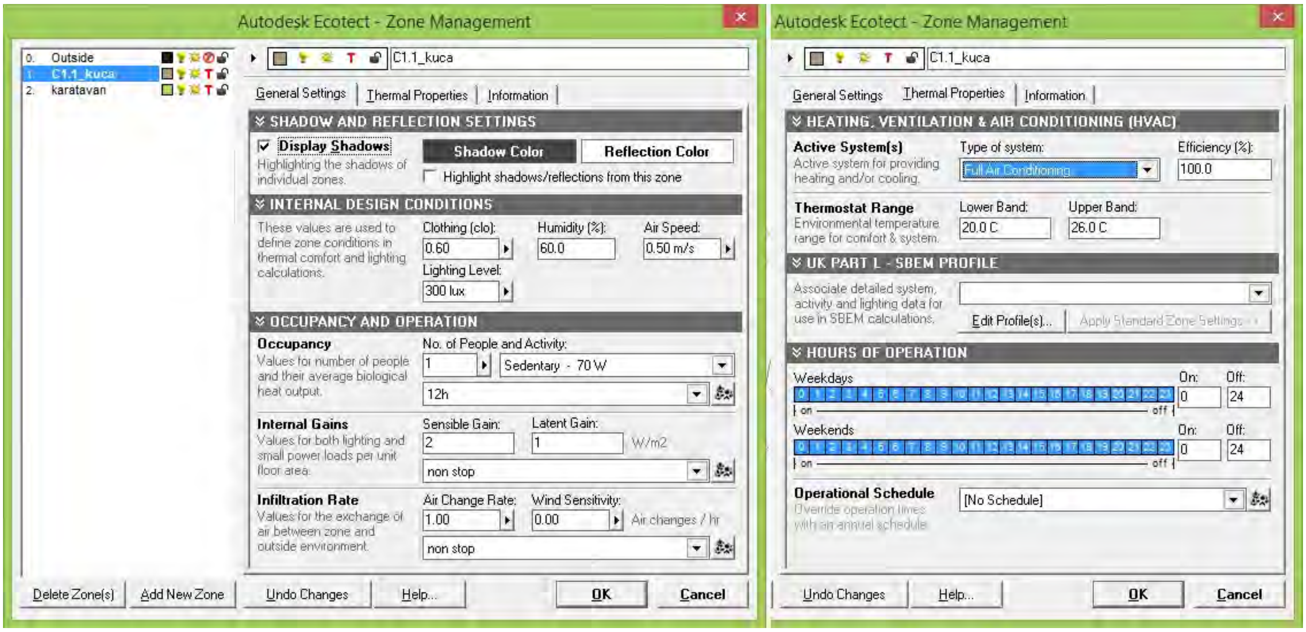

FIG. 4.3 Zone management area in *Ecotect* software

4.4 Results and Discussion

Since the simulation method gives the values of energy need for heating and cooling on a daily basis, irrespective of the heating season (Fig. 4.4.), in order to compare these values with the calculated ones, we need to limit them to the defined heating season, not taking into account any heating needs that usually occur in the transient months.

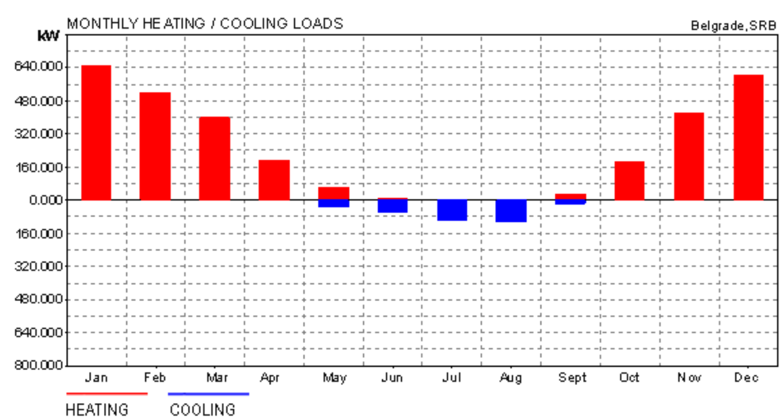

FIG. 4.4 Monthly heating/cooling loads distribution, M0

The overall comparison between the obtained energy performances in terms of energy need for heating shows similar results in all three models using methods of calculation and simulation (Fig. 4.5.). Calculation results show higher values of energy need for heating in the present state (M0), possibly because no thermal mass effect is taken into account, and the analysed building shows a high level of thermal inertia (massive brick walls).

