The computer aided modelling and energy analysis of the spatial and structural components of building

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Summary

The article concerns the modelling and energy analysis problem of the spatial and structural solutions of newly designed buildings or those under renovation. The results of that task serve as a base for defining of thermal indices of the project on different design stages.

The core of the developed automated system is formed of integrated graphical digital spatial models of the parts of buildings. These models include different kind of structured geometric and non-geometric (physical, economical) information about the object.

The proposed method could be used by interested experts as a tool for control of thermal and energy indices at various design stages, searching for rational architectural forms and structural solutions. It takes into account the latest requirements of Lithuanian building regulations concerning heating energy saving.

Keywords. Computer aided design, buildings, 3D models, energy analysis.

1. Introduction

Recently researchers, designers and representatives of municipal and regional authorities as well as building production consumers in Lithuania and East European countries actively investigate heating and energy saving problems in buildings, try to find more rational ways and tools to solve them. In Lithuania national codes and regulations are prepared and published [1, 2, 3]. They regulate the heating issues of the newly designed and objects under renovation. There are different editions published by the specialists of this area and computer programmes created as well. All that makes better preconditions for designing and renovating the objects with regards to the energy related factors.

Anyway, there are no methods created and adapted according to the country's environment conditions allowing objective analysis and giving a complex evaluation of the projects of new buildings and their renovation according to the energy related aspects. The methods and computer programmes created and adapted in our country (the choice of thickness of isolation materials for claddings, the settling of thermal resistance, calculation of thermal fields of structural junctions) occur as the solution of partial tasks of the problem.

2. Objective of the work

Objective of the work is to create the methods and computer-based tools for the structure modelling and energetic analysis of newly designed and buildings under renovation and reconcile them with Lithuanian climate and heating standards and economic data as well.

The method proposed is based on the integrated graphical digital models supported by the environment of open architecture computer aided design system AutoCAD. These CAD models are interpreted as a universal database where all the necessary data needed for solving the task is being collected and saved. These models include various kinds of data (geometric, physical, economical) about the whole object and its parts.

3. Structure of the system and methodological grounds

The computer aided modelling and energy analysis system of the spatial and structural components of building consist of the following main parts:

- the subsystem of the general geometric modelling of building complex or building and its components;
- the subsystem of the geometric modelling of the construction of building components;
- the subsystem of the analysis of metrics of the building model;
- the subsystem of the energy analysis of the building model;
- the subsystem of the evaluation project variants.

In the viewpoint of methodology the geometric modelling of the entire objects and their components is based on the paradigm called “Types & Instances” and its main concepts (design vocabulary, substitution, level of detail, hierarchical structures) formulated by the well-known American architect and expert in information technology William Mitchell [4].

In designing and modelling the elements of the design vocabulary could be simple geometric forms (types) identified with the building, parts of the building and its definite structural components. A rectangular box as a type (the building, the level of the building, the fragment of the wall, the column or the beam) will be defined as an instance with the particular properties: length, width, height, colour etc.

The concept of the substitution, outlined by G. Schmitt [5], has three main meanings: first - the substitution of the alternative by another one according to the predefined constraints. It means the full substitution of the object by another one; second - the substitution of one class objects to appropriate objects of another class; third - the substitution of general symbols of the objects to more complicated and more similar to real objects. The substitution as a procedure could be used during investigation of the alternatives by repeating the condition “What if...” interactively. Thus the principle of the design vocabulary with the elements exchangeable could be defined.

The definition and fixing of the degree or level of detail allow us to adjust the CAD model of the object to the design stage and to the degree of the object understanding. This tool enables us to overview different variants of the object represented in various degrees of details. Main properties of the object like position, size, relations to other parts of the building remain the same, but the details of the form and the internal structure will be changed.

The tool of the definition of hierarchical structures allows us to create more complicated structures of CAD models and to study alternative solutions effectively.

We realize the process of the designing or reconstruction of the object as a process of the searching which is implemented in practice by changing and defining more precisely, by removing and returning again to the previous solution, by stretching and re-building of the initial forms of the model. This approach and the concepts described earlier led us to the main ideas implemented when designing the subsystem of geometric modelling.

4. The function of the computer aided modelling and energy analysis system of the spatial and structural components of building

4.1 Formation of integrated graphical digital models of buildings and their structural components

The most important elements of the specialised system are integrated graphical digital models, covering the information on building and its parts, and mathematical tools ensuring model processing and system functioning.

