# AN ARCHITECTURAL UNDERSTANDING OF SOLAR POWER

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**Abstract** – Calls for readily effective solar design tools assume that an accessible bridge between the information needs of architects and the information provided by building physics has long been established. A general overview of the available means for supporting the building design process, however, shows that computer-based design guidance is still largely based on the working concerns of engineers, rather than architects. The paper delineates an analysis of these distinctly different classes of working concerns. In summary, design decision scenarios that can be termed *architectural* tend to work "from the inside out," that is, from human-oriented objectives towards the development of building geometry and passive building behavior (structural and thermal). The implementation of solar radiation models, on the other hand, is commonly limited to the context of thermal models for simulation analysis. Such calculation models inherently focus on climatic boundary conditions, typically on an annual basis, and treat the building envelope "from the outside in." Hereby occupant behavior is reduced to a secondary parameter and geometric design issues to an energy-flow topology. Two key, dynamic aspects of architectural design are thus practically eliminated from most energy calculation procedures: diurnal patterns of functional behavior and the spatial context in physical, geometric terms. The paper presents an approach to regain the architectural viewpoint for understanding valuable solar radiation information as meaningful design support. In the author's previously published research work, a method of "solar profiling" was developed using parametric calculation models. The described methodology has since been further refined through continual educational application.

## 1. INTRODUCTION

Increasing environmental impacts through harmful emissions and exploitation of fossil fuel resources have deeply affected the building industry to the extent that methods of low-energy construction and passive solar energy use have come to be dictated not only by public awareness, but also by global necessity.

Given the simple fact that the primary purpose of our extensively built environment is to provide shelter and comfort, the realization that this could and should be accomplished more intelligently so as to minimize the damage to the environment is gaining broad acceptance as a politically strategic objective. Internationally, this is also reflected in new building codes and increasingly sophisticated standards of thermal quality, as well as subsidy programs to promote the use of alternative energy systems in buildings

In architectural practice, the meaning of the term *passive solar* has evolved to encompass nearly all major strategies of environmentally responsive building design: to provide comfortable and inexpensive heating in the winter, cooling in the summer, and daylighting all year round (cf. Anderson 1990).

This trend poses a particular challenge to the development of innovative and experimental design ideas, for which, by definition, empirical data is lacking and must be compensated with computer-based building performance simulations. The application of promising building technologies in such design concepts calls for simulation methods that are sufficiently comprehensive for the reliable prediction of a building's dynamic thermal performance (Kreč and Rudy 1996). However, one trait is common to virtually all thermal building simulation programs that are currently available: they are so data-intensive and difficult to use that their application is generally reserved for specialists. Such tools are therefore out of reasonable range for most building designers who could theoretically use simulation results during the course of design work.

Conventional simplified calculation methods, on the other hand, are inadequate as soon as time-dependent effects such as solar gain and thermal storage have a significant influence on the results (cf. ASHRAE 1989, Goulding 1993) – which is generally the case with solar-supported, low-energy buildings (cf. Balcombe 1992).

A different tack altogether is proposed in the following, one that focuses on simulating essential solar dimensions in a manageable fashion to support building design decisions. Since the data required for the solar and climatic aspects of an overall thermal simulation model conveniently coincide with information that is available at the earliest stages of the building design process, a method defined as "solar profiling for architects" was developed based on diurnally parametric solar radiation models (Rudy 1999). The method aims to utilize such parametric information to reveal as much as possible about where the design stands in solar terms – without making any premature assumptions as to the thermal properties of the building envelope.

## 2. DESIGN STAGES AND INFORMATION NEEDS

*2.1 Architectural qualities vs. engineering quantities*

From the architect's point of view, solar building physics is immediately relevant to two primary aspects of design considerations: the optimization of thermal comfort and the economy of means. Beyond this, solar design issues also directly influence lighting options and, ultimately, psychological and aesthetic qualities of the architecture itself. Design values for technical aspects, in particular those that demand a high degree of pre-specification for assessment, are only of peripheral interest to the architect at early design stages.

The obvious difference in working methods to that of engineers is reflected in the means of rendering and communicating design ideas – from the proverbial "napkin sketch" onwards (as opposed to numeric calculations of design values). Underlying the difference in working methods we find an entirely different treatment of physical dimensions as a source of design information, especially regarding the importance of space and time in relation to other definable quantities. To a building designer, *energy* – the key solar dimension in building physics – is not a quality per se and, therefore, not a design concern unless it *flows* through a spatial geometry. Consequently, the solar quantities that can be most directly applied to the architectural design process are those that can be used to relate energy flow to three-dimensional space, i.e.:

- solar power (Watt = Joule per second) and
- solar flux (power density = Watt per square meter).

