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APPLYING SIMPLIFIED SIMULATION TOOLS AND TECHNIQUES TO THE DESIGN OF NEW COMMERCIAL BUILDINGS

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ABSTRACT

Despite the potential benefits of improved energy efficiency and enhanced comfort for eventual occupants, most architects and engineers resist using computer simulation methods in the design of new buildings. Issues of program complexity as well as the time required to produce a simulation have kept many otherwise progressive architecture and engineering firms from embracing this powerful analysis tool. This paper describes how powerful lighting and energy simulation tools in conjunction with simplified strategies can improve building performance right from the start.

INTRODUCTION

Building simulation program capabilities have reached an impressive level in recent years, and timesaving Graphical User Interfaces (GUI) have made these powerful tools available to a broader user group. That said, simulation tools are still not often used during the design of new buildings because:

(1) The perceived cost and time required to develop a model is prohibitive in the eyes of most owners/developers;
(2) The substantial benefits that can be reaped from simulation efforts in the earliest phases of design are not well recognized;
(3) True expertise with such tools is still limited to a relatively select group of consultants and researchers.

While it is true that certain energy-related design decisions are best addressed with a detailed simulation model that accurately depicts the arrangement of internal and external walls, windows and thermostatic zones, there are a great number of issues that can be adequately addressed with a simplified model. Such a model - which uses simplified thermal zoning and load assumptions - can be used to compare the performance of specific energy efficiency strategies, and to help formulate the conceptual design of architectural, mechanical, and electric systems. In addition, existing members of the design team (or the owner/developer, for that matter) can put the new breed of simplified, intuitive programs to good use evaluating key energy decisions - without the need to hire a simulation consultant. It is often the case that a few simple energy simulations performed early in the project planning process can establish building characteristics – building form and orientation are examples – that embody far greater life-cycle energy savings than any other single efficiency measure.

Oftentimes, designers argue that there is not enough detailed design information available to effectively employ simulation in the earliest phases of the design process. To the contrary, though, there are many design questions that can be effectively answered with reasonably simple models early in the design process. Early analysis of the performance of different building forms and orientations, floor-to-floor heights, and daylighting strategies can lend focus to conceptual design efforts. This, in turn, leads to a design that is inherently more efficient from the start – and which will require fewer corrective actions during later design stages to atone for poor decisions during the conceptual design phase.

This paper presents a discussion of the type of design decisions that can benefit from simplified simulation, and how such methods were applied to design of a new 56,000 M^2 owner-occupied office building in metropolitan Los Angeles, California.

TIMESAVING SIMULATION TOOLS

Most energy simulation programs divide input commands into groups corresponding to the program's particular sequence of calculations. DOE-2.1E, for example, divides input into four discrete command groups:

- LOADS: Internal and external sources of heat loss/gain imposed on the building;
- SYSTEMS: Distribution of thermal energy to meet heating and cooling requirements;
- PLANT: Energy conversion equipment to meet heating, cooling, (and sometimes power) requirements;
- ECONOMICS: Tariff structures for purchased fuels to meet building loads.

Before the advent of GUI-based simulation programs, a rule-of-thumb for budgeting time for developing a model was that each input section took about 50 percent as much time as the previous one to develop. For example, "SYSTEMS" inputs would take half the time required for "LOADS" inputs, "PLANT" inputs would take half the time of "SYSTEMS", etc. This rule demonstrates that developing "LOADS" inputs – the configuration and orientation of exterior walls, roofs, windows, as well as internal load assumptions – typically consumes more than 50 percent of the total effort (Table 1).

DOE-2.1E Simulation Input Type	Percent Total Project Time Required	Typical Time Requirement
LOADS	53%	25-50 hours
SYSTEMS	27%	13-25 hours
PLANT	13%	7-13 hours
ECONOMICS	7%	3-7 hours
TOTAL	100%	48-95 hours

Table 1: Typical[1] time requirements for DOE-2.1E simulation inputs using non-GUI program Interface

In the past, much of the time required to develop a simulation was devoted to typing in text commands using a word processing program. The two problems with this approach are that it is slow and that it can lead to program syntax errors due to typographical mistakes. Typical DOE-2.1e input files can encompass anywhere between 1,000 to 10,000 lines of code, depending on building complexity and programming style[2], so even a quick typist can expect to spend a substantial amount of time keying in the design information. What's more, it is not uncommon for the first attempt to compile and execute such an input file to result in hundreds of errors due to both syntax errors as well as inadvertent omission of required inputs. The number of errors drops off rapidly as individual errors are corrected and the associated downstream errors are indirectly corrected. Nonetheless, this is a time-consuming task.

