TRANSFORMATION FROM IFC DATA OF DESIGN RESULTS TO IDF DATA FOR ANALYSIS OF BUILDING'S ENERGY CONSUMPTION

Ma Zhiliang[1], Zeng Tonghua[2], Wei Zhenhua[3], Feng Yan[4]

[1]Professor, mazl@tsinghua.edu.cn; [2]ME Candidate, zengtonghua@163.com;
[3]PhD Candidate, weizh04@mails.tsinghua.edu.cn; [4]ME, fengyan03@163.com
Department of Civil Engineering, Tsinghua University, Beijing, China

Abstract

Current energy-efficient design of buildings usually needs large amounts of manual work on preparing the building model since the design result cannot be directly used, which leads to low efficiency and is prone to errors. BIM (Building Information Modeling) technology has provided a potential approach to addressing the issue by providing the computable and reusable information of the design result. The purpose of this paper is to develop a mechanism for the transformation from the IFC (Industry Foundation Classes) standard-based data of the design result to the IDF (Input Data File) format which is the input format of EnergyPlus, a mainstream software for analyzing energy consumption of buildings. The information requirement model for energy-efficient design of buildings is configured, and through analyzing the IFC standard and the IDF format, both IFC-based information model and IDF-based information model for energy-efficient design are established. Then a mechanism for the transformation from IFC data of the design result to IDF data is developed. A prototype software application has been implemented and applied successfully in a real project in order to verify the feasibility of the mechanism. As a conclusion, the mechanism has laid a sound foundation for the development of BIM-based energy-efficient design software of buildings used in China.

Keywords: IDF, IFC, Information model, Transformation

1. INTRODUCTION

The energy-efficient design of buildings has attracted wide attention all over the world due to the public concern on the sustainability. In recent years, the energy-efficient problem in China has become critically serious because of the rapid growth of building area which has been up to 1.8-2.0 billion square meters per year, and a large proportion of them are public and commercial buildings (Jiang 2008). Energy consumption simulation is of paramount importance in the energy-efficient design of these buildings. However, current software for this usually need large amounts of manual work on preparing the building model for the software since the design result cannot be directly used, which leads to low efficiency and is prone to errors.

BIM (Building Information Modeling) technology has provided a potential approach to addressing the issue by providing the computable and reusable information of design results. Meanwhile, the IFC (Industry Foundation Classes) standard has become the mainstream standard of BIM and can be used to share information between the multi-stage and multi-disciplinary during the building life cycle, including the energy-efficient design.

Among the existing energy consumption simulation engines, EnergyPlus developed by the *Lawrence Berkeley National Laboratory* is the mainstream engine. Since its input data format is IDF (Input Data File), the transformation from IFC data to IDF data has become the key point of directly using the IFC-based design result in the energy-efficient design. Up to now, several researches on the transformation have been carried out, mainly focusing on two major aspects.

With regard to the transformation of the geometry information, in an early research, the data on 9 IFC entities, e.g. *IfcSpace*, *IfcWall*, were extracted and transformed into IDF data by a direct transformation method (Bazjanac 2001). Since 2007, several further researches have been carried out on the IFC-based semi-automatic transformation by pre-defining code-embedded transformation rules in specific software. Each embedded rule corresponds to one or more algorithms which actually perform the transformation (Bazjanac 2007, Bazjanac 2008). By utilizing transformation rules, a geometry information transformation tool called *GST* was developed to transform IFC data into the specific data which could then be used to automatically generate IDF data by using *IDF Generator*. More rules have been accumulated in *GST* step by step. In 2007, the rules about the simplification of the wall and slab, the identification of the external wall and the handling of the concave polygon, etc. were added (Bazjanac 2007); in 2008, 7 new rules were added, relating to the transformation of the building shade, the transformation of the column embedded in certain wall, etc. (Bazjanac 2008); in 2009, 15 new rules were added, relating to the disregard of the wall contained in certain space, the identification of the roof and the identification of the external building shade, etc. (Bazjanac 2009). Furthermore, in order to make the transformation more accurate, the concept of higher-level space boundary was introduced (Bazjanac 2010) and a corresponding tool called *SBT* was developed (Bazjanac 2011).

