Building Energy Simulation In Practices With Integrated Design

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ABSTRACT
Building simulation activities in different design stages are reviewed and discussed. This paper categorized the major purposes of building performance simulation with various modelling purposes for informed decisions at different design stages. Limitations and challenges in building performance simulation are analyzed. From the practitioner point view, this paper proposed some possible measures aiming for improvement or solutions in building simulation consulting, to better refine the consulting and design practices for improving building energy performance.

KEYWORDS
Building energy simulation, Integrated Design, Practices, Design stages

INTRODUCTION

Building performance simulation has been increasably utilized in the building design process. However, in lots or design projects, building performance analysis and simulation is only an added instead of a built-in feature 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 traditional design process, the service of building energy simulation consulting has 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 improving building energy design and building energy performance, it is also facing challenges in practices and has limitations in its application.

SIMULATION WITH INTEGRATED DESIGN

The traditional design process typically involves conceptual design, schematic design, design development, and construction design stages and begins with architects to civil engineers, mechanical and electrical engineer and construction contractors. Achieving

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a good building energy performance at acceptable cost requires that designers have a good understanding of the impact of climate, building elements, control systems and occupant activity on energy performance (Clarke 2001).

In order to enhance energy efficient design, several authorities (NRCan 2006, CIBSE 1998) promote an integrated design approach that is widely cited in the literature (Grumman 2003). 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 (EDR 1998). 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 (Grumman 2003).

In the integrated design, building simulation plays a very critical role for improve 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, generally speaking, utilizing building simulation is categorized in several 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, LEED modeling; and
4) verification: energy saving verification, calibrated simulation, energy audit.

Conceptual design stage

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 (EUI) 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 goal and thus is inclined to choose energy efficiency strategies.

At the conceptual design stage, two important analyses are important: building massing analysis and HVAC system analysis. 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” shade, “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.

A mixed residential/office building in Minneapolis (ASHRAE Climate Zone 6A), Minnesota is presented in this paper as a study case. Four building massing options are proposed by the design architect for evaluation combined with two HVAC system options. A central system with packaged variable air volumes (PVAV) system and a distributed system with ground source heat pump (GSHP) system are analyzed with or without daylighting in perimeter offices and corridors. In total, 16 different combination scenarios are provided for analysis and comparison, which take into account the most important factors at the conceptual design stage.

As can be found in the simulation results (Table 1), massing options 3 and 4 has similar EUI with the distributed HVAC system when daylighting control is not presented. But option 3 has much lower EUI than option 4 with the packaged VAV (PVAV) system. Meanwhile, with dimming daylighting control presented, the lowest EUI is Option 4 with the distributed ground-source heat pump system, but Option 3 has the lowest EUI with packaged VAV system. This case study illustrated that the impact of building massing, HVAC system and daylighting on energy performance are interactive and the analysis should take into account these factors.

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 plan 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 work at previous design stage is not be of value any more 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 feedback. 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 and nor the HVAC systems aspects. The detailed input parameters include: 1) building operation schedules, 2) building construction materials, and 3) 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 analyzed 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 modeler 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 modeler in time. At 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 modeled 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.

