Строительство уникальных зданий и сооружений. ISSN 2304-6295. 11 (62). 2017. 93-102

Construction of Unique Buildings and Structures

journal homepage: www.unistroy.spbstu.ru

Building energy model detail level

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Article info

scientific article

doi: 10.18720/CUBS.62.8

Article history

Received: 04.09.2017

Keywords

Building energy modeling;
building information modeling;
BEM;
BIM;
energy model;
energy efficiency;

ABSTRACT

Three energy models of the apartment building with different level of detail were studied. The study was carried out to assess the possibility of simplifying the model of the late design stage or using the model of the early design stage to perform energy calculations. The maximum divergence of the calculation results of the simplified and detailed models did not exceed 10%. On average, the divergence of the results was equal to 8% in the case of the calculations of the concept and detailed models, and the divergence of the results was equal to 5% in the case of the calculations of the moderately simplified and detailed models respectively. In the case of energy calculations at the early design stage it can be considered a rather small value. The use of the simplified building model for energy calculations can be recommended. The use of the detailed model was considered to be irrational and can be recommended only in the case of the existence of compelling reasons.

Content

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1. Introduction

With increased emphasis on the problem of energy conservation and the need to estimate the efficiency of energy-saving measures, building energy modeling (BEM) is increasingly in demand [1-2]. BEM is a series of specific engineering calculations that allows estimating the volume and structure of the energy consumption of a building with a comprehensive account of the factors influencing it [3].

In spite of the fact that the calculations that were automated in the case of BEM are approximate [4-5], BEM becomes an important tool that allows to achieve high-accuracy results (the calculation results are close to the results of the verification tests in site) by comprehensive accounting of interrelated factors [6-8]. However, it is important to note that the high accuracy of the results does not mean that the BEM software calculation methodologies are in accordance with the requirements of the Russian Federation construction norms [9-10]. This factor limits the field of the BEM potentiality application.

The main directions of the BEM implementation are energy efficiency standard certification, energy service contracts and design of the object of industrial and civil engineering [11]. In the case of energy service contracts, the BEM calculations' accuracy makes possible the estimation of the project decisions' recoupment that in turn reduces the potential risks. In the case of the object of industrial and civil engineering design, BEM simplifies the possibility of the trial design [12] and contribute to the more efficient design decisions [13]. Simultaneously, the high accuracy allows to reduce costs caused by overpayment for excessive capacity of engineering equipment [14].The results of the expert survey that were presented in the paper [15] also confirm the positive economic results of the energy modeling.

BEM can be conventionally classified by the stage of the project on which modeling is carried out. There are following categories:

- energy modeling which is carried out at the initial stage of the design (usually with the purpose of estimating, selecting and justifying design decisions);
- energy modeling which is carried out at the following stages of design (for example, to obtain data on the estimated level of energy consumption);
- energy modeling which is carried out at the operational stage (for example, in the case of an energy service contract or development of a reconstruction project).

Each case has its own purposes, tasks and problems.

In the case of the objects under construction, more and more attention was being paid to the need for BEM at the early stages of the project [16-17]. This is linked with the features of the working on the project process, when the negative consequences of reviewing and changing the design decisions are less, the sooner such changes were made [18-19]. The most rational point of the initial estimation of the building energy efficiency is the stage of the feasibility study. The final decision on the project implementation should be made after such estimation was made [17].

It should not be forgotten, however, that the early stages of the project are characterized by incomplete information, and the corresponding information model or drawings are characterized by the lack of detail and accuracy specific to the following stages [18].

At the same time, the main design decisions are taken at the early stage and do not suffer significant changes during the project. Especially it is typical for the projects of apartment buildings, where such decisions can include the following:

- total structural volume, main dimensions and features (number of floors, area, etc.);
- glazing area and irregularity of the facades, which are often standard in the case of the apartment buildings as well as many public and industrial buildings;
- orientation of the building and windows, usually directly depending on the orientation of the surrounding buildings and the street-road network;
- type of the ventilation, heat, gas and electricity supply systems, the preselection of which can be made by analogy with the previous projects;

- estimated number of tenants, which can be applied from both design practice and requirements of the construction norms;
- thermal resistance of enclosing structures, directly dependent on the structures, materials and technologies used and often unchanged from project to project due to the successful cooperation with the supplier. Thermal resistance can also be applied based on the requirements of the construction norms.

In addition to the design solutions, parameters of the internal and external environments, such as temperature, humidity, air exchange, etc., can also be preselected based on the requirements of the construction norms and climate data. However, both the question of the sufficiency of these data for performing energy calculations to a required accuracy and the question of changing the results during the project are still open.

