PERFORMANCE SIMULATION AS A FRONT-END TOOL FOR "INTEGRATIVE" CONCEPTUAL DESIGN EVALUATION

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ABSTRACT

The building design process, with all its inherent complexities, is still by and large regarded and conducted as a series of rather discrete sequential operations. The architect is responsible for generating the initial design concept which is then passed onto to the various engineering professionals for detail technical implementation. This fragmentized approach has often created solutions that only serve a limited range of specific requirements without due consideration for the integral programmatic and performance related implications of the project. Conflicts invariably arise and compromising resolutions are made under pressurized conditions in the management of the project.

The role of building simulation, if at all considered, is often relegated to the "back-end" of the design process merely as a confirmation step to gain a quantifiable measure of the performance of the "designed" facility. The data is then used to justify the necessary technologies to ensure that the building works, sometimes even at the expense of unduly high energy consumption.

It is well established that the key to influencing the building costs and its performance standards lie at the beginning stages of a project's life-cycle. Therefore, this paper argues that systematic "front-end" feasibility studies through the use of computer simulation to aid preliminary design decision making is essential to augment the often used thumb-rules derived from past experiences. In the past, cost and availability of computing facilities were barriers that would have made the proposal economically undesirable. But advances in computer hardware and software technology have changed that scenario dramatically.

A conceptual framework for fundamental and comprehensive building simulation studies will first be presented, based on the human ecological understanding of environmental issues and the concept of integrative building performance. Descriptions of a number of research activities and case studies will demonstrate some significant aspects of the authors' contribution to the approach at the Center for Building Performance and Diagnostics at Carnegie Mellon University towards an integrative framework for front-end performance simulation.

1 INTRODUCTION

It is generally agreed upon that the generation of the concept of a building is perhaps the most important stage in the design process because of its impact on the on the subsequent design development and eventually construction of the building. In the last three decades, there has been a surge of research and development on building simulation to support preliminary design decision making. Coupled with the increasing availability of powerful digital processors, many computer-aided building modeling systems were developed. However, the application of such tools is still limited in the architectural practice world. Several attributive factors can be identified.

Firstly, the building delivery process in many countries is still very much a linear process whereby the architect is responsible for generating the design concept of the building. This then gets passed along the line to the engineering professional who are responsible for the technical implementation of the scheme. This traditional approach in many ways stifle the inherent necessity for an integrative and iterative processes that will meet the often complex programmatic and performance objectives.

Despite a dramatic proliferation of powerful personal and mini computer systems, the application of model simulation, if at all conducted, is in majority of cases effected by the engineering professionals to obtain building implementation specification (eg. load profiles and determination of plant / equipment / system capacities) at the detail design phase of the building delivery process. Its impact on and value to the overall design is therefore limited.

There is also the question of justifying the additional costs involved in conducting front-end performance simulations when the governing criteria is often first cost rather than life cycle cost considerations. Professional responsibility is still clearly limited to the timely completion of the project. Concern for long term performance and operational management is seldom raised and is assumed to be taken care of by facilities or building managers in the future.

In order to effectively explore these issues, directed efforts at two levels are necessary. Firstly, at the technical and organizational level, there should be :

- further development of simulation models to better represent real-world 'dynamic' conditions;
- integration of modeling tools for design support;
- popularization and integration of simulation methods within the design process.

At a higher level of integration, the complexity of the human response and his interaction with the built environment must be investigated.

This paper introduces the authors' contribution to the efforts of the Center for Building Performance and Diagnostics (CBPD) at the Department of Architecture, Carnegie Mellon University towards the development of concepts and refinement of tools to adequately address these topics.

2 THEORETICAL FRAMEWORK

2.1 The Human Ecological Approach

From the system theoretic standpoint, the act of building can be interpreted as a response of the inhabitants to an inequilibrium within the man-environment interaction system with the goal of maintaining homeostatic conditions. Therefore, modeling of the interaction between the buildings and the environmental factors has an important value within the human ecological approach in habitat design and evaluation. However, human ecology at the same time conceptually exposes the limitations of "energy-centered" analysis of environmental relationships (Knötig 1972, 1980; Mahdavi 1990/a, 1987, 1986/a, 1986/b; Panzhauser and Mahdavi 1989). To understand the significance of the human ecological position, some basic concepts should first be established.

Human ecology can be defined as the study of the inter-relationships between an individual, (or a group or all human beings) and his (or their) environment. Each of these environmental relationships reveals both a "matter-energy" as well as an "information" related aspect. The environmental relationships are almost always evidently taken into consideration in design either because of their "matter-energy" or because of their "information" related significance [Fig.1]. As an example, sound generation and propagation certainly has an energetic component which can be specified in terms of adequate sound levels (eg. power level, intensity level and pressure level). These levels however do not describe the informatic impact such as the qualitative desirability of sound events. It is a question of context and circumstances that one of these two aspects acquires a decisive importance.