Concerning the transformation of the HVAC information, the early research firstly established a hierarchical model to describe the HVAC systems, then the relevant IFC entities data were independently translated into IDF entities, and finally these IDF entities were assembled in a form that follows the topology of the hierarchy. A corresponding tool called *IFC HVAC Interface* was developed. However, the interface's data transformation processes were limited to the HVAC information that is directly related to buildings (Bazjanac 2004). The recent researches followed the same method with the transformation of the geometry information. However, relevant rules have not yet been developed (Bazjanac 2008, Bazjanac 2011).

In addition, both the *IFCtoEnergyPlus Utility* project of the *National Renewable*

Energy Laboratory and the *Building Energy Standards Modeler* project of the *California Energy Commission* are researching the transformation and also focusing on the generation of higher-level space boundary. However, the research findings have not yet been reported (Hitchcock 2011).

Overall, these researches have made many achievements. However, the key models and algorithms for the transformation have not been revealed, and the software applications that have been developed based on these achievements are not available for public. In particular, although several transformation rules are available from the papers, the corresponding algorithms are still not available to be used for developing a software application.

The ultimate goal of this study is to develop a BIM-based energy-efficient design software of buildings that can be used in China. In this paper, the information requirement model for energy-efficient design of buildings is configured, and through analyzing the IFC standard and the IDF format, both the IFC-based information model and IDF-based information model for energy-efficient design are established. Then a mechanism for the transformation from IFC data of design results to IDF data is developed. A prototype software application has been implemented and applied in a real project in order to verify the feasibility of the mechanism.

2. INFORMATION MODEL FOR ENERGY-EFFICIENT DESIGN OF BUILDINGS

2.1 Information Requirement Model for Energy-Efficient Design

According to Chinese specification on the energy-efficient design of buildings, specification indicator checking and energy consumption simulation are the two key contents of the energy-efficient design process, which involves two aspects of information, i.e. building elements information and thermal zone information. Specification information and meteorological information are involved as the external information. In more detail, building elements information consists of geometry information and material information, while thermal zone information consists of internal heat source information ,HVAC information and spatial geometry information. Among them, geometry information of building elements has a close relationship with spatial geometry information of thermal zone.

According to the specification, the geometry information and material information are used to calculate the specification indicators, e.g. the area ratio between window and wall and the thermal performance parameters, which are then checked according to the specification. If the checking results do not satisfy the threshold values in the specification, the energy consumption simulation process is required, in which the thermal zone information and the meteorological information are used. Based on the analysis, the information requirement model for the energy-efficient design of buildings was established as shown in Figure 1.

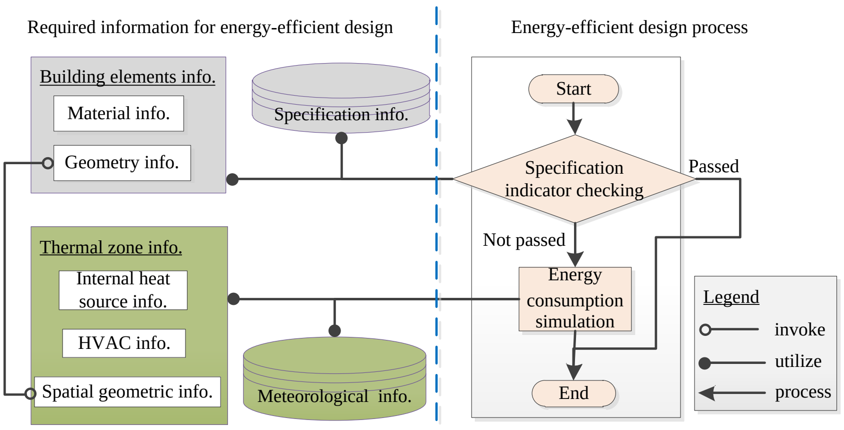


Figure 1 Information requirement model for energy-efficient design

2.2 IFC-based Information Model for Energy-Efficient Design

In order to extract useful information for energy-efficient design from the IFC-based design result, the information requirement model for energy-efficient design of buildings needs to be expressed by using the IFC standard. Accordingly, based on the information requirement model for energy-efficient design of buildings as shown in Figure 1, the IFC-based information model for energy-efficient design was established as shown in Figure 2.