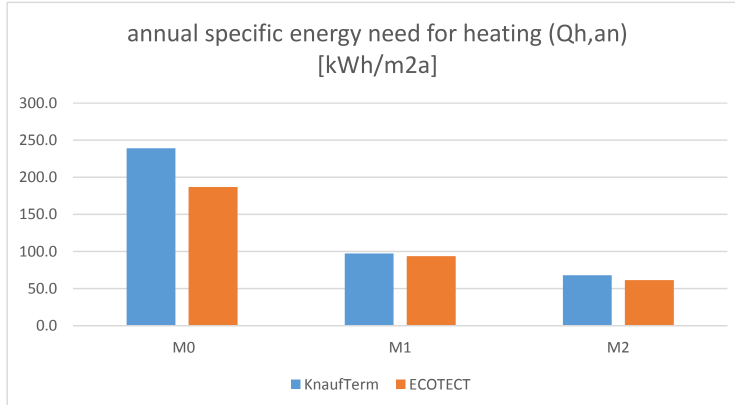

FIG. 4.5 Comparison between obtained values of energy need for heating for three analyses models by calculation in *KnaufTerm2* software and simulation in *Ecotect* software

The ratio between transmission and ventilation losses shows that transmission losses in all models have values up to 5 times higher than the ventilation losses (Fig. 4.6.).

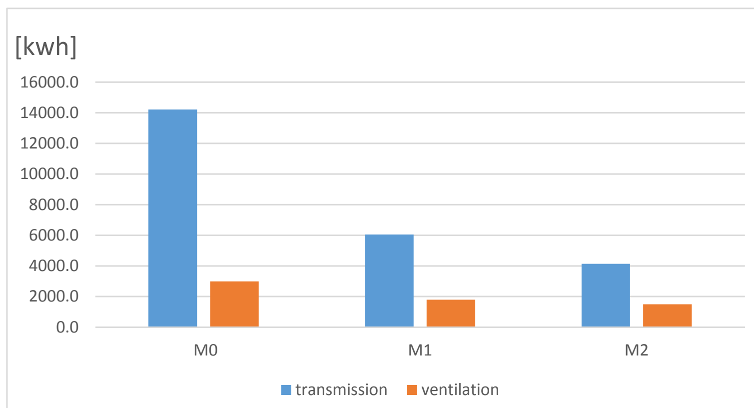

FIG. 4.6 Ratio between transmission and ventilation heat losses obtained by calculations in *KnaufTerm2* software for three case models

However, the gains/loads breakdown obtained through simulation results (Fig. 4.7.) shows that ventilation loads (marked in green) are more significant than the conduction ones (marked red). Additionally, in the gains section, significant sol-air (indirect) gains appear, mostly due to the overheating in the unconditioned attic zone.

These results are in line with the data found in literature, about the over emphasis on ventilation loads in Ecotect software simulations, especially when the infiltration levels are set high, as given in Hensen (2004), due to the calculation method which also takes into account wind speed from the weather file and the orientation, and not just the infiltration level. Other simulation software also shows less significant influence of transmission loads in the thermal loads structure compared to stationary calculation methods, as stated in a study by Dobrosavljević (2016).