In the case of energy modeling, which is carried out at the following stages of design or after the completion of the construction process, the problem of lack of the initial data is usually missing or can be resolved. The question of the amount and quality of the initial data that must be collected arises instead.

To sum it up, it may be concluded that in any case the question of the required level of the energy model detail arises.

Thus, **the aim** of the article is to assess the possibility of simplifying the model of the late design stage or using the model of the early design stage to perform energy calculations.

In this connection there are following **tasks**:

- to model a building with different levels of detail;
- to carry out a series of energy calculations using the models that were obtained;
- to assess the dependence of the results on the level of model detail.

2. Methods

2.1. Modeling and export of the model

A four-storey single-section apartment building was chosen as an object of modeling. To bring the object closer to the real objects of housing construction, the modeling was carried out based on the data of the project of the apartment building located in St. Petersburg.

The object was modeled in Revit Architecture 2017. There were three with different levels of detail. The subsequent export of the models to Ecotect Analysis, supporting the possibility of carrying out energy calculations, was conducted using the *.xml file format.

Location (St. Petersburg) and orientation of the building were set based on the data of the real project. The climatic characteristics were set by uploading the weather data file for St. Petersburg. Hourly climatic data were obtained on the basis of statistical data for the last 5 years of weather observation.

Each element was assigned the appropriate attribute (window, door, floor, ceiling, roof, etc.) and characteristics (layers of internal and enclosing structures, thermal characteristics, light transmission, reflectivity, etc.).

The inaccuracies and collisions that were being arisen during the export process were corrected as well. The replacement of the actual thickness elements (Revit Architecture) with elements of zero thickness (Ecotect Analysis) was mainly responsible for the collisions.

Figure 1 shows the result of the export of the models to Ecotect Analysis.

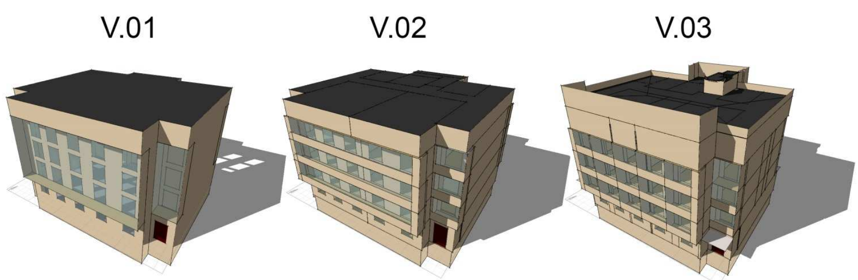

Figure 1. Result of the export of the models from Revit Architecture 2017 to Ecotect Analysis

In addition, it should be noted that the creation of the detailed model (type V.03) required significantly more (in comparison with types V.01 and V.02) labour time already at the stage of creating the architectural model. Moreover, there was a need for much more laborious work to verify the obtained energy model and to correct the identified collisions. Further work with the model of this type required the availability of powerful hardware. In this case, the calculation time increased several times.

2.2. Variations among models

As it was said above, there were three models with different level of detail (see Figure 1):

- Model V.01 corresponded to the earliest stage of design ("concept model"). It was represented by a unified internal volume surrounded by enclosing structures. The balconies were separated from the unified volume due to the large difference in the microclimate parameters.
- Model V.02 was more detailed than V.01. The internal volume of the model was represented by a system of main zones and surrounded by common enclosing structures.
- Model V.03 corresponded to the construction design stage. There was a division of the main zones into separate rooms, including the separate premises of the basement and technical attic. A staircase shaft on the roof was modeled as well as shading elements (shading structures, roof railing).

The variations among models are shown in Table 1 in more detail.

Table 1. The main variations among models

Parameter for comparison	**Model**		
	V.01	**V.02**	**V.03**
Enclosing structures	Roof – 1 type, Foundation – 1 type, External wall – 1 type Glazing structures and doors	Roof – 1 type, Foundation – 1 type, External walls – 4 types Glazing structures and doors	Roofs – 2 types, Foundation – 1 type, External walls – 8 types Glazing structures and doors
Shading elements	-	-	Shading structures, roof railing
Internal structures	-	Floor slab – 1 type, Internal walls – 2 types	Floor slabs – 4 type (first floor, second floor, intermediate floor and attic floor), Internal walls and partitions – 9 types (including special cases of additional hydro- and thermal insulation)
Openings, doors and windows	External wall openings: Door – 1 type; Window – 1 type, Balcony door – 1 type	External wall openings: Door – 1 type; Window – 1 type, Balcony door – 1 type	All openings: Door – 8 type; Window – 3 type, Balcony door – 4 type
Internal volume division	Unified internal volume, no floors	Internal volume is divided into floors and main functional areas. Technical attic and basement are separate zones	Internal volume is divided into rooms (including separate premises of the technical attic and basement)
Types of zones / rooms*	2 types: residential area and glazed balconies**	9 types**	17 types**
Comments: * Second floor (typical floor) zoning plans of the models are shown on Figure 2. ** Each type of zones is given the unique properties: air change rate, wind sensitivity, design and permissible temperatures, types of ventilation and heating systems, humidity, design operating loads, operating mode and schedule, heat input, lighting, etc. Data were applied based on design experience, statistical data and the requirements of the existing construction norms.			