Simulation programs with GUI capabilities can significantly reduce the time required to develop a preliminary model. Most GUI-based programs offer a selection of pre-defined building forms (rectangular, 'T'-shaped, 'L'-shaped) whose dimensions can be tailored to suit project-specific requirements. Predefined forms substantially reduce the effort required for LOADS inputs.

[1] Range of time requirements based upon authors' experience providing simulation services for commercial new construction on a consulting basis over the past ten years.

[2] There are vast differences in programming style among DOE-2 users. While some opt for fully-commented inputs and avoid the use of abbreviations, other users strive to make their code as compact as possible by abbreviating commands, typing multiple commands on a single line, and minimizing comments and other notations.

Some GUI-based programs also offer templates for other program inputs based upon the type and age of a facility. For example, a program called VisualDOE™ allows users to specify the age and overall level of energy-efficiency for a building, and the program then provides reasonable default values for lighting and HVAC systems. Another program called eQUEST™ produces detailed assumptions about space utilization and occupancy schedules based upon the type of building (office, school, retail) that is modeled.

These features make it possible for novice users to create useful models and conduct relevant analyses of design alternatives. Because much of the expertise required to perform simulations is related to developing proper thermal zoning and load assumptions, GUI-based programs with such capabilities built-in can move simulation within reach of a far larger user base. In the past, it was usually the case that a simulation consultant was hired to perform all simulation activities. The user-friendly programs that are currently available, however, make it possible for design teams to perform simple simulations without such a consultant.

Moving preliminary simulation activities from the realm of specialized consultants to that of the design team can play an important role in fostering an integrated design process; if designers (through their simulation efforts) are aware of the energy and comfort implications of different architectural and building system alternatives, they are more likely to make decisions that will enhance performance of the building as a whole, instead of just optimizing specific systems. The detailed models that are developed during the design development and construction document phases will still likely require a simulation consultant, but by that time the design team should have used their basic models to develop an efficient basis of design. Properly applied, simple building models bypass the substantial conflict that occurs when detailed simulations identify effective design alternations that cannot be implemented because the project is in the final design stages.

Between the predefined-but-customizable building forms and context-sensitive assumptions for lighting, HVAC and other inputs, GUI-based simulation programs allow a simple model to be developed in less than one hour in most cases – obviously a substantial improvement over the time requirements for developing a more detailed model that are presented in Table 1. While such a model obviously has its limitations, it can be used to provide reasonable predictions of overall energy use, heating and cooling loads, and quantified performance predictions for energy efficiency measures.

LIMITATIONS AND OPPORTUNITIES

Predefined building forms are perhaps the greatest timesaving feature of GUI-based programs. Unfortunately, they are also one of their greatest limitations. If a particular building shape of interest is not available, the user must pick one from the available list that most closely resembles the desired building shape. In some instances, this can lead to misleading results.

An effective way to get around this limitation is to use a program that can accept properly formatted electronic geometric data to create the proper building shape and thermal zoning. For example, many architects use 3-D modeling software tools such as form-Z™ (reference information for all software can be found at the end of this paper) to develop massing models of a proposed building that allow their client to visualize different building configurations (often called schemes, see Figures 1 and 2). Most of these programs can export their geometric input in the industry-recognized Document Exchange Format (also known as DXF format). A DXF file can be imported into a computer-based drafting program such as AutoCAD™ (Figure 3), to which the user adds additional information to represent the desired thermal zoning for the proposed building to create a two-dimensional zoning diagram for each representative floor (Figure 4). This zoning diagram can then be exported once again in DXF format, and read directly into certain GUI-based simulation programs. VisualDOE™ is an example of a program that can accept zoning information from a properly formatted[3] DXF file.

