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BIM-based real time building energy simulation and optimization in early design stage

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Abstract: Increasing requirements of sustainability has prompted architects to pay more attention to the energy performance of their design. The design decisions, such as building form, orientation, window size, and construction materials, made in the early design stages have the significant impact on the building energy performance. However, architects who has limited knowledge of energy modelling usually suffer from selecting and using the common building energy simulation tools. Consequently, building energy simulations are rarely used in the early design process. It is imperative to develop a tool integrated with the design tool to help architect to understand the effects of various design strategies on building energy performance. Fortunately, the simplified building energy calculation method and Building Information Modelling (BIM) provide an innovative approach for architect. In this paper, a BIM-based real time building energy simulation and optimization tool is proposed and developed based on quasi-steady state method, Revit API and Dynamo, which can assist architects to optimize the building form, building orientation and window to wall ratio (WWR) based on building energy performance in the early design stage to provide better strategies for buildings energy efficient design.

Keywords: Early design stage, BIM-based building energy simulation, Design optimization, Revit.

1. Introduction

The concept design stage, also called early design stage, is an especially crucial period for entire building design, when the project goals, design requirements, site development, initial architecture concepts, etc. are analysed and determined [1]. Building energy performance is largely impacted by the early design decisions. For instance, the building energy conception could be reduced by 30-40% without any additional cost if the building shape and orientation are well designed[2]. Many researchers claim that the building performance simulation tools should be integrated into the early building design stage to assist the designers to obtain high performance buildings [2-4]. The application of building energy simulation tools for concept design is a typical example. To achieve the greatest possible energy saving for buildings, building energy simulation should be imbedded into the early design stage. Design decisions on the building form, orientation, window to wall ratio, and construction materials are generally made during this stage and can have a profound impact on how the building will perform [2]. However, building energy simulation tools are rarely used in the early design stage in practice. The reasons include that the conventional building energy simulation is mainly used to perform compliance check for green building rating and to predict the building energy conception after building design [4]; building energy simulation is a costly and time-consuming process [5]; most of the current building energy simulation tools are inadequate, user hostile and too incomplete to be used by the architect (who is the main performer of the concept design) during the early design stage [2]. In addition, the architects prefer to explore “what if” scenarios and evaluate a



number of design alternatives in quick way, but the common building energy simulation tools may take between 20s and 5min for one time simulation depending on the building size on a standard computer [6]. Usually, the concept design decisions are mainly determined by the architects based on their prior successfully experience in design energy efficient buildings, rule of thumb and the regulation compliance, rather than energy performance feedback from the building energy simulation tools [5]. Consequently, building design are usually far from the optimized design. Many researchers were conscious of the absent of the building energy simulation in the early design stage, and they developed some building energy simulation methods for the early design stage. Ma and Fukuda [7], Ladybug [8], and Jakubiec and Reinhart [9] provided methods to evaluate the building energy performance in the early design stage with the purpose of minimizing the total energy consumption by using Rhino conjunction with Grasshopper. Negendahl and Nielsen [3], and Ahuja, et al. [10] evaluated the energy flows in a building at the macro level by using the quasi steady state method for the building concept design. Mengana and Mousiadis [11] utilized the visual programming tool of Dynamo together with design tool Autodesk Revit and Green Building Studio to investigate the different energy possibilities and outcomes during the early design stage. Carlos and Nepomuceno [12] presented a simpler methodology in the form of a spreadsheet for the energy analysis in early design stage. It This project is going to develop a BIM-based real time building energy simulation method for architect using in the early design stage for better energy efficient design in buildings.

2. Methodology

The proposed BIM-based building energy simulation and optimization system adopts the monthly quasi-steady state calculation method, according to BS EN ISO 52016. The quasi-steady state model applies aggregated transmission, ventilation, internal and solar heat flow based on average internal and external temperatures, to estimate the monthly heating and cooling demands. The calculation of the monthly energy need for heating and cooling is assumed without the influence of a specific choice of technical building systems by using standard indoor environment condition. This is the consideration for that the actual systems are absent or undersized in early design stage. The proposed BIM-based building energy simulation and optimization system is developed based on Revit Platform API and Dynamo BIM. In this paper, the customized Revit API is used to extract project data for energy calculation and analysis, and generate reports within Revit User Interface (UI) by Visual C#. The visual programming of Dynamo enables the users to create the customized program by manipulating the Dynamo's nodes graphically rather than by specifying them textually. The Dynamo program is designed to assist the user to modify the building model quickly and efficiently in this paper. The general working process of the proposed BIM-based building energy simulation and optimization system is presented in the Figure 1.

