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Energy Related Design Decisions Deserve Simulation Approach

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ABSTRACT

Building energy consumption and indoor climate result from complex dynamic thermal interactions between outdoor environment, building structure, environmental control systems, and occupants. This reality is too complicated to be casted in simple expressions, rules or graphs. After a general overview of building energy design tools, the paper describes how / why computer simulation systems can / should be used for design decision support related to building energy performance.
The main conclusion is: design decision support (systems) should employ comprehensive building energy simulation models, the designer should be able to "see" energy flows in a design alternative, and the machine should do the work !

1. INTRODUCTION

One could argue that the main objective of a building is to provide an environment which is acceptable to the building users. Whether or not the indoor climate is acceptable, depends mainly on the tasks which have to be performed in case of commercial buildings, whereas in domestic buildings acceptability is more related to user expectation.
As illustrated in Figure 1 (from Hensen 1991) a building's indoor environment is determined by a number of sources acting via various heat and mass transfer paths. The main sources may be identified as:
- outdoor climate (air temperature, radiant temperature, humidity, solar radiation, wind speed, and wind direction)
- occupants who cause casual heat gains by their metabolism, usage of various household or office appliances, lighting, etc.
- auxiliary system which may perform heating, cooling, and / or ventilating duties.

These sources act upon the indoor environment via various heat and mass transfer processes:
- conduction through the building envelope and partition walls
- radiation in the form of solar transmission through transparent parts of the building envelope, and in the form of long wave radiation exchange between surfaces
- convection causing heat exchange between surfaces and the air, and for instance heat

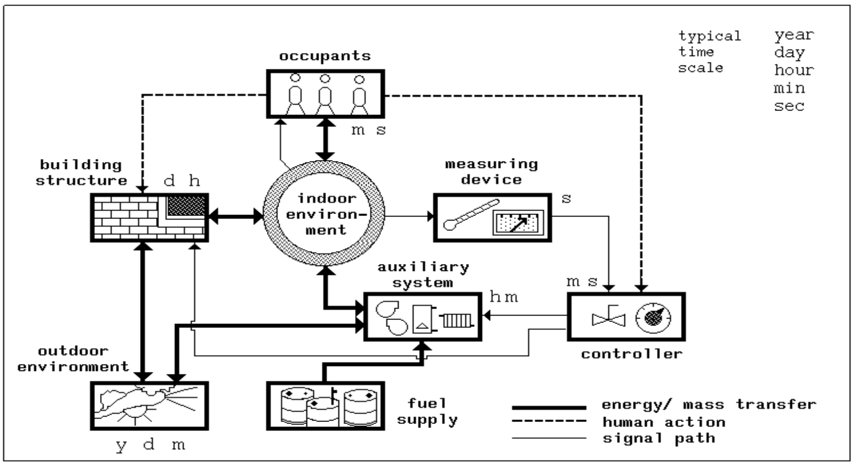

Figure 1 Diagrammatic representation of building and plant

exchange inside plant components
- air flow through the building envelope, inside the building, and within the heating, cooling, and / or ventilating system
- flow of fluids encapsulated within the plant system.

The indoor climate may be controlled by the occupants basically via two mechanisms:
- altering the building envelope or inner partitions by for example opening doors, windows, or vents, or by closing curtains, lowering blinds, etc.
- scheduling or adjusting the set point of some controller device which may act upon the auxiliary system or upon the building by automating tasks exemplified above.

Within the overall configuration as sketched in Figure 1, several sub-systems may be identified each with their own dynamic thermal characteristics:
- the occupants, who may be regarded as very complicated dynamic systems themselves.
- the building structure which incorporates elements with relatively large time constants, although some building related elements may have fairly small time constants (eg the enclosed air volume, furniture, etc.)
- the auxiliary system which embodies components having time constants varying by several orders of magnitude (eg from a few seconds up to many hours in case of for instance a hot water storage tank).

