Integrated Design and a Holistic Building Energy Performance Simulation Method for Staged Practices

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Abstract. Building simulation activities in different design stages are reviewed and discussed. This paper categorized the major purposes of building energy simulation with various modeling purposes for informed decisions at different design stages. Limitations and challenges in building performance simulation are analysed. From the practitioner point view for building designers and consultants, this paper proposed a holistic design and simulation strategy aiming for improvement or solutions in building simulation consulting, to better refine the design and consulting within the integrated design practice process for improving building energy performance in design, operation and management as the ultimate goal.

1. Introduction

Building performance simulation has been increasingly utilized in the building design process. However, building performance simulation application is limited to the late design stages in most cases [1-2]. Meanwhile, in many design projects, building performance analysis and simulation is only an added instead of a built-in feature and function in the design process. Most of the projects engaged with building performance simulation activities have economic incentives, code compliance, tax deduction or green building certification purposes.

Compared with the traditional design process, the service of building energy performance simulation consulting has a big impact on the building energy design at different stages of design process and overall building energy performance, from conceptual design stage to building operation validation. While building simulation is gradually recognized by the building industry as the merits and necessary methods to facilitate building energy design and building energy performance, it is also facing challenges in practices and has limitations in its application.

2. Integrated design and building simulation

The traditional design process typically involves conceptual design, schematic design, design development, and construction design stages and the design team begins with architects to civil engineers, mechanical and electrical engineer and construction contractors. Achieving a good building energy performance at acceptable cost requires that designers have a good understanding of the impact of climate, building construction and elements, environmental control systems and occupant activities on energy performance [1], which is challenging because of

- the different roles of architectural, building service system design, and energy engineering in conventional design processes,
- the communication barriers between architects and engineers,
the complexities of the systems, and
the difficulties in carrying out adequate analysis early enough in the design process [3].

In order to enhance energy efficient design, several authorities [4-6] promote an integrated design approach that is widely cited in the literature [7-8]. This involves a holistic building design to increase responsiveness to the external climate and the needs of occupants. To improve the whole-building energy performance, the integrated design approach requires strategies such as: 1) bringing together different disciplines from the beginning of design process, 2) assigning a design coordinator to integrate competing decisions, and 3) incorporating building energy simulation into the design process [9]. Experience proves that the greatest energy savings can be achieved during the very earliest design stages when strategic decisions are made; through each subsequent design stage, the potential energy savings diminish, but the required design effort and costs rise [8-9]. In the integrated design process, building simulation plays a very critical role for improving building energy performance. There are some major issues associated with building simulation within the integrated design practice framework, including but not limited to: timeline in the design process, limitation of simulation tools, lack of enough design parameters, data input errors, effective results delivery, as well as the iteration from design changes.

To better serve the integrated design in practice, generally speaking, utilizing building simulation is categorized in the following purposes at different stages:

1) conceptual design: energy goal setting, building geometry and massing analysis, building HVAC system evaluation;
2) schematic design and design development: code compliance, energy saving strategy evaluation, payback analysis;
3) construction design: construction document review, energy model refinement, predicted energy savings, green building certification e.g. LEED energy modeling; and
4) verification: energy saving verification, calibrated simulation, energy audit.

3. Conceptual Design Stage
At the early design phases, the design information levels are low and design changes are frequently with high uncertainty risk and excessive amount of calculation [10]. Augenbroe [11] argues to better inform the early design, building simulation tools need to support: (1) A rapid evaluation of designs alternatives, (2) different types of decision making processes and (3) designers’ ability to solve nonlinear and multi-criteria problems. Struck [12] supplements that building simulation tools must be flexible and fast enough to adapt to innovative design concept and to fit different information levels for conceptual building and system design. During the conceptual design stage, the unknown factors and uncertainties are very high as there are many impact factors besides building energy performance. At this stage, it is critical to setup an energy performance goal with the building owners and design team, either use energy use intensity goal or energy saving goal compared with the code level benchmark. With the energy setting goal, the building energy performance will have much more influence on the team design strategy selection and decision. For example, with an aggressive LEED Energy and Atmosphere Credit 1 energy goal setting, the design team will have an obligation to achieve the energy saving goal and thus is inclined to choose energy efficiency design strategies.