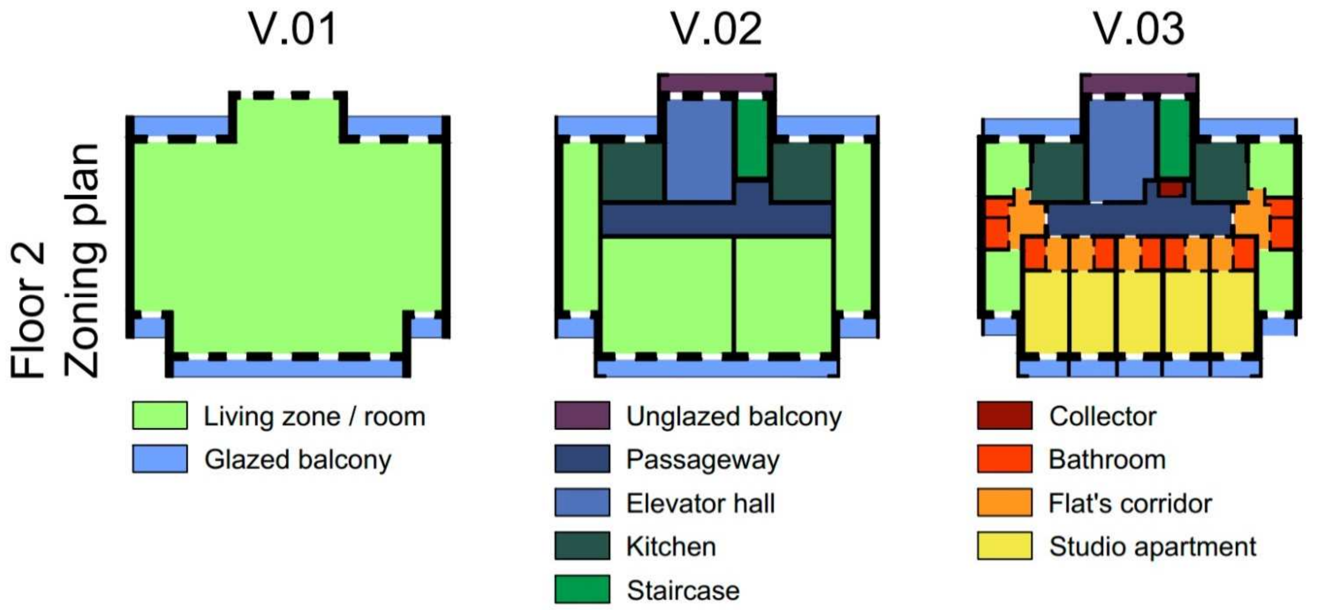

Figure 2. Second floor zoning plans of the models

2.3. Energy calculations

After setting up the models, the following calculations were made:

- Solar access analysis;
- Thermal analysis.

The results of the calculations are presented below.

3. Results and Discussion

3.1. Results

Figure 3 shows the graphical results of the solar access analysis.