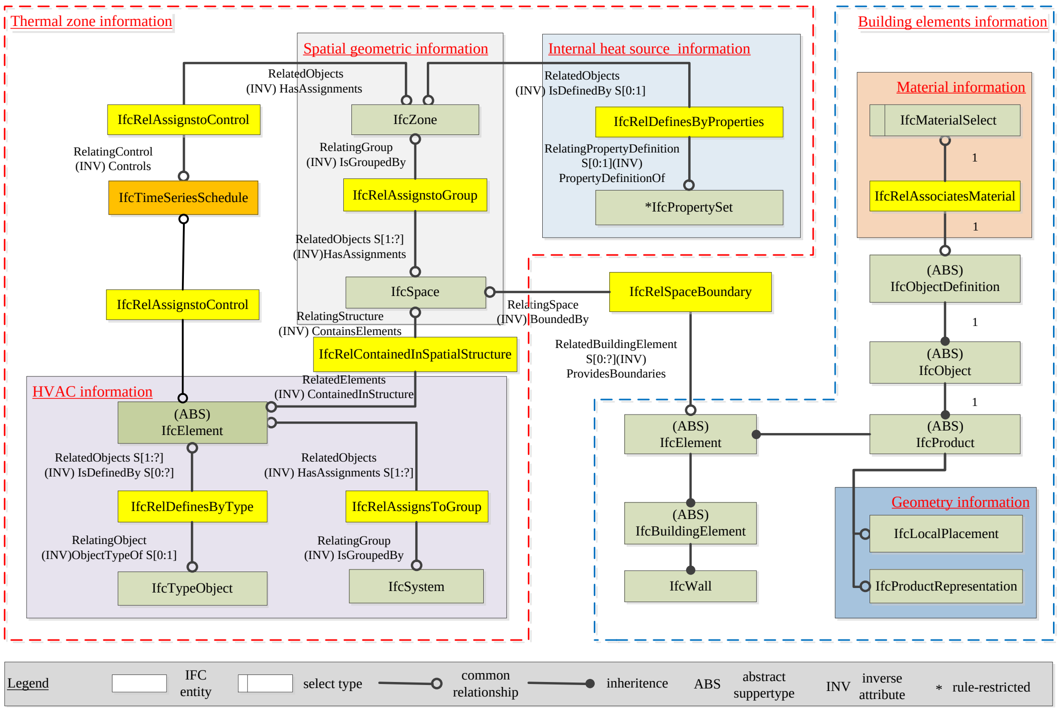


Figure 2 IFC-based information model for energy-efficient design

In the model, each aspect of information in Figure 1 is expressed by using IFC entities, IFC relational entities, etc. For example, the IFC entities used to express the geometry information act as the attribute of the building elements. The

IfcRelSpaceBoundary entity is used to express the spatial relationship between a space and its surrounding building elements. The *IfcRelAssignstoGroup* entity is used to express the assembly of several spaces which could represent a thermal zone. It is worth noting that the current version of the IFC standard (IFC 2x3) has no specific entities to express internal heat source information, so the *IfcPropertySet* entity is used to express it instead.

2.3 IDF-based Information Model for Energy-Efficient Design

In the IDF format, information is organized in an object-oriented way by using more than 400 IDF entities. In order to realize the transformation from IFC data to IDF data, the information expressed based on the IFC standard needs to be expressed by using the IDF format. Therefore, the corresponding IDF-based information model for energy-efficient design was established as shown in Figure 3 by analyzing the IDF format.