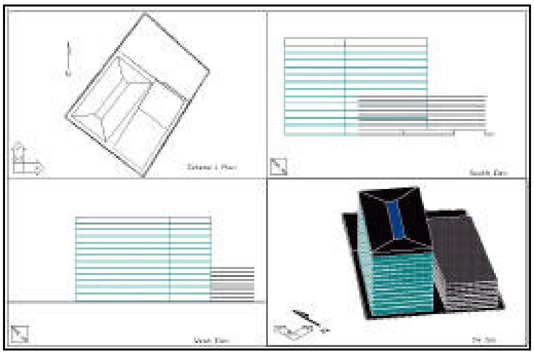

Figure 1: Scheme 1, the "baseline" massing scheme for a proposed 56,000 M² commercial office building in Los Angeles, California, USA.

[3] There are specific conventions that must be followed in order to make this work. For example, each zone must be a self-enclosed polygon; the program cannot interpret "shared" lines separating two thermal zones.

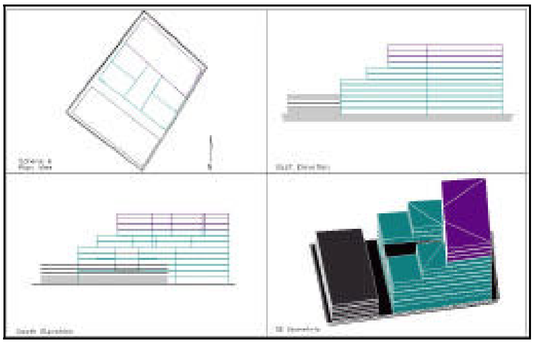

Figure 2: Scheme 6, one of approximately twenty alternative schemes for project shown in Figure 1.

While the zoning diagram shown in Figure 4 may appear exceedingly simple, it is appropriate for many early simulation activities because it acknowledges the thermal differences between perimeter and core spaces. Such a diagram does not speculate about the interior arrangement of offices, corridors, and unconditioned spaces because specific issues of space layout are not addressed by the architect and space planner until later in the design process. That said, it is essential to recognize that the arrangement of interior walls and partitions can significantly influence performance of certain energy efficiency measures. For example, a lightshelf design that is capable of directing incoming light 10 meters into the building (Figure 5) will not perform as predicted if the perimeter zones are eventually lined with private offices featuring full-height partitions that block daylight penetration only 3 or 4 meters in from the exterior wall.

It is also essential to understand the capabilities of various simulation programs to answer the design questions at hand. For example, even though some energy simulation programs can predict illumination levels resulting from incoming daylight, their algorithms are crude and do not account for many interior surfaces that intentionally or unintentionally redirect and block incoming light. As an example, the articulating glazing system and light shelf shown in Figure 5 cannot be accurately modeled using most energy simulation programs.

Data exchange between computer applications can streamline more than just energy simulation efforts. Lighting design programs such as Lumen Micro™ and Lightscape™ can accept data from a DXF file that in turn can be used to predict illumination levels based on natural light, artificial light, or a combination of the two. Certain Computational Fluid Dynamics (CFD) and nodal airflow programs can also accept DXF input.

Ideally, all simulation efforts performed during the conceptual design phase – be it energy, lighting, or airflow simulation - should be based on one consistent set of electronic geometric data. This has the two-fold benefit of (1) minimizing the time requirement to input redundant data into different programs, and (2) providing a consistent set of simulation results because all models are based on the same data. For the building form show in Figures 2 and 3, for example, it is likely that some simulation consultants would be inclined to manually input the building shape based on orthogonal positioning of the walls to simplify their inputs, instead of the slightly skewed shape that was conceived by the architect.

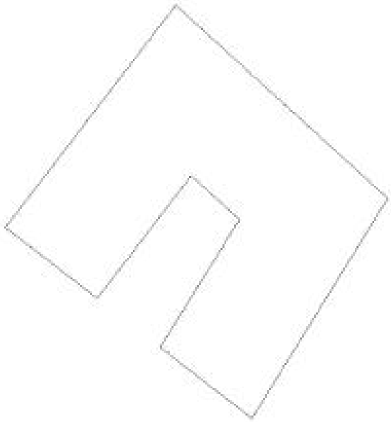

Figure 3: Imported geometric data for a typical floor of scheme 6.