There is a dual function allocated to each human environmental relationship either in a latent or in an explicit manner. The real function (sometimes regarded as the "first" function) refers to the bio-function or existential function. Most performance simulation programs usually provide data which address this functional category. The "symbolic" function (sometimes referred to as the "second" function) deals mainly with expression and representation. Again, the relative predominance of either of these functions clearly depends on the given context although both of them are evident in most environmental relationships.

Given these concepts, it is apparent that the simulation tools currently available deal mainly with energy related design parameters (eg. indoor climatic patterns, sound propagation, mass and heat flows). Although there are possibilities of statistical interpretation of energy related data based on physiological facts (eg. in the case of thermal comfort), simulation results and data still by and large focus on the matter-energy related aspects of environmental relationships. Any further integrative approach must necessarily involve concepts and methodologies of the human sciences.

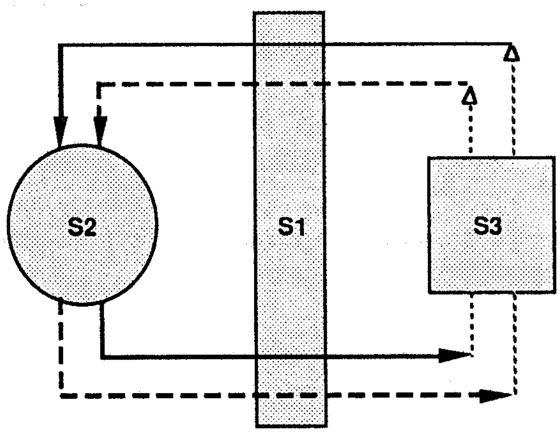


Fig. 1 Basic Interaction Schema
(S1 - environmental relationships,
(S2 - Human Being, S3 - Surrounding World)

2.2 Integrative Building Performance

In an attempt to break away from the traditional mono-dimensional approach to design which have resulted in many unsatisfactory buildings, the research efforts at CPBD (Hartkopf, et. al. 1986, 1985) have been consistently geared toward establishing a framework for integrative approach to design. For such efforts to have an impact on the professional design decision making process, this conceptual framework must be translated into workable models. Emphases have been directed toward the following objectives :

- Establishing the concept of integrative building performance, addressing the impact of thermal, acoustic, visual, air quality and spatial performance as well as building integrity;
- Assessment of the in-situ performance specification of products and integrated systems in building;
- Understanding of the interactions of measurable performance criteria and the human factors (eg. perception, evaluation, response and acceptance).

3 RESEARCH FOCI

3.1 Empirical Information Sources

In contrast with the well documented data sources on building material, component and system specifications, operational and occupational issues have generally not been sufficiently investigated.

In the *a priori* analytical approach to formalization of building-environmental interactions (eg. sound propagation and natural ventilation), computational frameworks for solving complex mathematical functions can be established. However, these must be solved for explicit boundary conditions, applying certain constant values. In many relevant architectural cases, empirical measurements are currently the most reliable data source for determining these values.

In this context, two benefits can be realized by conducting building related empirical studies. Firstly, the analysis of real-time building operations can shed light on problems within specific occupancy settings and behavioral responses which cannot be adequately captured by non-verified assumptions or hypotheses. Secondly, empirical studies provide in many cases an essential supplemental insight into the potential deviation of the *de facto* performance of the building elements and systems (*a posteriori* assessment) from the behavior predicted according to classical simulation tools.

Ongoing international field studies are being conducted by the CBPD which focus on advanced office building systems and environments. These endeavors have already highlighted some significant emerging trends in innovative approaches toward building system integration and enhancement of the workplace in terms of productivity as well as user satisfaction. Future field studies will aim to utilize empirical investigation strategies as a data source and model validation for both building performance and human response prediction.

3.2 Critique of Partial Specifiers

Given the limitations of tools in the past, it was necessary to reduce the quantity of information processing for design decision making by introducing "partial specifiers" and thumb rules. Given the increased computational capabilities and the conceptual development in environmental issues, many of these specifiers and rules should be critically reviewed.

3.2.1 Thermal Transmittance and Surface Temperature

For example, the concept of thermal conductances (Heindl, et. al. 1987, Panzhauser and Mahdavi, 1989, Panzhauser, et. al. 1990) demonstrates the limitations of U-value based calculations for the determination of heat flows, surface temperatures and critical relative humidities (essential for the evaluation of surface condensation risk) which can affect both the integrity of the building enclosure and human comfort. The underlying assumption of U-Value based calculations is insufficient to deal with many of the complex composite construction techniques available today and could yield erroneous results of both transmission heat loss and interior surface temperature calculations. Heat transfer through thermal bridges cannot be determined accurately using U-value based methods.