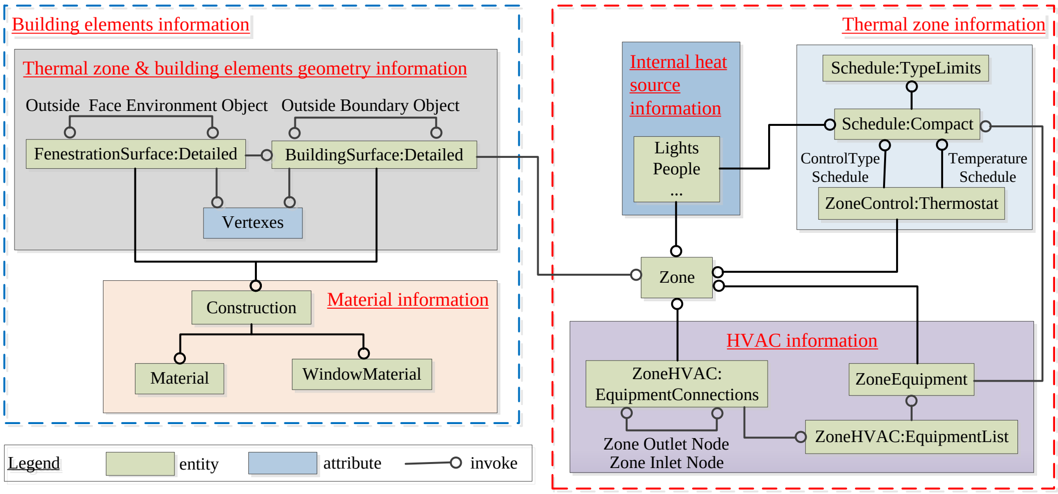


Figure 3 IDF-based information model for energy-efficient design

As shown in Figure 3, the information is expressed by using IDF entities which are associated with each other. For example, the adjacent relationship of the thermal zones is self-invoked by the *Outside Boundary Object* and the *Outside Face Environment Object*; the connection relationship of the air-conditioning system is self-invoked by the *Zone Outlet Node* and the *Zone Inlet Node*. It is worth noting that the spatial geometry information of a thermal zone and the geometry information of its surrounding building elements overlap in IDF data, so the two aspects of information are merged in the model.

3. TRANSFORMATION MECHANISM AND KEY ALGORITHMS

3.1 Basic Principles

The essence of the transformation is to generate information from one model to another model by simplification, translation and interpretation (Bazjanac 2007, Bazjanac 2008). Thus the relationship between the IFC-based information model and IDF-based information model for energy-efficient design must be analyzed to establish the mapping between the IFC entities and the IDF entities in the corresponding models. According to the analysis, a mechanism for the transformation from IFC data to IDF data was established based on the two models.

The mechanism consists of several key algorithms. In this paper, the transformation of the geometry information is focused because it is the most important and due to the limited space of the paper. In IFC data, the geometry information of the building elements and thermal zones can be expressed by various geometric modeling methods, e.g. solid model and surface model, while only surface model is used in the IDF data. Thus, the transformation can be divided into three key processes, i.e. generating a 3D surface model from the IFC-based 3D model, enclosing the 3D surface model to meet the specific requirements of IDF data, and calculating other IDF data like the internal/external attribute of boundaries. The relevant key algorithms will be introduced respectively in the following.

3.2 Generating 3D Surface Model from IFC-based 3D Model

The target of this process is to extract the 3D surfaces called feature surfaces from the 3D model of the building elements and spaces in IFC data to express the *BuildingSurface:Detailed* entities and the *FenestrationSurface:Detailed* entities in IDF data.

Usually, the centric surface of the 3D model is chosen as the feature surface, and the method is also employed in the samples of applying EnergyPlus. This method is simple and intuitive; however, three problems cannot be ignored. Firstly, the adjacent thermal zones are separated actually by the shared building element of certain thickness rather than directly contact with each other, thus this method changes the volume of the thermal zones. Secondly, the adjacent thermal zones do not share the same boundary but associate with two different boundaries on their shared building element. Thirdly, the transformation algorithms will be quite complex to handle various kinds of 3D models; especially the boundary-unclosed problem which will be mentioned below. In order to solve these problems, the algorithm of generating the feature surface from the IFC-based 3D model was established as shown in Figure 4.