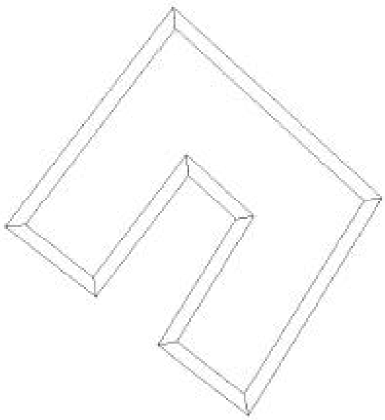

Figure 4: Typical floor plan for scheme 6 with five meter deep thermal zones along the perimeter.

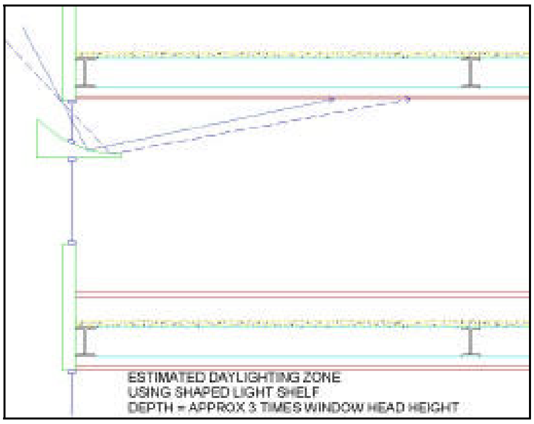

Figure 5: Floor-to-floor section of a proposed articulated glazing system and light shelf.

A final point to make about the value of using electronic geometric data is that it makes simulation possible (or at least useful) for complicated building forms. For example, during the design of the new Oklahoma City Federal Building[4], the proposed building form - which featured a number of unusual angles and an extensive curved element – was modeling based upon a DXF floor plan provided by the architect. Because of its complex shape, it is unlikely that any early simulation work would have been performed if the DXF approach were not available. As a result of some relatively simple simulations performed early on, however, many energy efficiency features were recommended for implementation – and the design consequences of certain features[5] were properly addressed right from the start.

The previous discussion assumes that the project architect has developed a massing model for the project using 3-D rendering software that has DXF export capability. For smaller projects that may not justify such efforts, preliminary building simulations will likely be based on one of the pre-defined building forms offered by most programs.

4 Located in Oklahoma City, Oklahoma, U.S.A., this building is the replacement for the Murrow building that was devastated by a terrorist bomb in 1994.

5 For example, the relative position of windows had to be changed to provide a proper window sill height when a 30 cm raised floor air distribution system was recommended for implementation.

CASE STUDY: CALTRANS DISTRICT HEADQUARTERS, LOS ANGELES, CALIFORNIA, USA

A simplified simulation strategy was employed during the conceptual design of a new 56,000 M^2 office building to be constructed in metropolitan Los Angeles, California. Energy and daylight simulation programs were used to influence the form, orientation, and specific building systems.

This building will house the employees of Caltrans District 7, the California State agency that is responsible for the design, construction, operation and repair of the extensive freeway system in the greater Los Angeles area.

The authors' firm worked closely with A.C. Martin Partners (ACMP) of Los Angeles, California to evaluate a number of alternate massing schemes for this project. ACMP was hired by Caltrans to develop the building design criteria with sufficient detail so it could be bid on a design/build basis[6].

This project had been initially budgeted based upon the "scheme 1" as depicted in Figure 1. The design team recognized that the rectangular form might be efficient from a construction cost standpoint, but that it left something to be desired from the perspectives of energy efficiency, functionality, and aesthetics.