At the conceptual design stage, two important analyses are important: building massing analysis and HVAC system analysis, corresponding to building design and system design. The massing analysis is considered as the very first step in reducing possible building energy use. In architectural design, the massing options usually are not as simple as rectangular, “T” shape, “L” shape, “+” shape and etc., as we have seen in most simple massing analysis. In the cold climate, a building with less envelope area will have a less heating load. However, the total building energy use may be inter-impacted by the building type, HVAC system selection, and daylighting possibility. An interlock analysis is often required to determine the combination for the lowest building energy intensity option. In building performance simulation practices, the most annoying part for simulation energy modeller
is the iteration changing of the building floor plans, as this will result in the changing of zoning and HVAC system design, often causing a simulation model start from scratch.

Some research [10] presents the application of multi-objective genetic algorithms for holistic building design that considers multiple criteria at the conceptual design stage. However, in design practice, adopting this application of algorithms may bring barriers to building energy performance. From the practitioner point of view, we proposed a built-in step with massing analysis in the model for projects with energy performance simulation needs at the conceptual design phase. This massing analysis will help the integrated design team identifying the possible energy performance pros and cons of combination of building design and system design, as well as help identifying the possible design and solution at later design stages.

Meanwhile, the development of computing capability and building performance simulation technologies and tools facilitate the application of massing analysis combined with daylight and HVAC analysis at the conceptual design stage. For example, the Rhino + Grasshopper modeling and simulation platform [13] facilitates the use of the machine intelligence to more effectively utilizing different simulation tools for obtaining optimized building performance results.

4. Schematic Design and Design Development

This is the design stage which most building energy simulation activities start at and fit in. Different from the conceptual design stage, at the schematic design stage, building massing geometry and floor plans usually have been decided and building HVAC systems also have been proposed, so more detailed modeling of building energy performance is possible. At the schematic design stage, many very specific design parameters, such as fan pressure drop and pump head may still be unknown, but the use of default values, code level sizing values or empirical values should be the feasible and reasonable solutions.

While in the design development stage, most design parameters should be available to the energy modelers and simulation model inputs generally should be design parameters. On one aspect, the design development energy modeling is the refined or adjusted modeling of the schematic design modeling. The transition from schematic level to the design development level should be smooth and in-depth process. On the other hand, the design development modeling could be a redo of the schematic design modeling from scratch with the design changes happened from the schematic design to design development stage. A significant floor plan arrangement change in most times is the worst case as all the previous modeling works at the schematic design stage is not be of value anymore and a new simulation model from scratch maybe required. Unfortunately, lots of design changes happen at this transition stage due to various reasons such as budget cuts or design review feedbacks. As usually the schematic design modeling is much more detailed and complicated than the conceptual design modeling, the modelers have to put much more time and efforts into this stage. Design is a dynamic process and requires interactions among team members. This puts forward the requirements of energy performance modeling adaptive to the design modifications.

As currently in the market there is no single simulation program able to handle the massive design changes, especially the design floor plan modifications which eventually change the zoning and HVAC configurations, a reasonable but practical solution will leave the very detailed modeling at the later design development stage to adapt to the possible architectural design changes. At the schematic design stage, detailed model inputs would be focused on the neither building floor plan nor the HVAC systems aspects. The detailed input parameters include:

- building operation schedules,
- building construction materials, and
- internal loads such as equipment intensity and schedule.

From the designer perspective, significant floor plan changes could be largely reduced with the massing analysis performed at the conceptual design stage, design options provided for evaluation, and thus a comparatively better option can be selected or adapted from previous design options. On the other hand, this approach not only provides more energy saving possibilities, but also proves the
effectiveness of integrated design process, which puts more efforts at the earlier stage and can largely reduce the efforts of redoing activities at a later stage.

At the design development stage, energy saving strategies usually are analysed and evaluated with the detailed design parameters. Usually a code level baseline model is created to evaluate the energy saving possibilities of each strategy. This is the design stage that request detailed design information. At this stage, the interaction and coordination between the design team and energy modelers are very frequent with the required data for the energy model inputs. Meanwhile, any design change which may affect the energy model may need to be updated for the modeller in time.

In the design development stage, a list of energy saving measures can be evaluated from the building envelope configuration to HVAC system selection to specific products or controls. Each strategy can be modelled individually to evaluate the energy saving possibility and meanwhile it is easier to check the results and inputs for possible errors as only one variable is presented each time in the simulation model. This process presented the good opportunity for the quality control of modeling.

As most of the design details are available, a simple cost payback or life cycle cost analysis can be conducted to provide more informed decision for the building owners and design team. The energy saving strategy can be integrated into the design drawing before the construction design. Simulation analysis results with individual strategy saving possibilities and simple payback for each strategy are very beneficial to the owner and design team for decision making.