To the engineer, this means thinking in derived dimensions, since energy is seen as the relevant base dimension (Joule), a calculatable potential, which can be mathematically transformed as needed through functions that describe its interdependency with the dimensions of coordinate space and time. The engineering approach to calculating design values strives to reduce the complexity of such derived dimensions back to their common base, in this case energy, in order to obtain standardizable sets of calculation results.

Since the development and use of most solar radiation models is commonly limited to the context of thermal models for simulation analysis, the calculation results are generally compatible with this type of "engineering-style" analysis. Such simulation models focus on defining the thermal properties of a building envelope and applying boundary conditions as driving functions. Hereby occupant behavior is reduced to a secondary parameter (as a boundary condition) and geometric design issues to an energy-flow topology. The calculations are run to yield results over a defined time frame, typically a year. In order to simplify results analysis, power quantities are usually summed over the given time frame to obtain energy dimensions (e.g., Watt-hours per annum).

In the process, the two geometric and dynamic aspects that are key to architectural design are essentially eliminated from the final results of most engineering-based procedures for energy-related calculations: time-dependent patterns of functional behavior and the spatial context in physical, geometric terms. When the engineer does involve these dimensions in final evaluations, then only at such a detailed level that only one aspect can be analyzed at a time in conjunction with other parameters (e.g., in the form of compiled graphs with either one coordinate or one time axis).

To illustrate the fundamental difference in approaches, figure 1 relates the solar parameters involved in modeling the exterior boundary conditions for thermal simulation analysis. The photo below (figure 2) shows an architectural detail in which the designer created an interplay between exterior and interior spaces using surfaces, materials, and light in such a way that the overall effect is substantially enhanced by the shading pattern that moves across the interior surfaces over the course of a day.

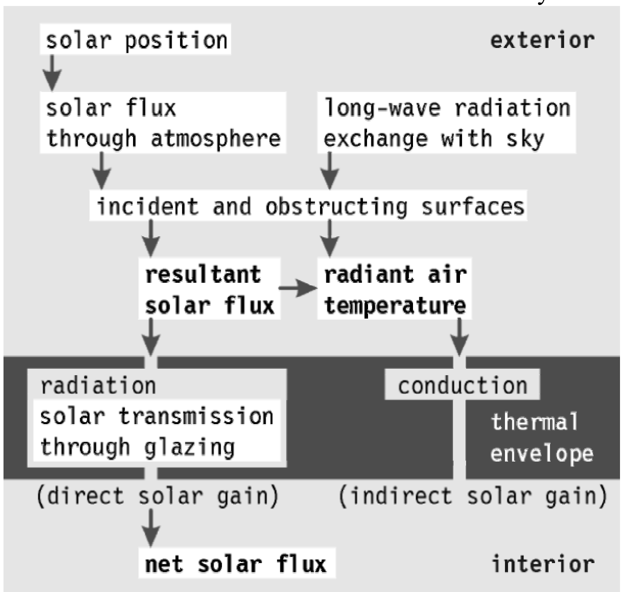



**Figure 1**: Components of the simulation model for solar gain in relation to the thermal envelope.

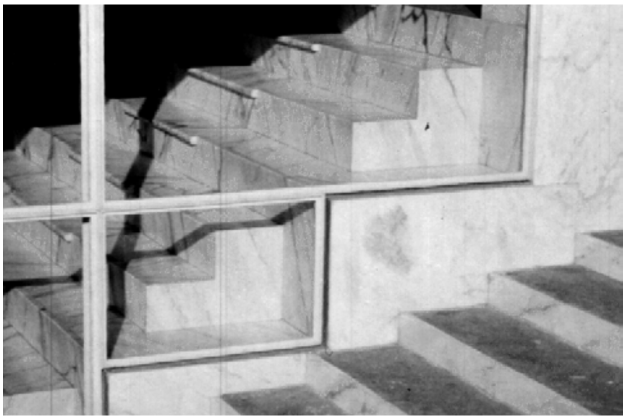


**Figure 2**: Detail of interior and exterior staircases, Banco Borges & Irmao III, Alvaro Siza (Villa do Conde, Portugal, 1982).

In engineering terms (as in figure 1), endless tables of numerical data, compiled in innumerable graphs, would have been needed to capture and analyze all of the spatial and time-dependent data that this relatively simple architectural detail entails. Only a fraction of the output data, however, would have been of any effective use to the architect, and then only if selected and presented with a mind for his immediate design concerns.

*2.2 Interpreting quantities as qualities*

Quantities can only serve to inform the design process effectively if communicated on the basis of comparisons that allow the architect to relate them qualitatively. This entails visually supporting the interpretive translation of numeric differentials ("more/less") into the kinds of semantic differentials that a designer uses to compare competing options, such as "better/worse," "efficient/inefficient," "hot/cool," and so on.