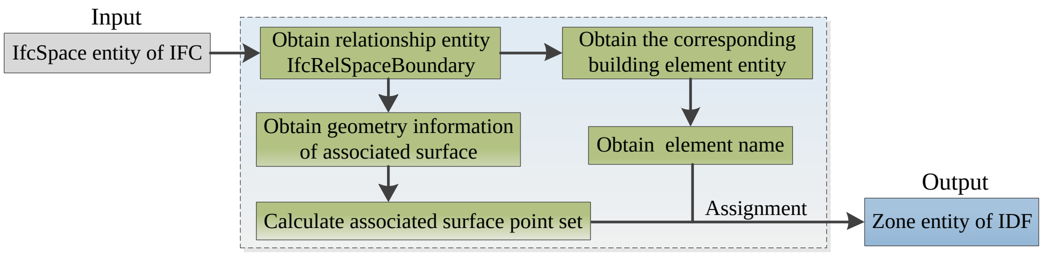


Figure 4 Algorithm for generating feature surface from IFC-based 3D model

In this algorithm, the associated surfaces of the surrounding building elements and space are chosen as the feature surfaces. The *IfcRelSpaceBoundary* entity which is shown in Figure 2 is not only used to express the relationship between the *IfcSpace* entity and the IFC building elements entities, but also used to describe the associated surface. Specifically, acting as the *"ConnectionGeometry"* attribute of the *IfcRelSpaceBoundary* entity, the *IfcConnectionSurfaceGeometry* entity and its subtypes define various 2D geometric modeling method, e.g. the subtype *IfcBoundedSurface* entity, which can be simply transformed into a point set to represent the feature surface.

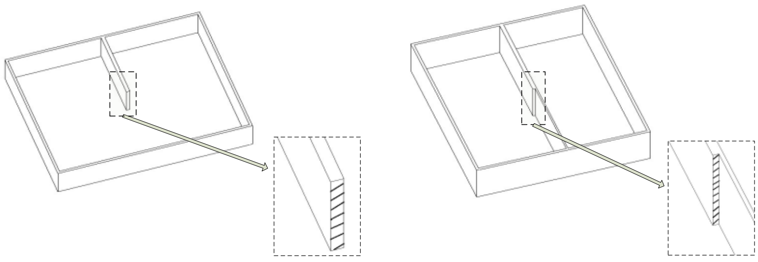
3.3 Enclosing 3D Surface Model

The generated 3D surface model by using the previous algorithm may not strictly meet the specific requirements of IDF data. A typical case is that the generated feature surfaces performed as the boundaries of a certain space may not form a closed space.

Theoretically, all the *IfcRelSpaceBoundary* instances of a certain *IfcSpace* instance should describe a closed space. However, according to our analysis on several IFC files, when the boundaries of walls are used, two kinds of boundaries are not included in IFC data so that the space is not closed. They are the side face of a wall which extends into a space (called case 1, as shown in Figure 5a) and the outside face of the connection part of two walls with different thickness (called case 2, as shown in Figure 5b). Accordingly, the algorithm of handling the unclosed space was established as shown in Figure 6. The algorithm contains two different parts as indicated by the rectangles area shown in Figure 6, i.e. the closure judgment of the space, handling case 1 and case 2.

Obviously, if a space is strictly closed, each boundary must have a common edge with another boundary. On the other hand, if an independent edge exists, the space must be unclosed. Therefore, as shown in Figure 6, the closure judgment algorithm is established by checking all the boundaries of a space and collecting the problematic boundaries and their independent edges.

The algorithm for handling both cases needs to build a new boundary in each gap. Firstly, the related two problematic boundaries of the gap, i.e. the hatched area in Figure 5 are found according to the two cases: in case 1 the boundaries belong to the same wall, while in case 2 the boundaries separately belong to two walls which have connections with each other. Then the new boundary is formed by using the independent edges of the two problematic boundaries.