The cycle periods of the exitations acting upon the system are also highly diverse. They range from something in the order of seconds for the plant, via say minutes in case of the occupants, to hours, days and year for the outdoor climate.

From the above it will be apparent that a building is indeed a very complicated dynamic system. Many of the governing relationships are highly non-linear. Apart from a few trivial relations, this reality is just too complicated to be casted in simple expressions, rules or graphs.

2. BUILDING ENERGY DESIGN DECISION SUPPORT

One activity throughout the building design process which has been (and still is) receiving much attention, is building performance appraisal in terms of energy and other environmental issues. These efforts have resulted in a range of *building energy design decision support* tools.

At one end of this range are the so-called "correlation based methods". These are usually based on the results generated with more comprehensive techniques. Often such a method presents correlation graphs from which for example the yearly energy consumption can be read for various values of a certain independent variable (eg facade glazing ratio). Because this independent variable is obviously just one of the factors involved, there need to be many sets of these graphs (eg to accomodate for orientation of the facade, thermal capacity of the building, type of heating system, level of lighting, etc). A recent example of such a method is the LT Method 3.0 (LT standing for Lighting and Thermal) by Baker and Steemers (1993).
It will be clear that these methods must, by nature, be very limited in scope. In generating the graphs, many of the input parameters to the more comprehensive technique must be given assumed values. It is up to the user then to be aware of these, and of the basic principles underlying the model, in order to fully appreciate the applicability and limitations of such a method. Obviously this is not a trivial task for anyone who is not an expert in this field.

Another type of energy design decision support tool at this end of the range are the "manual methods". These are usually based on an analytical description of a simplified model of reality (therefore often referred to as "simplified design tools"). Usually these models also incorporate some correlation elements to take into account those factors which are too difficult to describe analytically (eg utilization factor of solar heat gains, effect of intermittent occupancy patterns, etc). Due to this, these methods suffer from the same limitations in terms of content and applicability as described above.
The term "manual" may be misleading in the sense that nowadays these methods are often computerized, either by incorporation in some general spread-sheet package or through some customized program. A recent example of the latter is NORMA by Santamouris (1993).
Nevertheless, these are "manual methods" and therefore the same limitations apply.

On the other end of the range of energy design decision support tools is "building energy simulation". Within this type of tools there is again a wide range of approaches. There are specialized programmes which focus on one particular (energy) aspect (eg on air flow in Computational Fluid Dynamics, or on lighting in Visualization Models), but there are also simulation systems which aim to take into account all building energy flow paths as indicated in Section 1. Within the latter type of simulation approaches (now making a different cross-section) there is again a range: from simplified (ie based on a simplified model of reality) to comprehensive models. The differences and similarities between these models in terms of applicability, resource needs, and usage is the subject of the next Section.

Before addressing those issues, it is perhaps interesting to consider Figure 2 (after Clarke 1985), which shows predicted energy consumption as a function of glazing percentage. These are not general graphs (as referred to earlier in this Section) but are results for a typical test case (a multi-storey hotel complex) employing various energy prediction methods. The graphs labeled "ESP-r" result from a comprehensive building energy simulation environment (Aasem et al. 1993). The graphs labeled "calculator" are results from computerized manual methods.