Fig. 2 illustrates the point by comparing simulation results of minimum interior surface temperatures using both the exact numeric method versus the simplified U-value based method for 30 types of common residential constructions. In this case, the simplified method tends to provide over-estimated values in most instances.

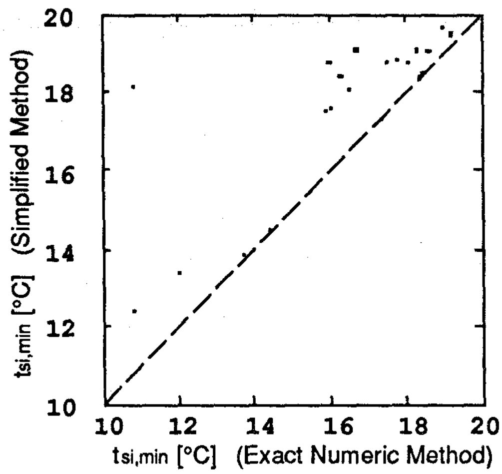


Fig. 2 Comparative analysis of indoor surface temperatures for 30 residential constructions using different simulation methods.

3.2.2 Sound Transmission

For many years, the specification of sound transmission between adjacent spaces was based only on the Sound Reduction Index (R_W values) of the partition elements (walls, floors). Only as a consequence of recent development, the effective sound transmission (sound level difference) involving all flanking transmission paths was considered to be the appropriate parameter for building acoustical requirements [ÖNORM 1990, DIN 1989, Mahdavi 1990/b].

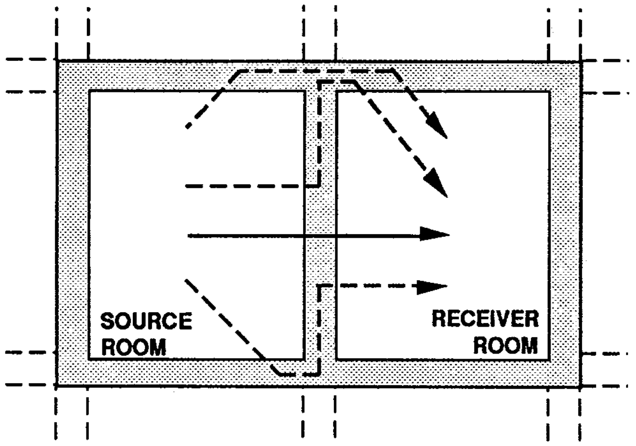


Fig. 3 Direct and Flanking Sound Propagation Paths Between Adjacent Spaces

A similar configuration to that shown in Fig. 4 is used to demonstrate the potential impact of the flanking transmission on the overall sound level differences.

Fig. 5 illustrates the deviation between the effective sound level difference between the two adjacent rooms (including the contributions of the flanking transmission paths) from the sound reduction index of the partition element. The relevant underlying assumptions are summarized in Fig. 4 as follows :

Element	Area (m^2)	Mass (kg/m^2)	R_W (dB)	Junction Geometry (+, T)
Partition Wall	12	100 to 700	38.8 to 66.2	N/A
Exterior Wall	15	400	56.3	T
Interior Wall	15	100	36.8	+
Floor	20	300	52.3	+
Ceiling	20	300	52.3	+

Fig. 4 Matrix of Modeling Assumptions (cp. Fig. 5)

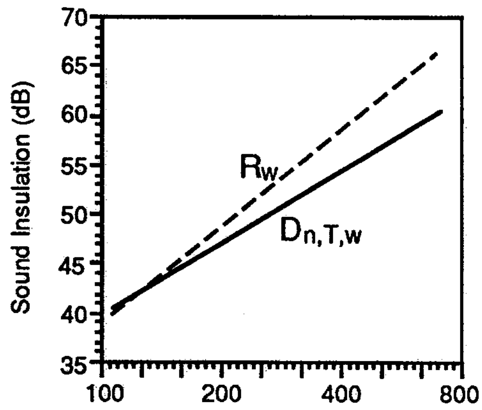


Fig. 5 Deviation of the effective sound level difference between two adjacent rooms in a typical massive construction from the sound reduction index of the partition element as a function of the surface density of the partition element.

3.2.3 Daylighting

Building codes of numerous countries contain simple rules to address the minimum requirements concerning natural lighting. For example, certain codes stipulate the requirement of certain glazing area to floor area ratios in residential rooms. Computer aided simulation of the illumination distribution of realistic room-window configurations shows however that in many instances, more elaborate specifications are necessary to ensure the desired daylight quality.[Mahdavi and Berberidou, 1991].