Architecturally meaningful interpretation of energy data is also facilitated by visualizations of energy flow in terms of spatial and cyclic patterns of temperature and flux. The complexity can range from annual or diurnal plots to animated, three-dimensional renderings.

For reliable interpretation, the data should ideally be modeled with the same level of detail and validity as the geometric information that architects are accustomed to working with. A tight coupling of solar radiation data and design geometry from the start of the design process serves to enhance intuitive understanding of solar influences, as well as to establish comparable profiles to accompany the design process through development.

In this context, it is important to distinguish between patterns of empirical data and patterns that constitute an analytically characteristic profile. Figure 3 shows three different annual representations of the same climate parameter. The top curve, which plots temperature values of a meteorological reference year, is far too "messy" to serve as a profile for analysis. The other two, significantly smoother curves were mathematically generated on the basis of the reference year data using characteristic climate parameters. While the bottom curve of mean daily temperatures provides an adequate profile for most forms of annual analysis, the middle curve includes superimposed temperature swings on a daily basis and could also serve as the basis for seasonally characteristic, diurnal analysis (Kreč and Rudy 1996).

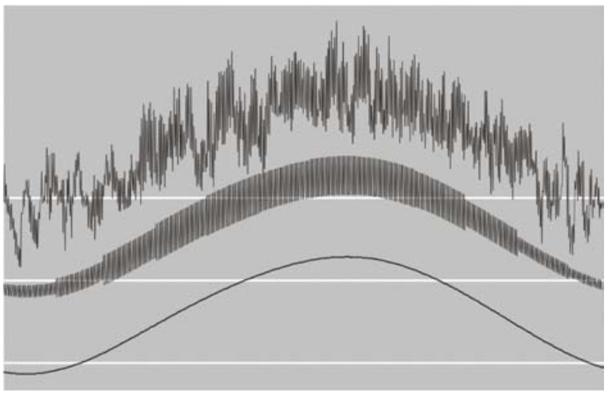


**Figure 3**: Three descriptions of air temperature fluctuations over a year.

The same principle applies to patterns of solar radiation, i.e. characteristic profiles should be free of all meteorological "noise" that is not relevant to design decisions. Figure 4 shows the difference between the diurnal pattern of meteorological reference data (cf. Solar Energy Laboratory 1994) and parametrically generated profiles for solar radiation.

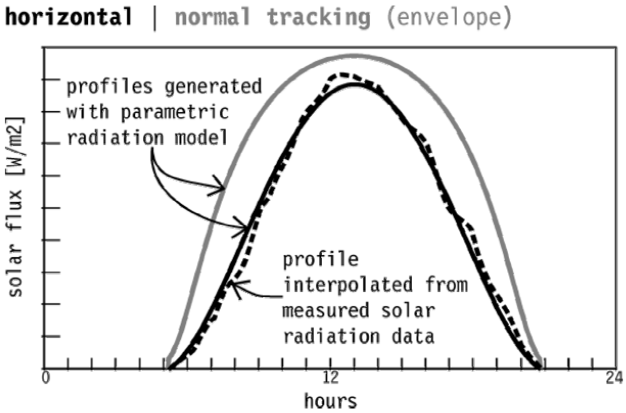



**Figure 4**: Different descriptions of incident solar flux on a horizontal surface (and normal on a theoretical tracking surface) over a day.

*2.3 Correlating design concerns for solar profiles*

Previous research work by the author took its point of departure from a general analysis of architectural working methods, which served to clarify and structure the information needs at each point of entry, i.e. to determine which quantitative and qualitative parameters are meaningful and definable at various typified design levels. The processing of information was addressed within the identified framework, specifically: the form and level of precision that quantitative data could most usefully assume, as well as how the characterizing data should be modeled consistently from schematic to detailed design levels. Finally, appropriate visualization methods were developed in the form of "mockups" based on the calculation results of extensive parameter and case studies (Rudy 1999).

The overall scheme of the resulting *solar profiling method* is mapped out in figure 5, in which the entire extent of the building design process is broken down into four main phases in order to roughly categorize the types of design decisions encountered and tools needed (Balcombe 1992). The specific content of each phase is, of course, dependent on the project context at hand, and especially on whether the design is for new or retrofit construction. Nonetheless, the four identified stages do provide a theoretical framework for relating thermal considerations in general – and solar dimensions in particular – to more or less equivalent levels of design information.

As the design model is developed through subsequent levels, it should yield further and increasingly specific profiles, and ultimately serve as the basis for more involved thermal performance assessments.