The first and the second parts of the methods are mainly related to the aspects of creation of geometric models of buildings and their components. The ways for creating geometric models, integrated into a single system, can be distinguished by common features:

1) formation of models is based on orthogonal geometry. For this purpose, the design of standard functions for performing the most popular geometric transformations may simplify;
2) the same graphical objects are applied (2.5D polylines, 3D face) for creating a more "democratic" system, without large computer resources;
3) available details of a model in different stages of its creation, i.e. the details of the outside contour of the model, the surface of the object, general details of the volume of the object.

One of the methods can be realised by using the programme complex "TiVa" ("Types and Variants"). Spatial (3D) profiles are created with the help of computer based means and saved in a database. Later they can be taken out of the CAD database and included into the graphic window, transformed and analysed in detail. This way the generalised spatial model of a building is formed. The model of the living house created by package "TiVa" is shown in figure 1.

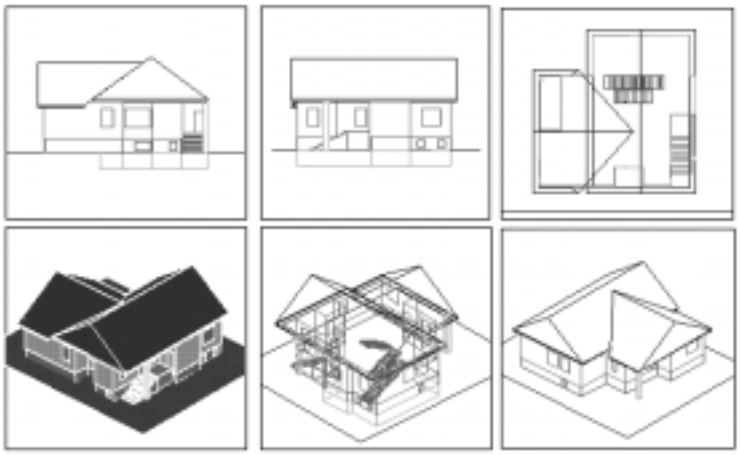

Fig. 1 The computer model of the living house, 2 fasades, roof plan

The main principles are included into the programme complex "TiVa":

- operative and non- restricted generation of the object forms;
- design vocabulary formation from 3D profiles, while realising it as a database in practice;
- establishing the relations between various levels of details in profiles and their free interchange in the model;
- application of methods for the design of different variants.

While applying another method, devoted to create a model for the building or its components, being designed or renovated, technologies of scanning and treating of image views have been applied. Images views are two- dimensional architectural drawings (plans of floors, facades, etc.) taken from the existing design documentation. Having created the image files of the building components, they are moved into the AutoCAD environment. Further the image views are processed with the help of complex programme. First of all they are vectorised, then schematic views of 2D floor plans are formed and the files of the data of a building are prepared. On the basis of the external text data file the model of a building and its components is automatically generated and visualised. Surfaces of spatial model of a building (outer walls, openings, slabs, etc.) are described by the three-four angle faces (3D face graphical entities).

For describing spatial models of flat and slope roofs, the same 3D face graphical entities are used.

The building can be modelled by using other ways or the industrial computer aided systems (e. g., AutoArchitect, Softdesk Inc.). The main thing is that it has to be the CAD model presented in an electronic form.

The cladding construction of a building model can be defined in automated system in two ways:

- by the automated graphic formation of the cross- section scheme with desirable heating peculiarities;
- by the use of graphical- digital models, prepared beforehand and saved in the database of the system (see figure 2).

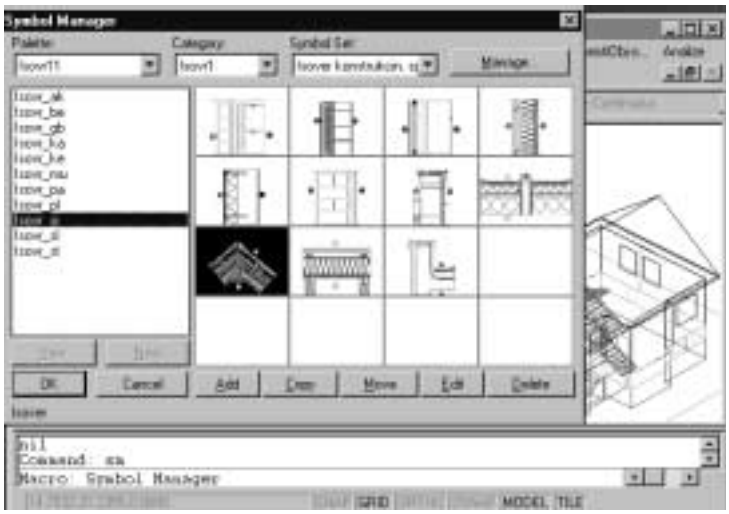

Fig. 2 The graphical digital database of the construction solutions of the building model cladding parts

In both the cases non- graphic data of database elements (construction titles, heating-technical characteristics) are associated with the elements of the geometric model.