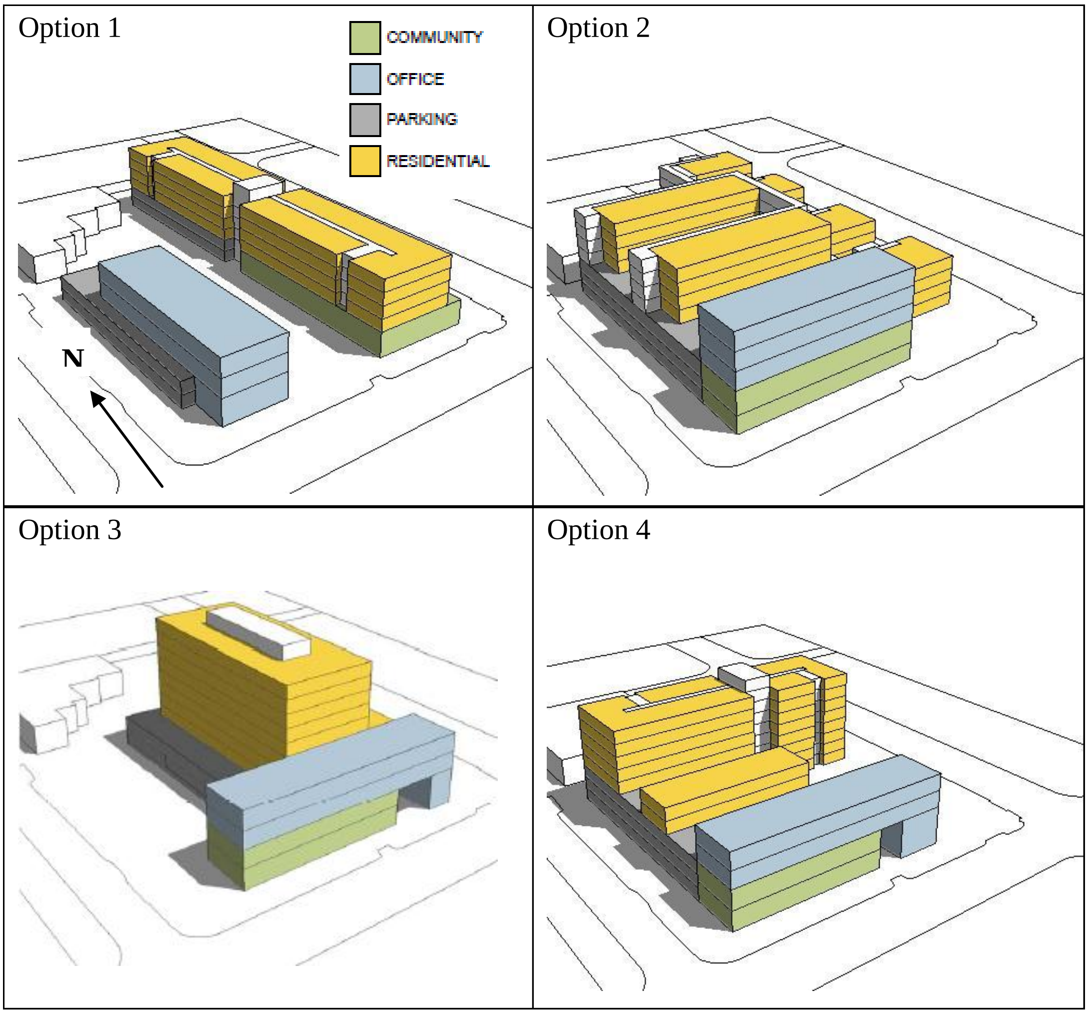

Figure 1. *Case Project with Massing Options (Source: Mithun Architects)*

Table 1. *Simulated Results with 4 massing options*

Strategy	Itemized KBtu/sf					Total
	Heat	Cool	Fan/ Pump	Lights	Equip	KBtu/sf
Massing - GSHP - No daylighting - Option 1; GMAV1	3.4	5.6	13.9	10.8	9.2	42.83
Massing - GSHP - No daylighting - Option 2; GMAV2	4.3	5.6	10.8	10.9	8.2	39.80
Massing - GSHP - No daylighting - Option 3; GMAV3	2.8	4.9	11.9	10.6	8.7	38.96
Massing - GSHP - No daylighting - Option 4; GMAV4	3.7	5.5	10.3	10.6	8.8	39.00
Massing - PVAVS - No daylighting - Option 1; GMAS1	30.6	3.5	5.4	10.8	9.2	59.39
Massing - PVAVS - No daylighting - Option 2; GMAS2	33.7	4.9	4.5	10.9	8.2	62.31
Massing - PVAVS - No daylighting - Option 3; GMAS3	25.8	3.0	4.6	10.6	8.7	52.59
Massing - PVAVS - No daylighting - Option 4; GMAS4	31.8	5.7	4.3	10.6	8.8	61.21
Massing - GSHP - With daylighting - Option 1; GMAV5	3.5	5.3	13.9	9.5	9.2	41.34
Massing - GSHP - With daylighting - Option 2; GMAV6	4.5	5.2	10.7	9.2	8.2	37.86
Massing - GSHP - With daylighting - Option 3; GMAV7	2.9	4.8	11.9	9.9	8.7	38.05
Massing - GSHP - With daylighting - Option 4; GMAV8	3.9	5.2	10.3	9.2	8.8	37.27
Massing - PVAVS - With daylighting - Option 1; GMAS5	31.4	3.4	5.4	9.5	9.2	58.77
Massing - PVAVS - With daylighting - Option 2; GMAS6	34.6	4.8	4.5	9.2	8.2	61.30
Massing - PVAVS - With daylighting - Option 3; GMAS7	26.1	3.0	4.6	9.9	8.7	52.17
Massing - PVAVS - With daylighting - Option 4; GMAS8	32.6	5.5	4.3	9.2	8.77	60.28

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 CD design 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 facilitate 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 modeling is primarily acting as document modeling tool instead of the measure to improve energy design and 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 (Sheffer 2011).

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
- 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.

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 (IPMVP 2002). The US DOE measurement and verification guidelines (FEMP) (2000) 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 (DOE 2000). 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:

- building 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,
- 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 (Ni Riain *et al.* 2000), monitoring energy end uses is rarely affordable (IPMVP 2002), especially on an hourly basis (Novoselac and Srebric 2002). 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 very beneficial to the future projects.

DISCUSSION

The building simulation begins at the design development or construction design stages in the traditional design process. At this stage, there are limited feedback and impact from performance simulation results on the design as most design features have been fixed. If the goal setting is to advance energy performance beyond the conventional design, usually a integrated design process is required and building energy design and analysis are involved in the earlier design stages. The early participation brings more interaction between the design team and energy modeler. Meanwhile, as different stages will requires different information for decision making, different results needs to be provided for the analysis and thus different simulation tools may be necessary. All these increases the complexity of building simulation and the time and efforts spent in the design process. As discussed in the building simulation user group, not all the building design projects have the same standards for the building energy performance. So it is important that the building owner and design team set the goals for energy performance. The track presented in this paper generally aims for aggressive energy conservation goals.

CONCLUSION

This paper presented a track that building simulation is used to improve overall building energy performance during the different stages of building design, within the integrated design framework. Facing these limitations and challenges, from the practitioner point view, this paper proposed some possible measures for the improvement or solutions in building simulation consulting, to better refine the integrated design practices. The paper discussed the effective track of integrating building energy simulation into different design stages at which results can be presented in a timely manner and also fit in the design process to have positive impacts on the design process, improving building energy performance.

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