5. Construction Design

Usually a construction design document review is required to make sure the design includes the energy design features and measures at the construction design stage. At the same time it is a quality control process to check the energy model inputs corresponding to the design. In the construction design (CD) stage, the combination of various energy saving strategies can provide a map showing the energy saving range relative to the code level baseline. For the LEED energy simulation work, the energy model is based on the construction design document. As the LEED modeling does not require the energy modeling involvement in the previous stages, a direct LEED modeling will not provide the chance for design team to revise and refine the design for better building energy performance, as most design has been fixed the chances to improve building energy performance at the construction design stage are very limited. The LEED model is primarily acting as document modeling tool instead as the measure to improve energy design and building performance in most cases. Some building simulation practitioners have realized this drawback and proposed earlier energy modeling activities involvement at the earlier design stages in the LEED modeling [14].

From the simulation quality control perspective, if a modeling process begins with the CD drawing stage, it is not beneficial to improve the quality of simulation models as all the detail inputs have to be entered in the simulation model at the same time and this could largely increase the model input error chances. Energy saving strategies include measures from building envelope, lighting, HVAC system and controls. As various energy saving strategies and inputs are combined in the same model, it will be difficult to find out whether the final results are the real representation of design strategies and identify the possible errors in the model. In a staged modeling process, the model begins with the most important features or factors of the design and the detailed information of each strategy can be gradually entered, thus this process can reduce the possible inputs errors. At the final modeling stage the model inputs has been screened at previous stages and provide much improved quality control for the simulation model.

Simulation model information extract is one important aspect of simulation quality control. The model information extracted from the models can be used to establish model database for the quality control of future model results. This can provide empirical validation of simulation model. The major information exacted from the model includes but is not limited to:

- building information: city, building type, building floor area, major space types and areas, building levels, window to wall ratio, roof and wall U-values;
lighting and equipment information: lighting power density, lighting operating hours, equipment load density, operating hours;

- HVAC system information: heating system, cooling system, air distribution system type system, outdoor air flow rates; and

- energy results: energy end use intensity for heating, cooling, fan, pump, service hot water and total building energy use, peak energy use.

The data from the simulation provided approximation information of the building related to the energy part. With accumulated data, this will provide the database for benchmark and evaluate the building simulation results and thus a method of quality control of simulation models when monitored data are not available at design stages.

6. Verification Modeling

With numerous variables in the simulation model as well as complicated systems and time-varying operating patterns in the actual building, uncertainties exist in simulation. Simulation models will provide better quality data when calibrated using metered energy use data. The calibrated simulation model is especially important when used for evaluating energy conservation measures (ECMs). Either hourly or monthly data can be employed for calibration [15]. The US DOE measurement and verification guidelines (FEMP) [16] provide some options for measurement and verification of building energy performance. Option D is the calibrated computer simulation analysis method of measurement and verification, which is based on use of a computer simulation model calibrated with whole-building and end-use energy data [16]. The LEED EA Credit 5 provides the option for Measurement and Verification using the calibrated simulation model. The following data usually is collected and used besides the building design data:

- HVAC systems operation schedules,
- historical utility data for 12 months (energy use),
- hourly weather data for at least 12 months,
- lighting, plug loads and occupancy densities and schedules after occupancy, and
- information on indoor thermal conditions

With measurement systems, including building automation systems and data loggers, the building energy end uses and indoor temperature trends can be recorded. Using sub-meters to monitor energy uses in subsystems can provide additional information to evaluate individual system energy performance [17], monitoring energy end uses is rarely affordable [15], especially on an hourly basis [18].

Due to the complexity as well as time and efforts spent on the operation data collection, usually the verification stage modeling is not so frequently conducted. However, simulation models will provide better quality data when calibrated with metered energy use data. With field-monitored data and calibrated simulation models, designers can evaluate the effects of alternative design strategies, identify potential problems and solutions. This will be beneficial to the future projects.

On the other aspect, monitored building energy uses may also mislead the energy simulation data, especially when the actual building operation is not under normal or correct operation conditions, at which we often find big difference between simulated and monitored energy performance data. In this case, field monitored building end uses such as cooling, heating, fan, pump and etc., with sub-meters will facilitate the identification of the differences and eventually find the problem in the building operation and management.

7. Conclusion

This paper presents a holistic practice track that staged building simulation process is used to improve simulation model quality and overall building energy performance. Facing different limitations and challenges, from the practitioner point view, staged modeling, instead of one simulation model for all, can better refine the design practices for informed decisions and results
presenting. The holistic method of integrating building energy simulation into different design stages at which various design parameters are required for modeling. Within the holistic modeling process, various details of results should be presented at different stages for better fitting energy simulation purposes and results are presented in a timely manner and fit in the design process so as to facilitate the building energy performance design.

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