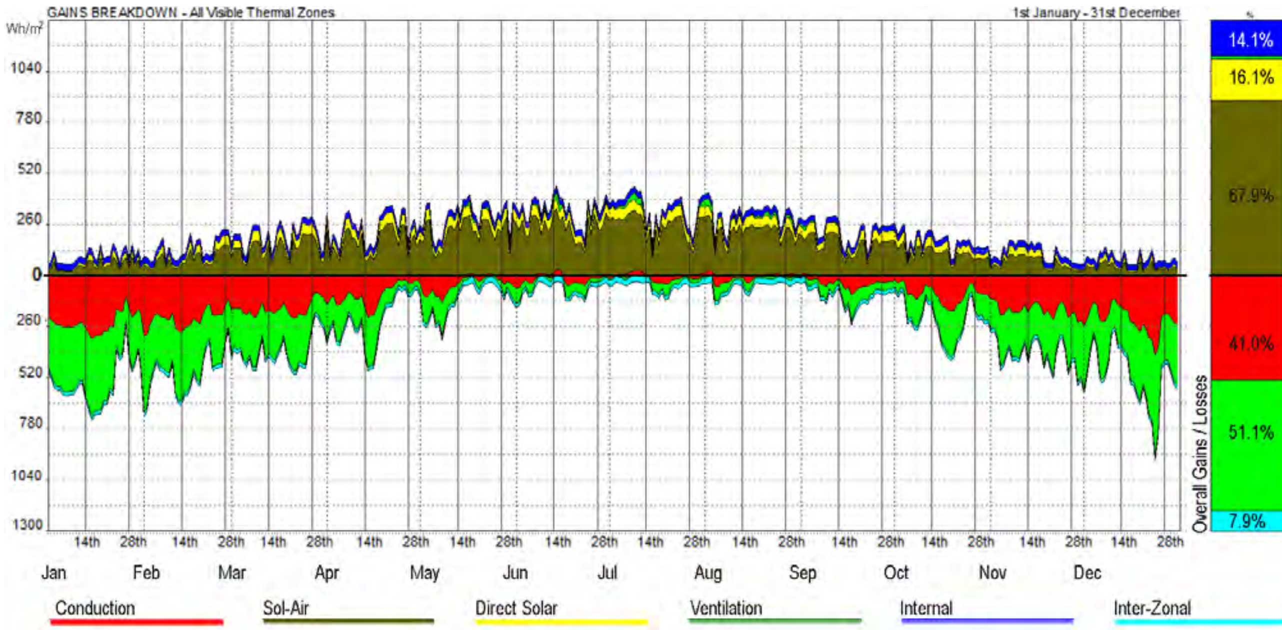

FIG. 4.7 Gains/loads breakdown obtained by thermal simulation for M0 model

Very low cooling loads in all three investigated models can be explained by a low glazing percentage and low solar gains, as well as the influence of thermal inertia. In addition, low cooling needs can also come from the imprecision of the thermal simulation engine and related calculations; literature-based data were found that support these claims, such as De Saulles (2009) and Hensen (2004).

5 Conclusions

Building energy performance can be assessed at various stages of the building design process and with more or less precise methods. Among numerous tools and methods for addressing the energy performance of buildings, calculations are mostly used for the verification of achieved performance and certification according to regulations, while whole building thermal simulations can be used for numerous purposes, depending on the simulation software.

As a representative verification tool, *KnaufTerm2* is presented, a widely used tool in Serbia for the certification of buildings based on domestic regulations, in line with EN ISO 13790 standard. *Ecotect* is presented as a representative of the simulation tools, used widely as a design assistance tool for simple dynamic simulations of energy performance.

The energy performance of the three test case models were assessed by calculation and simulation. The first model is a present, unrefurbished state of a typical single family house in Serbia, while the other two models are two variations of its improvement. The differences between overall energy performance assessed by methods of calculation, by stationary method, and simple dynamic simulation are about 20% for the present state model, and less than 2% for the refurbished models. By comparing the structure of the thermal loads and gains, as well as the influence of the energy need for heating in the overall energy balance, some data found in literature have been confirmed, which testifies for the limitations of the applied calculation method and the simulation tool.

However, despite the differences that exist in results of calculations and simulations using different tools, it is strongly suggested that simulation tools are used early in the design stage, because the greatest advantage of their use is optimisation of design. When used in later stages, usually a very robust model is created, in which the manipulation of design options is complicated, and although results are trustworthy, their applicability is questionable.

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