ACMP developed about twenty different massing schemes for the project that would meet the project's space programming requirements. 3-D massing models for each scheme were submitted to the client for review. Based on this review, seven of the most promising schemes were evaluated using the DOE-2.1E simulation program. Because of the aggressive schedule for this project, the seven simulations had to be developed quickly. To facilitate this effort, ACMP provided the authors' firm with DXF files for the seven schemes to be analyzed. This information was subsequently used to develop thermal zoning diagrams using similar zoning criteria[7]

Each of the schemes was then imported into DOE-2.1E with identical wall and glass construction materials, as well as identical mechanical and electrical systems. Each model was then evaluated using an hourly weather file for Los Angeles to determine the amount of site energy, source energy, and operating cost for each scheme. As shown in Table 2, all but one of the schemes that were considered was found to be more efficient than scheme 1. Scheme 6 (Figure 2) was found to have the largest improvement in energy efficiency, with annual energy costs projected to be six percent lower than scheme 1. Based on this improved performance, as well as aesthetic and functional considerations, the team recommended that the client consider scheme 6.

The analysis then shifted to focus on building system improvements that could improve efficiency and comfort. The design team was interested in making the project extremely energy efficient, and as a result a number of aggressive load reduction and energy efficiency strategies were evaluated, including high efficiency lighting, daylighting controls, high performance glazing, underfloor air distribution, a high efficiency chiller plant, Thermal Energy Storage (TES), and a 500 kW photovoltaic array. Evaluation of these technologies concluded that peak electric demand could be reduced by 67 percent (Chart 1) if all measures were implemented, and that annual energy costs could be reduced by about 50 percent.

The design team recognized that the DOE-2.1E program was effective for modeling some, but not all, of the proposed measures. For that reason, it was decided that a daylighting analysis would be conducted in order to evaluate different glazing and solar control configurations. Again using geometric data in DXF format, models were developed of representative spaces when empty (Figure 6) and also with modular furniture installed (Figure 7). It was essential to model the furniture because the partitions between individual workstations would reduce daylight penetration.

Using Lightscape ™, we developed photo-realistic renderings to effectively convey our daylight analysis findings to project stakeholders. The value of effective visual presentation of performance for different light shelf configurations to non-technical members of the client group was immense.

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6 Design/build refers to a process where a team of designers and contractors is responsible for constructing a building that meets specific functional and aesthetic criteria outlined by the client, but where the design/building team is responsible for most of the detailed design work.

7 Individual perimeter zones were assigned based upon a 5 meter depth, with one zone per major exterior orientation.

As a result of the efforts of the design team, the client has requested additional project funding to accommodate all recommended technologies. Though it is not certain at this time whether the necessary funding will be obtained, the simplified simulation strategies employed for this project resulted in a number of essential features being integrated into the current design:

- The site plan now includes space for a one million gallon above-ground tank for the chilled water TES system.
- Floor-to-floor heights have been adjusted to accommodate the raised floor system, as well as pendant-mounted direct/indirect luminaries.
- Glazing positions have been adjusted to accommodate the raise floor system.
- The top level of the 1,000 space parking structure has been earmarked for a large photovoltaic array, along with the roof of the building.
- Modular furniture selections and positions have been recommended that feature lower partition heights perpendicular to the glass, in order to promote daylight penetration.
- Dialog between the design team and the client has begun to address other ways to maintain solar access for more building occupants.

Any one of these accomplishments would have been difficult or highly impractical to change later in the design process. Through the use of simple, time-efficient simulation strategies however the project team is considering these issues in the earliest phases of design when they are easiest to accommodate.

CONCLUSIONS

Because a typical building will consume many times its initial construction cost in energy cost over its life, it is essential to make informed design designs with regards to energy efficiency. Though it is unreasonable to treat the results of simplified simulations as absolute predictions of energy use, such tools can identify the relative differences in performance among alternatives under consideration with sufficient confidence to allow an informed decision-making process to occur.

SOFTWARE REFERENCES

For additional information about the software mentioned in this paper, please contact the following organizations:

AutoCAD, a popular computer-based drafting program, is available from AutoDesk, Inc. Their URL is http://www.autodesk.com. From this URL, you will be directed to a regional source for product support.

DOE-2.1E, an hourly building energy simulation program, is available from a number of sources. James J. Hirsch's version of DOE-2.1E (one of the most widely used versions) is available from http://www.doe2.com.

eQUEST, a simplified building energy simulation program, is available free-of-charge from http://www.energydesignresources.com.

form-Z, a 3-dimensional modeling and rendering program, is available automatic design systems, inc. (auto*des*sys, inc.). Program information is available from http://www.formz.com.