(a) Case 1 (b) Case 2

Figure 5 Schematic diagram of special boundaries of unclosed space

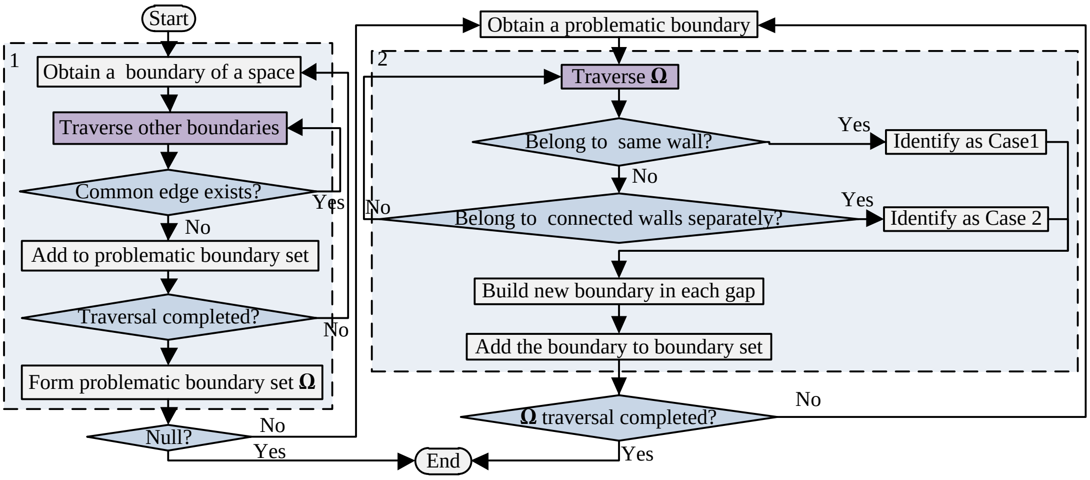


Figure 6 Algorithm for handling unclosed space

3.4 Judging if Boundary is External or Internal

In addition to the above geometry information obtained, the IDF format requires to clarify if a boundary is internal corresponding to the internal wall or external corresponding to the external wall. This attribute of boundary is judged by using an algorithm based on the IFC data, as shown in Figures 7 and 8.