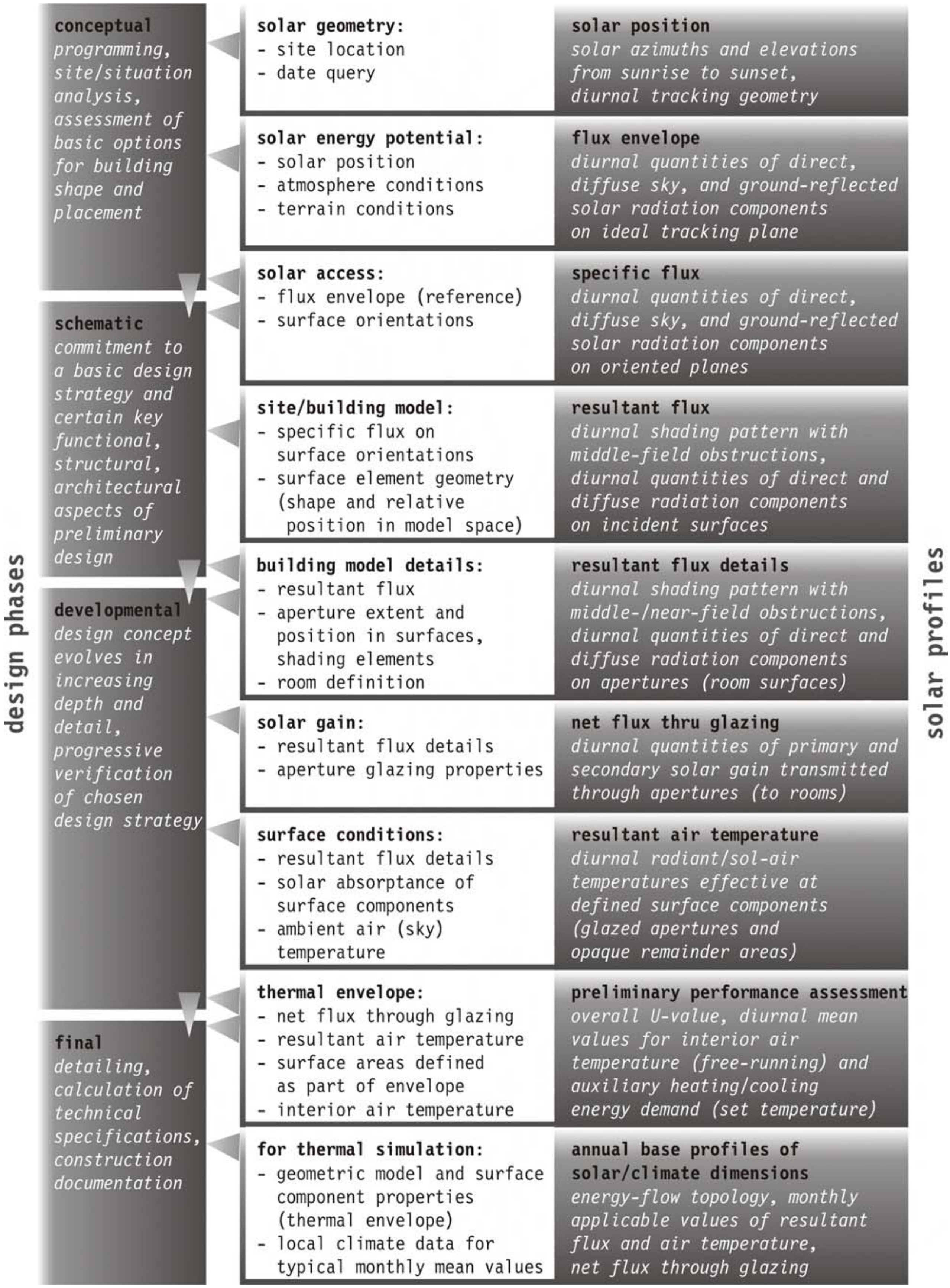



**Figure 5**: The levels of the solar profiling method and their associated solar design parameters.

## 3. APPLICATION IN DESIGN SCENARIOS

*3.1 Climate cycles and design issues*

With solar design considerations, assessing the impact of decisions on diurnal patterns is just as important as grasping the effect over an annual cycle. This makes it necessary to "sample" individual days of the year in order to obtain an informative picture of the relevant diurnal patterns in a seasonal context. Since solar/climate profiles are not only defined by the types of questions commonly asked during early design phases, but also implicitly targeted at future thermal profiles, the choice of which days of the year to sample (query dates) is especially important if the results obtained are to bear relevance for later evaluations related to thermal performance.