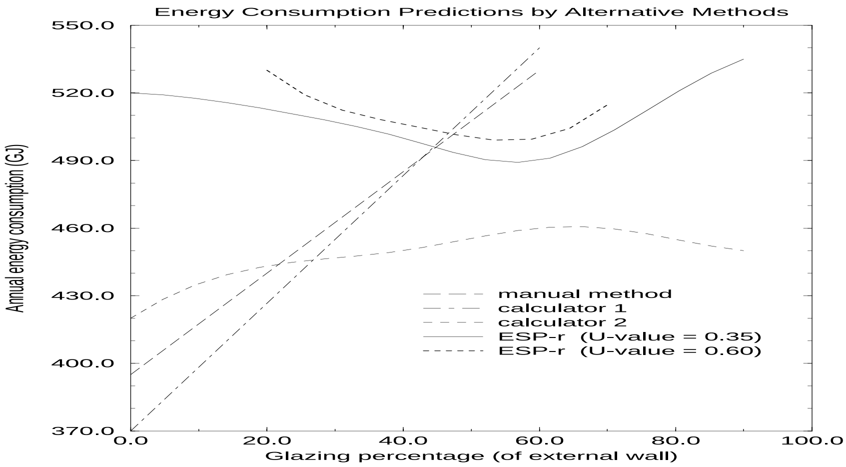

Figure 2 Energy consumption predicted by various methods (after Clarke 1985)

Without going into detail about how and which methods were actually used, the main conclusion which can be drawn from these results is that the absolute values of the predictions seem to be "arguably reasonable close" (ie within a range +/- 20%), however conclusions based on trends as suggested by the manual methods would be wrong; ie they suggest that minimal glazing ratio would be optimal which contradicts with the results of the more comprehensive method.

Now this may perhaps be a slightly exaggerated example, but it does clearly indicate the risk - in terms of design decisions - of using simplified approaches outside or near the edges of their respective scope of applicability (the boundaries of which are difficult to establish for anyone but perhaps the authors of the method in question).
It should also be noted that although usage of (computerized) manual methods is still quite understandable in the context of an architectural competition, this paper sets out to argue that this is not the case for professional architectural and building engineering practice. In the professional context, building energy simulation should be employed to make design decisions.

3. BUILDING ENERGY SIMULATION

Currently the most powerful technique available for the analysis and design of complex systems (like buildings) is computer modelling and simulation. Modelling is the art of developing a model which faithfully represents a complex system. Simulation is the process of using the model to analyze and predict the behaviour of the real system. In that sense simulation can be used to emulate future reality.

Modelling and simulation have become indispensable engineering techniques in the fields of design (eg of building and plant configurations, and of components thereof) and operation (system control, understanding, and interaction).
Especially after the emergence of building performance standards - as opposed to prescriptive building standards - simulation came into view as a viable tool for building design and environmental engineering.
In the current context, modelling and simulation is thus used for predictions in order to support design decisions on real world problems regarding buildings and the HVAC

systems which service them. The building in question may be an existing structure, a proposed modification of an existing structure, or a new design.

Building energy simulation models range from simplified to fully comprehensive. In this context, simplified means that certain assumptions are applied to the underlying thermal network and/or solution scheme so that some energy or mass flowpaths are approximated or omitted entirely. This implies a "risk" of leaving out important aspects.

Simplified models always need some sort of "adjustment" in order to account for certain aspects. As an example consider the thermal inertia of a masonry wall. Depending on the frequency of the temperature fluctuation next to the wall, a smaller or larger part of the wall’s thermal capacity will actually contribute to damping down these fluctuations. In case of very slow fluctuations the whole of even very heavy walls will be effective; that is why in a cathedral it feels relatively warm in the winter (even without heating), and relatively cool in the summer (even without cooling). Masonry walls with normal thickness just follow the yearly average outside temperature fluctuation, but for faster fluctuations (say 24 hour fluctuations) such walls do show a temperature damping effect. For even higher frequency fluctuations (say within an hour; eg due to solar penetration or occupancy patterns) only part of the wall will heat up and cool down (the so-called "penetration depth").
This means that the "effective thickness" of the wall in terms of thermal inertia, depends on the frequency of temperature fluctuation. Most simplified simulation models use this effective thickness. therefore they need to be "tuned" to a certain frequency. Most commonly this will be the "dominating" 24 hour fluctuations. This means however that all fluctuations at a higher and at a lower frequency will not be represented adequately.
When predicting the yearly energy consumption for heating this is probably not so important (due to the integrating nature of this phenomenon), but in case of predictions in terms of comfort or for cooling this is a very serious shortcoming.

Comprehesive models on the other hand try to take into account the full complexity as sketched in the introduction. Referring to the example above, a comprehensive model will be able to adequately represent (or take into account) all the fluctuation frequencies.