Informational graphical models of buildings are the complexes ones. They include geometric elements, described by computer based means in the system that are joined together by functional relations and connected by geometrical and physical numerical data. These properties are expressed in views, texts and mathematical subordination.

For the structurisation of integrated graphical digital models of buildings in the geometrical point of view, first of all their different components are described and the relations among each other as well.

General volume of the building is divided into partial volumes, thus making the kind of a scheme of the geometrical description of the building model: building → floors of a building → premises on the floors. The inside volume of a building is separated from the outside by claddings (walls, windows and doors, roof, the slabs of non- heated basement and a garret), that belong to certain floors at the same time.

Sorting the parts of a building model according to the purpose, types and floors allows the calculation of certain geometrical quantities, such as cladding areas, premise volumes and perimeters (the subsystem of the analysis of metrics of the building model) and formation of certain spatial views and orthogonal projections.

4.2 Energy analysis of building models and peculiarities of formation of project variants

Geometrical data of a building are related to the graphical expression of spatial model of a building. The heating- technical characteristics are related to the construction of a building model (2D models). They also determine the cross- section view of cladding construction. The constructional heating numerical data together with geometrical numerical data after integrating them into certain parts of a building are necessary in energetic calculations. Filtered geometrical dimensions and heating-technical characteristics are applied in mathematical expressions of the computer aided modelling and energy analysis system of the spatial and structural components of building. The expressions can serve the evaluation of heat losses in a building, etc.

The relations between graphical numerical model and the subsystem of energy analysis are presented in a block-scheme (see figure 3).

Peculiarities of the design models are analysed while referring to the samples of real objects, newly designed and renovated [6].

Variants of a building project can be prepared by changing spatial solutions of a building, dimensions of claddings and their construction (see figure 4). Spatial solutions of a building and the dimensions of claddings are characterised by geometrical parameters (length, width, height, etc.) and the construction of claddings – heat index values, that depend on the layout of the materials on the layers of claddings and the relations among the layers.

The subsystem of evaluation and review of project variants allow the selection of the most rational designed spatial and constructional solutions in the point of view of energy and economics.

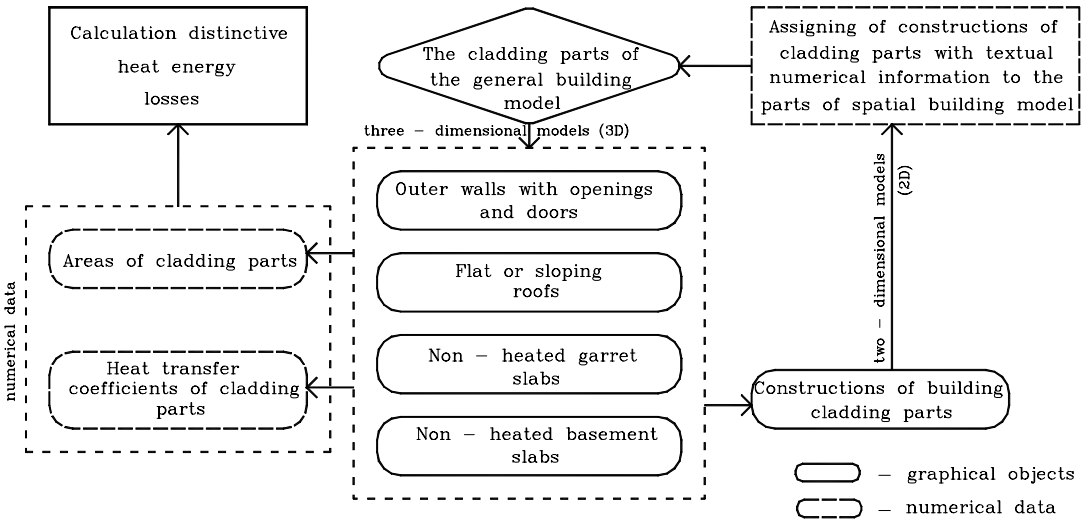

Fig. 3 Interrelation of the geometrical model, numerical data and indices of energy estimation (is being estimated the main transmission heat losses of cladding parts of a building in a concrete case)

The projects are reviewed while operating geometrical parameters and the values of heat indices evaluated in changes of distinctive energy losses and economic (the most popular is payback period by using own means) indices (see figure 5).