For mild to tropical climates, in which the annual and diurnal temperature swings are minor in comparison to the variations in solar radiation, days that characterize *solar seasons* are most informative: winter and summer solstices, with an equinox as transition. Most climate zones, however, have pronounced heating and cooling seasons (i.e. the mean temperatures vary significantly over the year). For such building sites, it is more useful to profile *climate seasons*: mid-month days in January and July, with April as a transition month.

The choice of standard profile characteristics (e.g., for cloudy or clear sky conditions) depends on whether the cases to be eventually considered later on in the design process are typical or extreme (critical/optimal) in thermal terms. This, in turn, is a question of the thrust of analysis beyond the strictly solar issues that can be addressed initially, and should be kept in mind from the very beginning in the course of developing design case models.

Another way of looking at it is in terms of design scenarios, which are best classified by the nature of the answers sought, in conjunction with the design model in progress. Generally speaking, extreme scenarios more readily point up the impact under either critical or "best / worse case" conditions, making them most useful in the earliest stages, both for avoiding solar design mistakes as well as optimizing the use of solar potential. Typical scenarios, which are necessary to reliably estimate the performance of a given building design under actually expected conditions, come to bear mainly in later phases, when the necessary technical specifications for building simulation have been established (point of entry for "engineering-style" calculations).

The implicitly sequential nature of the solar profiling methodology reflects likely sequences of questions raised in the architectural design process. Since its initial formulation in Rudy 1999, it has been further clarified and expanded for implementation in architectural design training at the affiliated university[1] (Pfeiffer-Rudy 2001).

[1] Design studios conducted by the department of structural design and timber engineering (*Institut für Tragwerkslehre und Ingenieurholzbau*, http://www.iti.tuwien.ac.at), in cooperation with the department of building physics and human ecology.

Some examples of solar design questions, along with illustrations of the types of answers obtainable, are given in the following section. These are loosely structured with respect to the progressive levels of case model development, as well as the underlying architectural design issues (figure 5).

*3.2 Site and situation analysis*

The task of programming a building project entails defining the primary project requirements and constraints (in terms of function, location, space, access, budget, etc.). Programming is typically accompanied by a thorough site analysis for determining the range of basic design options given by the urban context, available space for building, pedestrian and vehicular access, building regulations, and so on.

Analogously, a solar site analysis seeks to profile climate conditions and solar potential in such a manner that an initial assessment of promising solar design strategies can be made. This means gathering some basic information on the site in order to generate profiles of **solar geometry** (fig. 6), as well as **solar energy potential** and **access** (fig. 7), which provide answers to such questions as, for example:

*Where is the site situated? How hot does the summer get outside? How cold is it in winter? Where is the sun when I need it? Where is it when I don't?*

*How much sun power is there? How much sun can I hope for under perfect conditions and what's left on a cloudy day?*

*Are there mountains or other obstructions on the horizon? Does the site have a "solar sweet spot" for building placement? How much of what is potentially there am I using?*

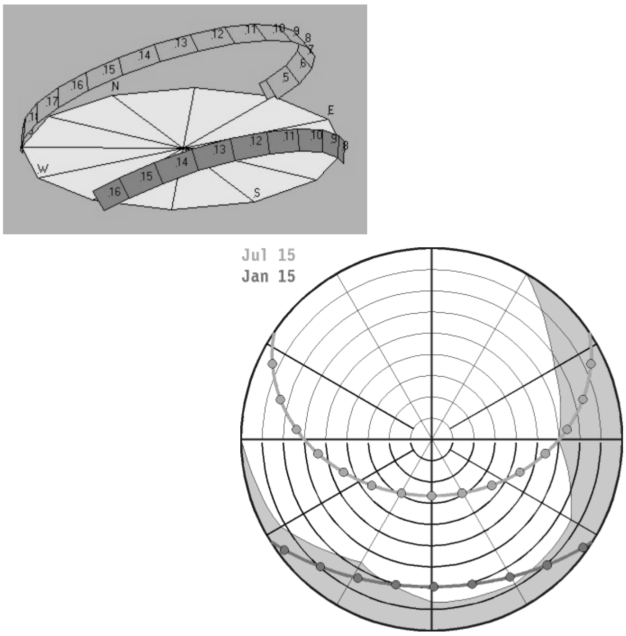



**Figure 6**: Diurnal solar positions (azimuth/elevation) rendered as tracking surfaces and plotted in a polar diagram [°] (including distant-field obstructions).