Energy demand for heating and cooling a building is given by:

$$Q_{H,n,an} = \sum_{m=1}^{12} Q_{H,n,m} \quad (1)$$

if $\gamma_{H,m} \leq 0$ and $Q_{H,hg,m} > 0$:

$$Q_{H,n,m} = 0$$

if $\gamma_{H,m} \leq 0$:

$$Q_{H,n,m} = 0$$

else:

$$Q_{H,n,m} = Q_{H,ht,m} + \eta_{H,hg,m} Q_{H,hg,m} \quad (2)$$

$$Q_{C,n,an} = \sum_{m=1}^{12} Q_{C,n,m} \quad (3)$$

If $(1/\gamma_{C,m}) > 2$:

$$Q_{C,n,m} = 0$$

else:

$$Q_{C,n,m} = \alpha(Q_{C,hg,m} + \eta_{C,ht,m} Q_{C,ht,m}) \quad (4)$$

where $Q_{H,n,an}$ is the annual heating demand (kWh), $Q_{H,n,m}$ is the monthly heating demand (kWh), $Q_{C,n,an}$ is the annual cooling demand (kWh), $Q_{C,n,m}$ is the monthly heating demand (kWh), $Q_{H,ht,m}$

and $Q_{C,ht,m}$ are the monthly heat transfer for the heating and cooling mode (kWh), $Q_{H,hg,m}$ and $Q_{C,hg,m}$ are the monthly heat gain for the heating and cooling mode, $\gamma_{H,m}$ and $\gamma_{C,m}$ are the dimensionless heat-balance ratio for the heating and cooling mode, $\eta_{C,ht,m}$ is the dimensionless gain utilization factor, $\eta_{C,ht,m}$ is the dimensionless heat transfer utilization factor, and α is the dimensionless reduction factor for intermittent cooling which is set as 1 in the proposed system.

The input for the monthly heating and cooling demands calculation consists of building geometry, climate data, materials of building fabric, and the basic building operation data. In the proposed BIM-based building energy simulation system, the building geometry is extracted automatically from the Revit architecture model by customized Revit API, mainly including the total exterior wall area, total exterior window area, the total area of different direction of exterior walls (e.g. south facing walls), the total area of different direction of exterior windows (e.g. south facing windows), total floor gross area, ground floor gross area, the perimeter of ground floor, total building volume, building orientation, and window to wall ratio (WWR). The output of the proposed BIM-based building energy simulation and optimization system consists of 3 parts, including general results, optimization results, and detailed results. The general results include monthly heating demand, monthly cooling demand, annual heating demand, annual cooling demand, and annual total energy demand. The optimization results are used to indicate the float of the heat and cooling energy consumption due to the change of window to wall ratio (WWR) and the building orientation. The proposed system is able to provide suggestions of optimized WWR, optimized building orientation, and optimized combination of average WWR and building optimization. For the users, who has relevant energy knowledge background, the system could also provide some results from the calculation process, such as heat transfer by ventilation and transmission respectively, internal gains, solar gains, heat balance ratio, etc..