In these and many other similar cases, the accuracy, reliability and effectiveness of common rules and specifiers must be critically examined. Given the currently available simulation possibilities, some rather limited concepts should be regarded as anachronisms.

3.3 Case Study : CBPD

Although the design decision making process for the proposed Center for Building Performance and Diagnostics (CBPD) is still in a preliminary phase, some design analysis results have already indicated the significance of front-end simulative strategies. The following synoptic description should clarify this point.

The CBPD is conceptualized as a full-scale "live-in" laboratory which is set up to conduct research and to demonstrate the various facets pertaining to issues discussed. The proposed project is to be constructed as a roof top extension to an existing university campus building. The building is designed with certain built in flexibility for accommodating change in anticipation of innovative systems which will continue to evolve over time. It will also be a show case for the cutting edge technologies (components and systems).

3.3.1 Schematic Design Proposal

The preliminary design proposal for the Center was initially based on a rather diffuse semantic notion of the the programmatic requirements and environmental concerns. Preliminary simulative investigations showed however that the fundamental questions of the building envelope configurations in terms of geometry and elemental composition are not trivial. For example, such decisions cannot be made without critically reviewing and ensuring a reasonably reliable micro-climatic database.

Fig. 6 illustrates the significant variance in diffused and direct solar irradiance on a south slope roof surface between using a simplified clear sky model and a more sophisticated energy simulation program with actual local weather data.

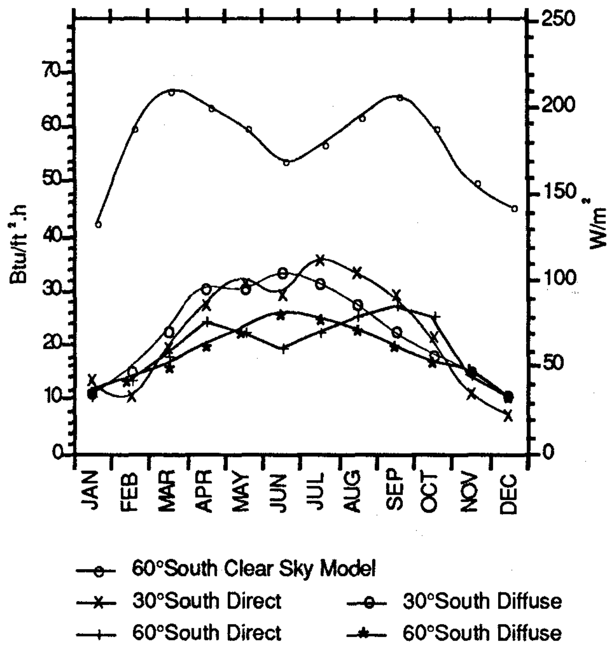


Fig. 6 Diffuse and direct components of the solar irradiance incident on south sloped surfaces (30° and 60°) based on extensive hourly simulation, compared with the result obtained by applying a simple clear sky model for direct component on a 60° pitch south facing surface.

3.3.2 Energy Utilization Methodology

One of the initial concepts underlying the design approach to thermal performance is to tap and maximize the potential solar energy utilization in the building. The simulation model offers a technical decision making platform based on the impact of configurational and material related variations of building components on the energy use effectiveness [Fig. 7]. However, further integrative decisions cannot be achieved without an interface to "extraneous" parameters (eg. initial and life cycle costs, maintenance, ecological concerns and educational objectives).

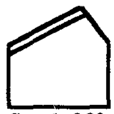
	Passive Solar	Active Solar (Photovoltaics)	Active Solar (Collectors)	Active Solar (Cooling)
 South 60°	+	-	+	-
 South 30°	-	+	-	+

Fig. 7 Example of a local technical decision making platform based on energy simulation data (relative evaluation of two roof configurations for the proposed CBPD building with regard to their effectiveness for different solar energy utilization strategies).

4 CONCLUDING REMARKS

The traditional fragmentized and sequential approach to the building design and delivery process has often created inadequate solutions by neglecting the integral implications of long term building performance and integrity as well as user satisfaction. As a consequence of this circumstance, a limited view of building simulation as a compartmentalized activity is prevalent. Thus, the potential of building simulation as a tool to support the generative design phase has not been sufficiently explored.

For the effective and pragmatic implementation of performance simulation as a front-end design tool, directed efforts at two levels of integration are necessary. Firstly, there is a need for further enhancement of simulation techniques as generators of technical decision making frameworks. These are to be incorporated as an essential element within the gamut of building design support systems. Secondly, continued human ecological oriented investigation of the complexity of response patterns and man's environmental relationships should be pursued. This investigation should preferably rely on the paradigm of both the energy and information related aspects of the environmental relationships to formulate appropriate problem solving strategies.

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