In the following sub-sections the issues of applicability, resource needs, and usage of simplified versus comprehensive building energy simulation models will be discussed further.

3.1. Applicability

One way of describing the difference between simplified and comprehensive models is to state that simplified and traditional (analytical) approaches (as indicated in Section 2) try to generate an exact solution of an approximation of the real problem. Comprehensive methods on the other hand, try to find an approximate solution of an "exact" representation of the problem. Undoubtedly the latter approach has much more potential in the long run. Unlike for simplified models with there implicit limitations, in the case of comprehensive models it is just a question of more resources and computing power to get better (ie more accurate or more realistic) results.

As an illustrative example, consider the usage of inside surface convective heat transfer coefficients. These coefficients play an important role in the case of a "wall" with low thermal resistance (eg a window), and in case of inside air temperatures under free-running conditions (ie no auxiliary heating or cooling). In simplified models these coefficients usually need to be set to a certain fixed value (because the variables on which these coefficients depend are not known). In a comprehensive model it is possible to evaluate these coefficients as a (highly non-linear) function of the inside surface temperatures.

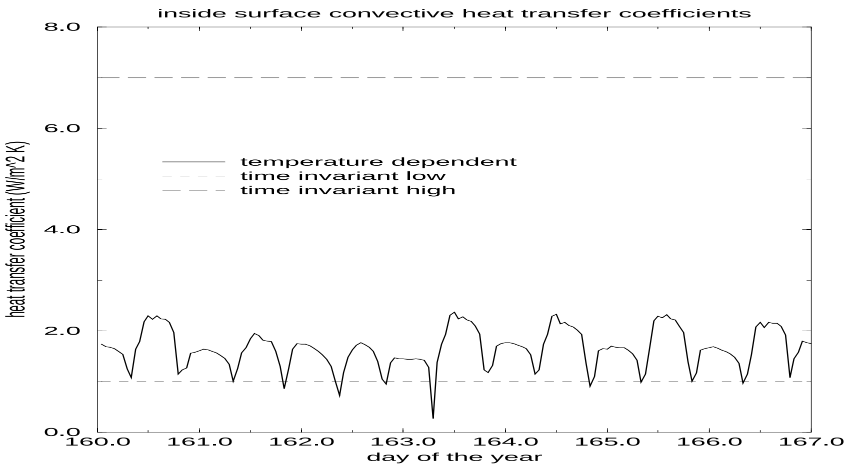

Figure 3 Inside surface convective heat transfer coefficients; fixed and predicted on the basis of surface temperature

Figure 3 shows the time dependency of these coefficients as predicted by a comprehensive model for an outside wall in a typical office during a summer week. Figure 3 also shows a high and a low temperature (and therefore also time) invariant estimate which could be used in a simplified model.

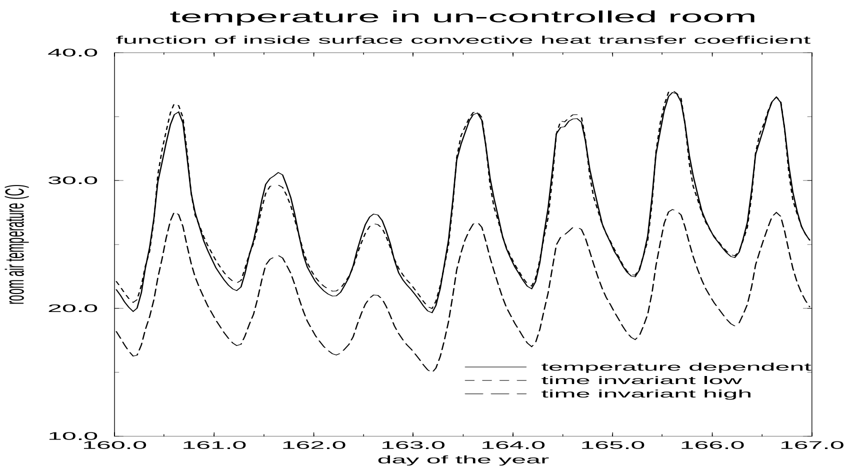

Figure 4 Predicted inside air temperature using temperature dependent respectively independent inside surface convective heat transfer coefficients