Lightscape, a lighting design program that produces photo-realistic renderings, is available from Discreet Software. Program information is available at http://www.lightscape.com.

Lumen Micro, a lighting design and analysis program, is available from Lighting Technologies, Inc. Program information is available at http://www.lighting-technologies.com.

VisualDOE is available from Eley Associates, 142 Minna Street, San Francisco, CA 94105, USA, phone 415-957-1977, fax 415-957-1381, info@eley.com, http://www.eley.com.

ACKNOWLEDGEMENTS

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Scheme #	Site Energy (Mbtu/yr)	Source Energy (Mbtu/yr)	Energy Cost ($/yr)	Energy Perf. vs. Scheme 1
1	67,561	143,030	$ 1,391,450	0%
2	65,313	139,983	$ 1,362,530	-2%
3	68,200	145,040	$ 1,408,277	1%
4	66,034	140,617	$ 1,369,789	-2%
5	64,325	137,942	$ 1,345,509	-3%
6	**61,592**	**133,851**	**$ 1,310,395**	**-6%**
7	65,120	139,548	$ 1,360,634	-2%

Table 2: Preliminary evaluation of seven massing schemes concluded that scheme 6 was the most inherently efficient selection.

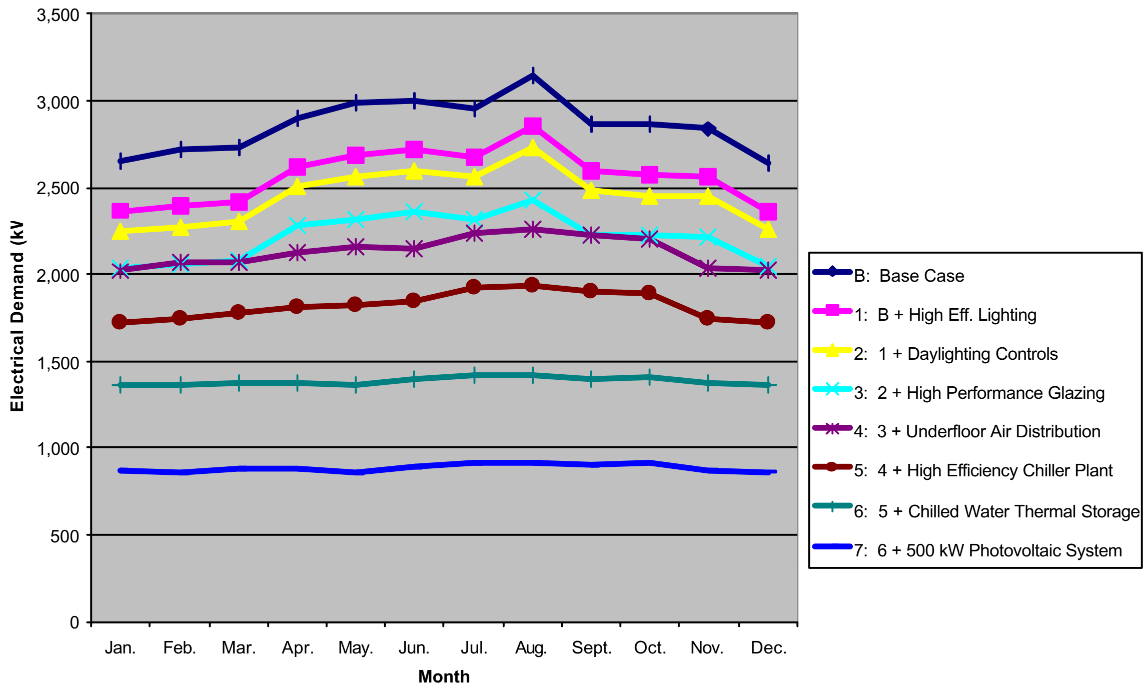

Chart 1: Preliminary simulations identified a package of energy efficiency measures that reduce peak electric demand by 67 percent, and provide a stable annual electric load profile.

Figure 6: Rendering of daylight penetration with articulated glazing and light shelf on a typical south facade, 12:00 PM on December 21st (no furniture).

Figure 7: Rendering of daylight penetration with modular furniture installed.