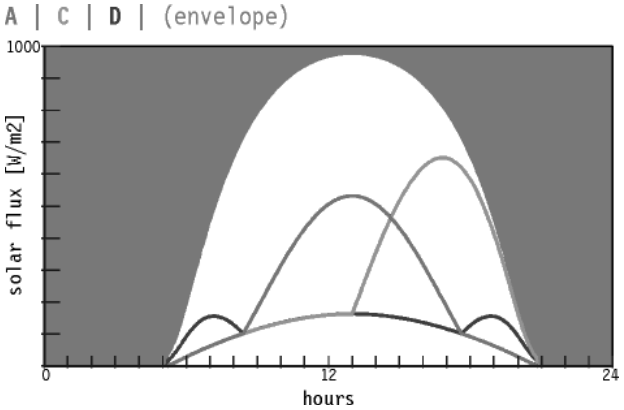


**Figure 7**: Diurnal plots of the global specific flux for different surface orientations set against the flux envelope (reference value = flux on an ideal tracking surface).

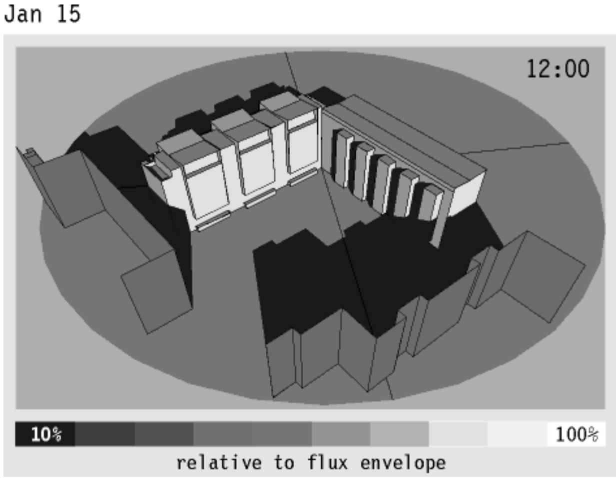


**Figure 8**: Noon-time pattern of global specific flux on a site and building model, in relation to the flux envelope (reference value).

*3.3 Schematic design development*

Existing buildings surrounding or on the site constitute significant middle-field obstructions, especially in an urban context. A complete picture of the site situation with respect to overall solar access can be gained by analyzing a three-dimensional site model for shading patterns over the course of the selected days (query dates).

Beyond helping to avoid egregious misassumptions, gauging the relative reductions in overall insolation due to existing or designed obstructions provides a valuable measure for working with solar geometry consciously and effectively.

Central design issues that arise at this stage revolve around aperture placement and sizing, as reflected in **model profiles** of the overall building site (fig. 8), key façade details (fig. 9), **solar gain** profiles (fig. 10), and in the following questions:

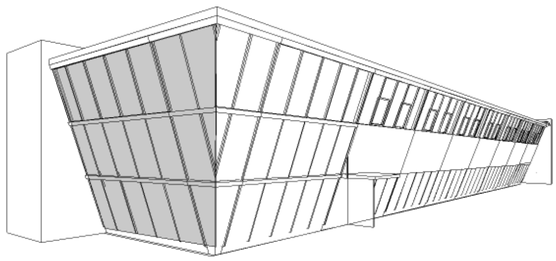
*When will that nearby building block the sun? What do I gain or lose if I situate the building differently?*

*Where do I want my views? Will those windows ever see direct daylight? How big can that aperture be without causing trouble?*

*Where may I get too much exposure? What can I devise to control it? What shading dimensions will get me through? How much useful energy will get blocked if I keep the shading elements that way all year round?*

*How much sunshine will those windows let in? When and where will there be excessive gain? How good does the glazing need to be?*

Particular attention must be paid to questions of whether or not a given room is likely to overheat because of excess amounts of solar gain entering via the apertures. Where a tendency to overheat has been identified, it can most likely be corrected at this stage by manipulating the aperture areas, adding shading elements, or considering a different type of glazing.



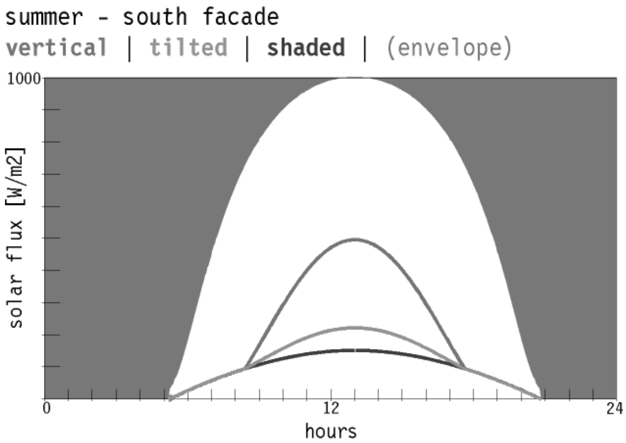


**Figure 9**: How much does tilting the façade reduce incident solar flux? Do I need to devise shading elements or does the modular framing structure of the glazing already completely block the direct beam?