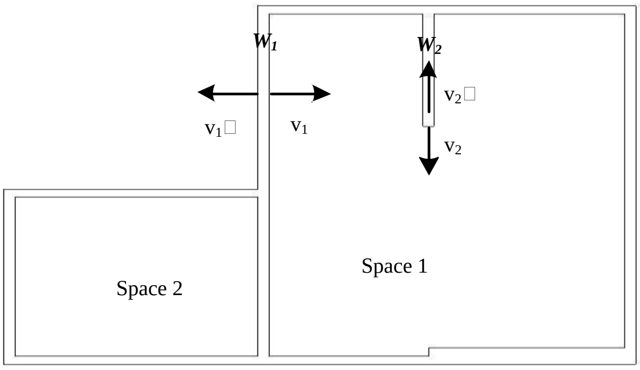


Figure 7 Example of internal and external boundaries

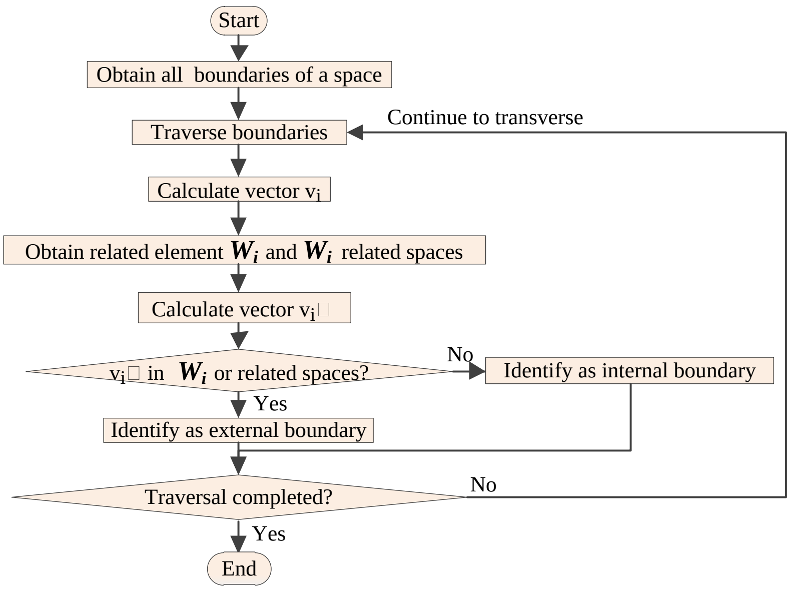


Figure 8 Algorithm for judging internal/external attribute of boundaries

The algorithm is explained by using Figure 7 without losing generality. Firstly, the unit normal vector v_i of each boundary is calculated as shown in Figure 7 and its origin is set as the center point of the boundary. Secondly, vector v_i ' is calculated by translating the inversion of v_i by the thickness of the relevant wall $\boldsymbol{W_i}$ in the inverse direction of v_i, e.g. v_1 'against v_1 and v_2 'against v_2 as shown in Figure 7. Finally, judge if v_i ' is in the interior of $\boldsymbol{W_i}$ or one of the spaces related to $\boldsymbol{W_i}$ by the *IfcSpaceBoundary* instances: if so, it is identified as an internal boundary; otherwise, it is identified as an external boundary.

4. APPLICATION AND VERIFICATION

The transformation mechanism and key algorithms described in this paper have been implemented in *BIM-EnergyDesign* which is a prototype of BIM-based energy-efficient design software of buildings developed by our research group. The main interface of the software is shown in Figure 9. The software is compliant with the "*Chinese Energy-Efficient Design Standards of Public Buildings*" which is the mandatory specification of the energy-efficient design of buildings in China. C++ language is used as the programming language, and the IFC Engine DLL as a toolbox to parse the IFC file when the software is developed.

BIM-EnergyDesign has been applied in the energy-efficient design of a real project. The results show that the established mechanism and algorithms can quickly and accurately implement the transformation from IFC data to IDF data for energy-efficient design. By reducing the manual work on inputting IDF data to prepare the building model, the efficiency of the energy-efficient design is improved significantly.

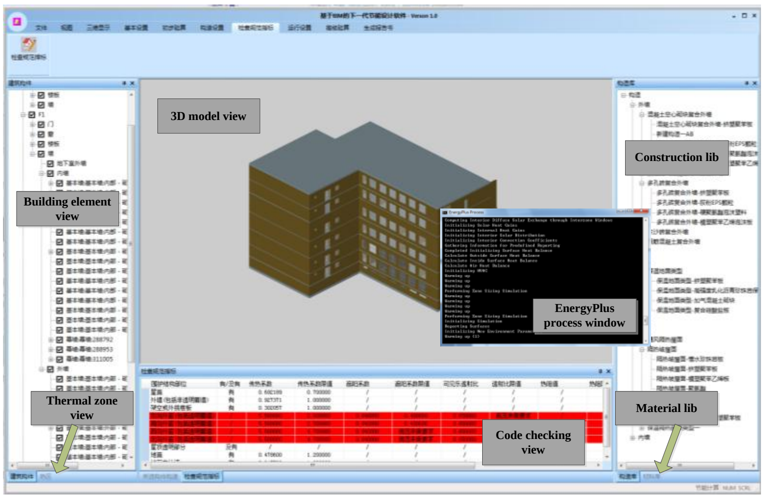


Figure 9 Main interface of *BIM-EnergyDesign*

5. CONCLUSION

BIM-based energy-efficient design software of buildings can directly use the computable and reusable information in the BIM-based design result, thus can greatly improve the efficiency of the modeling work of the energy-efficient design of buildings. In this paper, the information requirement model for energy-efficient design of buildings was configured, and through analyzing the IFC standard and the IDF format, both the IFC-based information model and IDF-based information model for energy-efficient design were established. Then a mechanism for the transformation from IFC data of design results to IDF data was developed. A prototype software application has been implemented and applied successfully in a real project in order to verify the feasibility of the mechanism. This study has laid a sound foundation for the development of BIM-based energy-efficient design software of buildings.

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