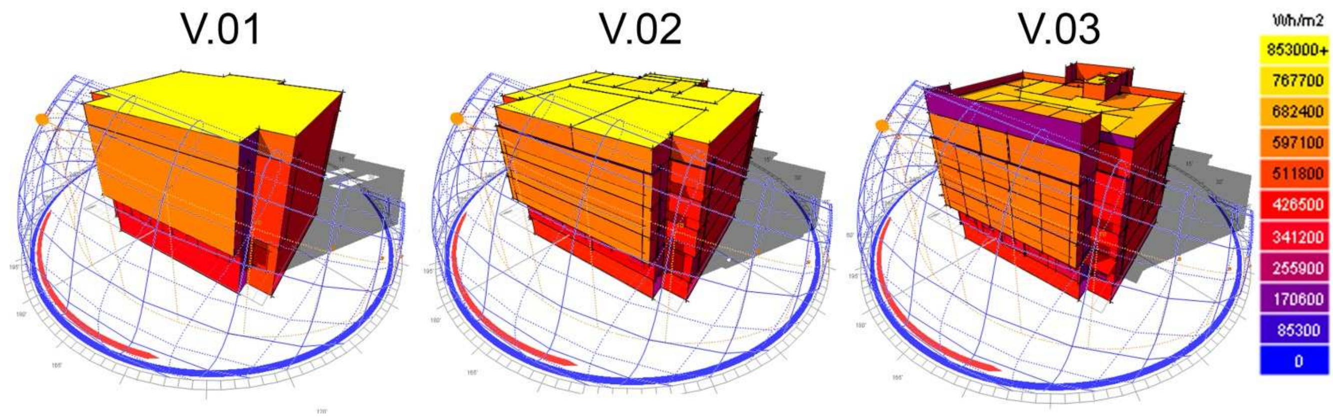

Figure 3. Graphical results of the solar access analysis (for one-year period)

Table 2 presents the numerical results of the calculations.

Table 2. Main numerical results of the calculations

Parameter for comparison	Units of measurement	Model			Divergence of results of the calculations	
		V.01	V.02	V.03	Of V.01 and V.03	Of V.02 and V.03
Total annual heating load	$\frac{MJ}{year}$	936154.14	925623.30	971141.76	3.7%	4.9%
Total annual heating load per square meter	$\frac{MJ}{year \cdot m^2}$	333.15	330.12	347.31	4.2%	5.2%
Solar gains	$\frac{MJ}{year}$	2436.17	2232.91	2095.37	15.0%	6.2%
Maximum heating load	kW	152.60	132.23	137.89	10.1%	4.3%

The divergence of the results of the calculations (including partial results, which were not included in Table 2) did not exceed 10%. On an average, the divergence of the results was equal to 8% in the case of the calculations of V.01 and V.03, and the divergence of the results was equal to 5% in the case of the calculations of V.02 and V.03.

The heat loss and heat gain structures are shown in Figures 4 and 5, respectively.

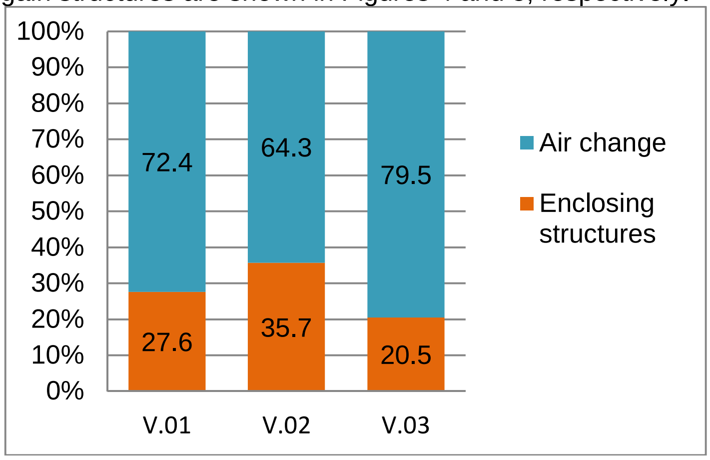

Figure 4. Structure of heat losses

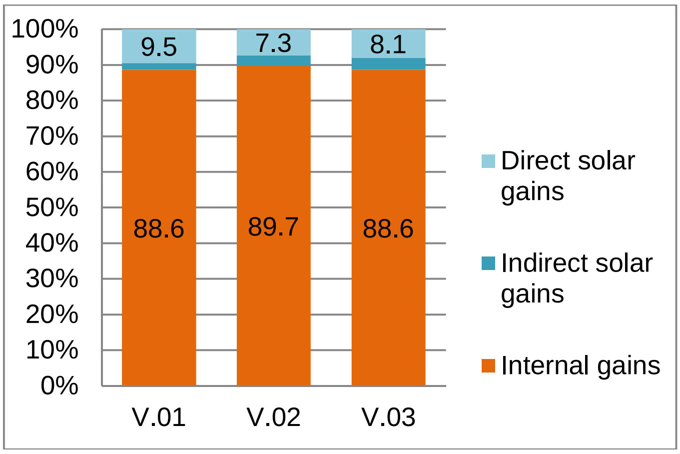

Figure 5. Structure of heat gains

3.2. Discussion

The divergence of the results of the calculations did not exceed 10% and was equal to, on the average, 8% and 5% for the models V.01 and V.02 respectively (see Table 2). The heat loss and heat gain structures suffered insignificant changes (see Figure 4 and Figure 5). The graphical results of the solar access analysis also did not show significant differences (see Figure 3).