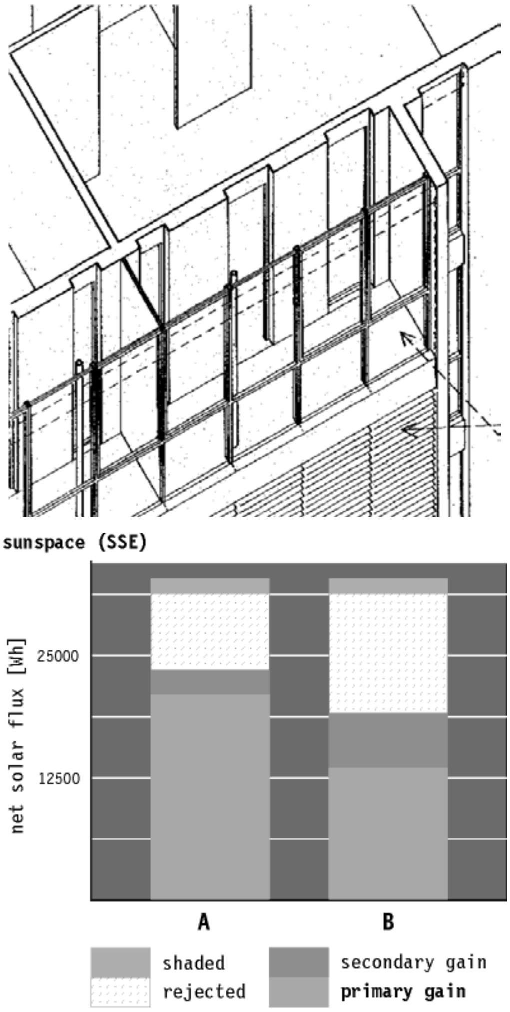



**Figure 10**: Diurnal sums of solar gain in a sunspace for different glazing types, set against the resultant incident flux.

*3.3 Final target evaluations and analysis*

Some detail questions about the building's **surface conditions**, i.e. the effective radiant air temperature (including influence of long-wave radiation exchange with the sky, figure 11) can be answered without modeling the entire building envelope, such as:

*How much do the exposed surfaces effectively cool off at night? How strongly does the sun warm that exterior wall? Is my skyward glazing uncomfortably cold on a clear winter night? Does it matter what color I paint the house?*

To answer the following typical design questions, basic material properties of the **thermal envelope** need to be established in the design model. While preliminary profiles can be calculated on the basis of U-values to gauge the overall thermal quality, **thermal simulation** analysis is necessary to determine the diurnal and annual characteristics of competing design options (fig. 12):

*Does it get uncomfortably warm in summer? What is the most effective design measure to control the overheating? Will I need to heat much during a typical winter?*

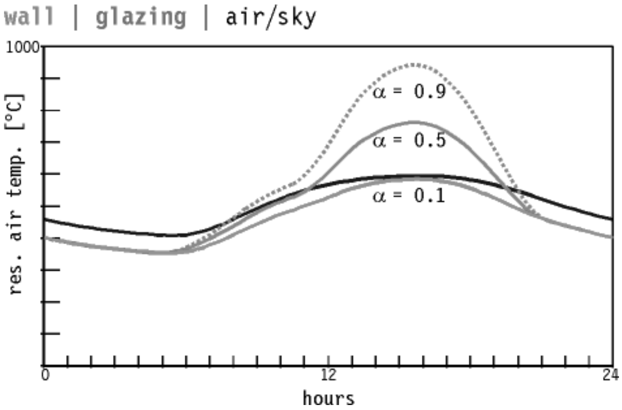



**Figure 11**: Diurnal plots of resulting radiant air temperature at surfaces with different solar absorptance factors, set against the ambient air/sky temperature.