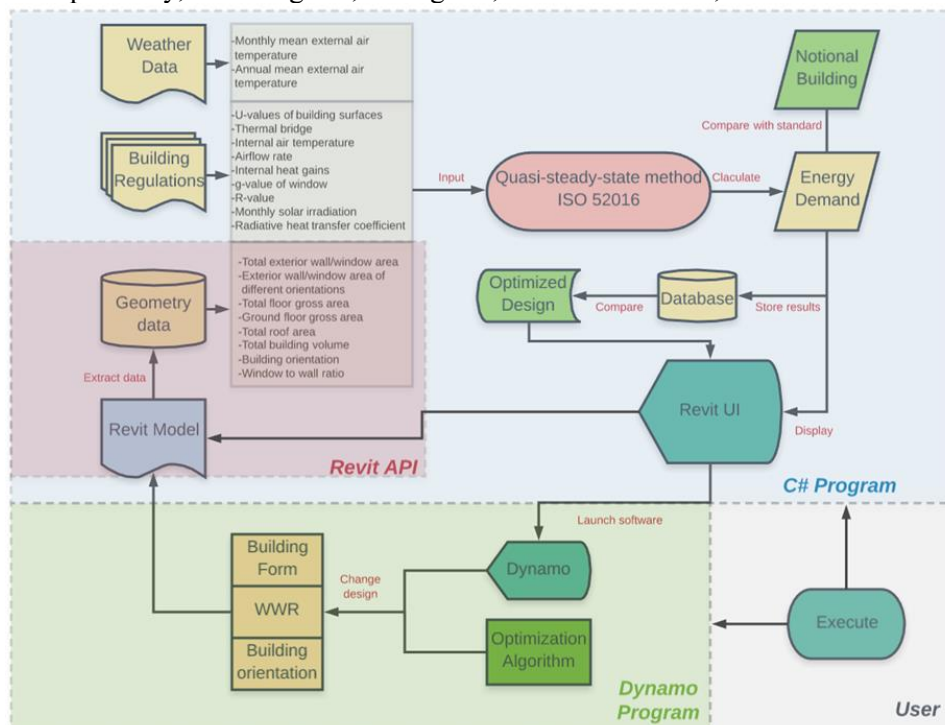


Figure 1. The general work process of the BIM-based building energy simulation and optimization system

3. Verification

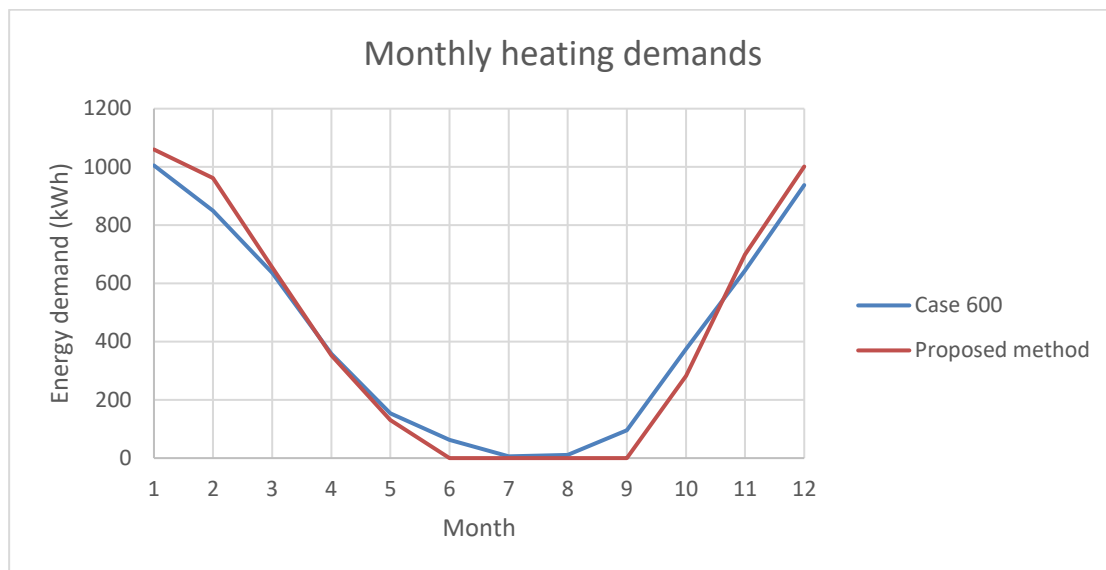


Figure 2. Verification of the heating demands

This is just an initial step of verification of the proposed system in terms of the heating demands. The results of the proposed tool are initially verified based on the BSETEST 600 case as described in ANSI/ASHRAE, which shows that the heating demands estimated by the proposed tool are acceptable. The proposed system would be further checked by the commercial building simulation software, e.g. IES-VE and EnergyPlus. More information about the verification would be provided by the future research.

4. Conclusion

A BIM-based real time building energy simulation and optimization tool is developed in this paper, which can assist architects to optimize the building form, building orientation and window to wall ratio (WWR) based on building energy performance in the early design stage. This approach is developed based on monthly quasi-steady state method, Revit API and Dynamo. The principle of the monthly quasi-steady state method based on BS EN 52016, the workflow of the Revit API developed by Visual C# programming, and the framework of the Dynamo program developed by visual programming are presented and introduced in this paper. The results of the proposed tool are initially verified based on the BSETEST 600 case as described in ANSI/ASHRAE, which shows that the heating demands estimated by the proposed tool are as expected. In the future work, the verification process would be conducted in detail, including the verification on heat transmission, ventilation heat transfer, internal heat gain, and the solar heat gain.

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