The obtained value of the divergence can be considered satisfactory for the thermal engineering calculations, inasmuch as the thermal engineering calculations are approximate [4-5]. The value of the divergence is comparable with value of the divergence between simulation results and in situ measurements, estimated in different cases at 5-10% [6-8].

The obtained value is several times less than the value obtained in the case of performing energy calculations in various BEM software as well. The divergence in that case reached 35% [5]. Thus, the choice of the tool for modeling and calculations has a greater impact on the results than the simplification of the calculation model.

It also suggests that the results of the calculations performed in the same software at different stages of the project should not suffer significant changes in the case of the residential building projects. Thus, it is possible to conduct energy calculations with sufficient accuracy at the early design stage already.

Taking into account the need for the additional labour time as well as the availability of the powerful hardware in the case of the work with the detailed model (type V.03), the following recommendations could be given:

- to carry out the energy calculations using V.01 model for the early design stage (before making the final decision on the project implementation) and V.02 model in all other cases;
- to use of V.03 model for the energy calculations only in the case of the existence of compelling reasons.

It should be also noted that the results obtained in the paper were obtained for the four-storey single-section apartment building in the climatic conditions of St. Petersburg, Russia. It has been assumed that the study final results are not dependent on the given climatic conditions. However, the correctness of the direct comparison for countries located in different climatic zones is controversial [20-21]. It is reasonable to suppose that similar results can be obtained in the case of studies of similar buildings located in similar climatic zones, such as Finland, Canada, Iceland [22]. For more generalization, further research is required. There are the main factors that can influence the result: climatic conditions, access to sunlight, shading structures, glazing, type and volume of the building [23].

4. Conclusions

Three energy models of the apartment building with different level of detail were made. The obtained models were exported to Ecotect Analysis.

After carrying out the necessary preliminary work, the solar access and thermal analyses were performed.

The obtained graphical and numerical results were analysed and found to be satisfactory.

According to the results of the study, it was recommended to use the simplified model of the building for the energy calculations. The use of the detailed model was considered to be irrational and was recommended only in case of existence of compelling reasons.

It was established that many of the energy calculations are possible at the early design stage. This expands the range of considered methods of increasing the energy efficiency allowing to include in it methods that can be applied only in the case of their inclusion in the project at the initial stage.

This research establishes an objective and empirical foundation for the future discussion about the required accuracy and level of the energy model detail. For potential further studies, researchers can make another analysis with the same or another methodology taking into account other climatic and geographic conditions, characteristics of the object under study. Further studies conducted in alternative BEM software are also required. It is assumed that the results may change in that case due to the difference in algorithms and calculation methods.

This and further researches can identify weaknesses and errors in the calculation methods of BEM software as well as a number of inappreciable factors and influence further improvement of the methods.

An alternative line of investigation with the aim of the refinement the results should be development of specialized normative documentation and methodologies that specify requirements for energy models. Such documents are necessary both from software vendors and at the national level, taking into account the local features of the construction industry.

Subsequent refinement of the calculation results will provide an opportunity for further development of the researches in the field of building energy efficiency improvement and to find new energy saving methods.

The improvement of precision of the calculation and in situ measurement results has significant potential. Fine precision will allow expanding the application field of energy saving methods for their application throughout the life cycle of the building. At the moment, to predict the behavior of the building for such a long period of time is problematic, which reduces the popularity of scientific researches in this area.

In the future it will also ensure the universal acceptance of energy modeling as an official tool for energy calculations, will affect the simplification of normative documentation and the calculation procedure and allow the scientific community to concentrate efforts on characteristics of individual components and structural elements.

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Уровень детализации энергетической модели здания

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ИНФОРМАЦИЯ О СТАТЬЕ	ИСТОРИЯ	КЛЮЧЕВЫЕ СЛОВА
doi: 10.18720/CUBS.62.8	Подана в редакцию: 04.09.2017	энергетическое моделирование зданий; информационное моделирование зданий; BEM; BIM; энергетическая модель; энергоэффективность;

АННОТАЦИЯ

В работе исследуются энергетические модели условного жилого здания разных уровней проработки. Исследование проведено с целью оценки возможности упрощения модели поздней стадии проектирования или использования модели ранней стадии проектирования для проведения энергетических расчётов. Максимальное расхождение результатов расчётов упрощённой и детальной моделей не превысило 10% и в среднем составило порядка 8% и 5% для случаев сильного и умеренного упрощения модели соответственно. В случае проведения энергетических расчётов на ранней стадии проектирования, полученный результат является достаточно малым расхождением. По результатам исследования рекомендовано использование упрощённой модели здания при энергетических расчётах. Использование детальной модели является нерациональным и рекомендовано только в случае достаточного обоснования.

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