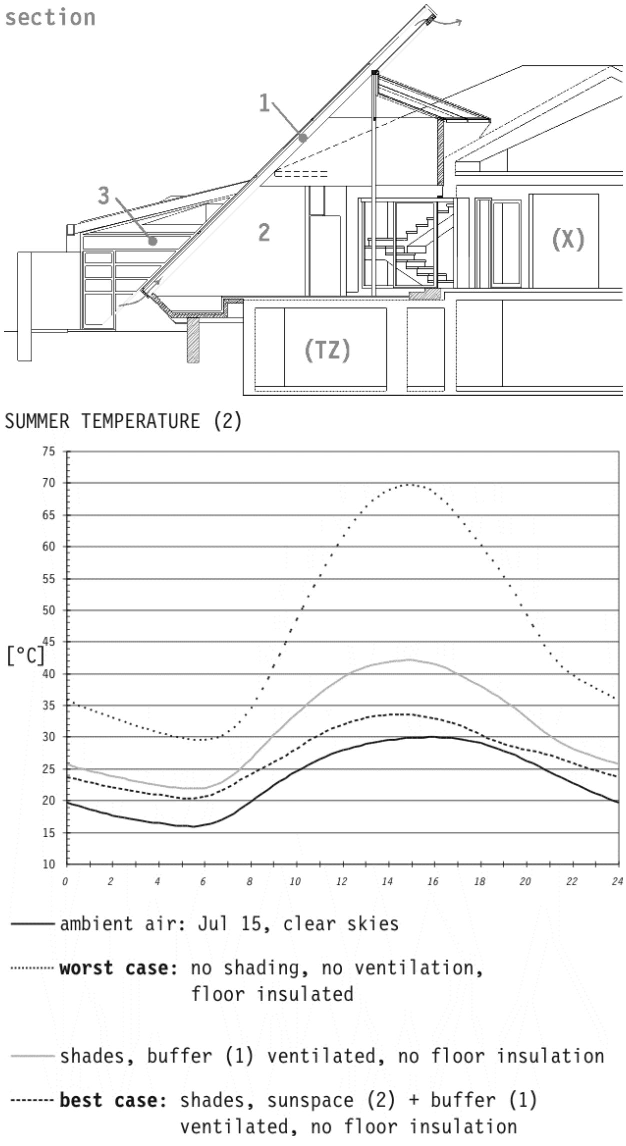



**Figure 12**: Diurnal plots of the interior air temperature in a sunspace for different configurations of shading, ventilation, and insulation.

*3.4 A note about solar design support tools*

Aside from comprehensive sources of solar radiation data (e.g., Lemoine and Preuveneers 1984) and design guides (c.f. ASHRAE 1989, Goulding 1993), a number of computer-based tools are available for calculating solar position and shading geometries. Many CAD programs also include solar analysis modules, which allow three-dimensional renderings of shading patterns to be generated automatically for preset dates and time intervals.

Unfortunately, to the author's knowledge, no three-dimensional modeling and visualization tools for consistently coupling building geometry with characteristic solar power quantities exist to date. Consequently, such model profiles as the one illustrated in fig. 8 must still be generated manually in a tedious procedure. To alleviate this situation, a so-called "solar toolbox" application was designed by the author, which is structured closely along the lines of the solar profiling method outlined in figure 5 and was originally conceived to contain modules to facilitate the generation of the following types of profiles (Rudy 1999):

- solar geometry – solar position,
- solar energy potential – solar flux envelope,
- solar access – specific flux,
- site/building model – resultant flux,
- building details – resultant flux on details,
- solar gain – net flux through apertures.

Of these, the first three – for solar site analysis – are available in the form of a web-based *solar workshop*, either in an offline version (available through the author) or online with supporting information[2].

## 4. CONCLUSIONS

Passive energy-use strategies are by definition a matter of the entire building envelope together with its utilization and, therefore, a core concern of architectural practice. In order to effectively reduce the negative environmental impact of erecting and operating buildings – without compromising thermal comfort or other functional and psychological priorities – architectural design concepts should adequately reflect environmental concerns from their inception. Such an integrative approach implies a fundamental departure from the increasingly common practice of consulting specialists for energy arguments "after the fact" of architectural design.

While the client defines what can or cannot be done within the budget of time and money, and the engineer calculates what can or cannot be done within the constraints of material properties, building code and regulations, it is the architect's job to focus on what is the best and what achieves the most – in every respect (given the possibilities of what *can* be done according to both client and engineer).

Solar power information can be made useful to support the architect in deciding which design solution is *better* and achieves *more* – both architecturally and environmentally – if it is

- analytically modeled in parametric terms that consistently correlate geometry with radiation,
- selectively implemented in diurnal profiles that capture meaningful seasonal characteristics, and
- rendered to reveal the interdependence of solar dimensions to the building designer.

Such solar profiles address questions posed to a given design that can – at least partially – be answered in quantitative terms. By analogy, this approach is currently being adapted to also make structural criteria accessible for architectural design decisions in the context of interactively enhanced information systems[3].

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[2] Pfeiffer-Rudy M. (1999-2003) "The Sun, Climate & Architecture" and "the solar workshop." *bau><studio in the web: solar work*, http://www.baustudio.com/SolarWork.html.

[3] Research project of the Austrian Science Fund (FWF), currently in progress through 2004: *Building Information Systems as Interactive Design Support: Development and enhancement of building databases with integrated structural design tools*, http://www.fwf.ac.at.