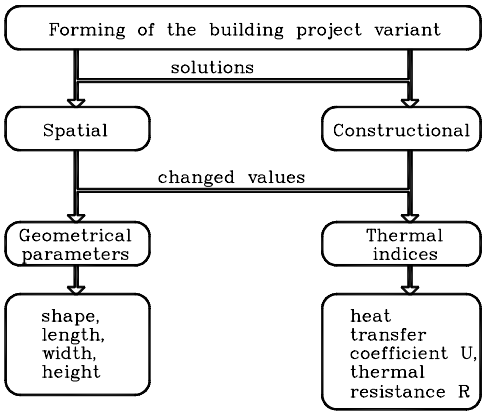

Fig. 4 Project variant solutions of a building

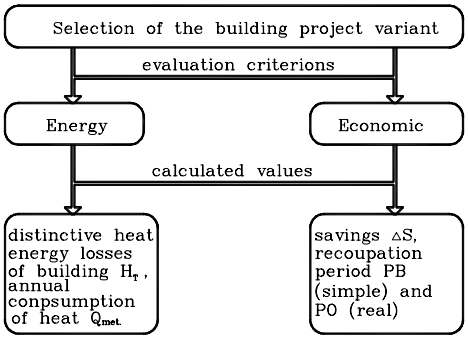

Fig. 5 Project variant evaluation criterions of a building

The computer- based tools of the system of automated modelling of buildings and their energy analysis allow to form geometrical models of real buildings while changing the level of details. Having arranged the alternatives for design solutions of building models, the energetic and economic analysis of objects and their parts are performed. As a result of variant automated design and analysis, certain conclusions have been made:

1) The computer- based model of a building can be arranged by the means of the system, discussed at work as well as by the other industrial systems of computer design. Nevertheless, the model must be made from graphical objects of appropriate types (3D face, Region), proper in the geometrical point of view.

2) The main criteria of evaluation of the variants for the newly designed object are distinctive heat energy losses H_T, because these indices are very useful for evaluating project variants, i.e. they evaluate the geometry and construction, but they do not make any influence on the concrete building site. A simple but rather precise methodology is used for the analysis of the variants of the object under renovation. The annual consumption of heat Q_{met} for building heating is calculated according to the above- mentioned methods, widely used in our country nowadays.

3) The selection of project variants according to the economic aspect is performed in case, when the claddings are heated. Economic evaluation criteria of design variants are considered to be savings ΔS and payback periods *PB* (simple) and/or *PO* (real).

4) While arranging the variants of the project, different dimensions (variables) may be changed at the same time: geometrical parameters and heat indices. This way, several alternatives can be tested and the most rational in the energetic point of view spatial and constructional solutions can be chosen.

5. General conclusions

1) A complex problem has been solved in the work. It includes spatial and constructional structure of a building, energy and economic issues. Therefore, there are foreseen the possibilities for the choice of variants in the methodology, while evaluating the spatial solutions, construction, cladding peculiarities and the economic aspect. For the complex and quite precise solution of the task, formulated at work, there have been used the integrated CAD models.

2) A specialised system, integrated with CAD system, has been created for the solution of tasks of geometrical informational model. This is the system, realised in an open architectural computer aided design system, and it is based on graphical editor and programme making tools.

3) The structure of information model of certain objects has been analysed in the methodology and levels of detail and informational relations among the parts of a model have been defined.

4) Graphical digital models (CAD models) of buildings and their structural parts have been prepared, where the structure based geometrical and textual digital information of the object is properly joined.

5) Algorithms and programme means have been prepared, that allow an operative generation of building geometrical models, to formulate alternatives of design solutions, to change the level of detail in the models, to perform the energetic analysis and evaluation of the object and its parts, while choosing rational, spatial and constructional solutions.

6) Graphical digital models of cladding parts of a building prepared in a certain way help the consumer in choosing constructional solutions. The models are saved in the graphical database that can be operatively supplemented in the process of work.

7) Different calculation methods at consumer's discretion have been foreseen to carry out the energetic analysis of the building model. There have been presented the tools for the filtering of geometrical data of a building model and integrating non-graphical data (heating characteristics) in the model.

8) Modern interface has been created in the system for the user. The functions of the system have been illustrated in a much more fragmentary way with the help of the means, mentioned above.

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