Figure 4 shows the predictions by a comprehensive model for the inside air temperature in that office, using the heat transfer coefficients as described above. The differences will be clear.
Two other interesting conclusions follow from Figure 4:
- it is possible to "nudge" the coefficients so as to get a reasonable fit for a specific case; it is however not as simple as just taking the time averaged value (see Figure 3),
- it is quite easy to emulate a simplified model with a comprehensive model, but the other way around is just impossible.

Apart from any other simplifications which might impose more restrictions, the fact that the heat transfer coefficients need to be fixed (ie time invariant) means that simplified models may be suitable for predictions on:
- yearly energy consumption for heating of buildings which are *inside* the scope of the model,

but are certainly **not applicable** for predictions on:
- yearly energy consumption for heating of buildings which are *outside* the scope of the model,
- energy consumption for cooling of buildings,
- summer overheating risk,
- thermal comfort in free-running conditions,

influence of plant in terms of: efficiency (ie fuel) and comfort assesment

3.2. Resource Needs

In computer modelling and simulation of a real world problem there are three distinctive main tasks: (1) information collection and input data preparation, (2) simulation, and (3) results analysis.
Data preparation is the transformation of knowledge about the problem, first into information and then into data suitable for the model. Simulation is the generation of "raw" results data. In the results analysis phase, this "raw" data is first transformed into information, and then into knowledge in terms of the problem.

From a user's perspective, information collection, input data preparation, and results analysis are the "difficult" and most time and resource consuming parts. In general these are the same for a simplified and a comprehensive model. Sometimes a simplified model may require less input data (eg U-value of the wall instead of thermophysical properties of the individual layers), but this is easily offset by the usual "lack" of pre-constructed databases of constructions, occupancy patterns, optical properties, etc. Therefor the input burden is roughly equivalent.
For a user, performing the actual simulation is "merely" a question of "pressing the right buttons". Then there is the question of computing resources, since a comprehensive model has higher demands than a simplified model. This is true, but it is also true that current "small" computers in professional practices are likely to be powerful enough to cater for comprehensive models. This follows from the observation that current demands for a comprehensive energy simulation model must be probably roughly equivalent to the requirements for running CABD (Computer Aided Building Design) applications.

3.3. Usage

Important in terms of usage of all building energy simulation models is that simulation is not an end in itself, but it is rather a means to an end (ie the building design). Also important is to use it, and not abuse it!

When comparing simplified with comprehensive models one should realize that in the latter case it is not always necessary to use the full richness. Most comprehensive models can be operated on input data ranging from "simplified" to "detailed" depending on the application on hand (by supplying defaults for the missing values in the "simplified" mode).

When using simulation (instead of the traditional prescription based methods) there is a need for a different approach. With traditional methods, the user needs to know techniques. With simulation the user needs to understand/ study the basics (ie the fundamentals) and needs to have an appreciation for the complexity (ie the interactions). There is no need (for the user) to learn or concentrate on (simplified) solution methods; the "machine" will take care of that. The user does however need to have an "intuitive" feeling of what’s going on; should almost be able to "see" thermal processes like solar radiation penetration and long-wave radiation exchage inside a room, etc. Because if a designer (architect, building design engineer, environmental engineer, etc) does not have that feeling, most likely he/she will not evaluate the proper design alternatives, will not be able to cope with the complexity of the problem, and - more importantly - will not arrive at the "optimum" problem solution.
This "energy intuition" can be acquired through learning (teaching with emphasis on fundamentals and understanding instead of on techniques) and training (for example by studying best-practice case study exemplars).

As described in a previous paper (Hensen 1993), currently computer simulation is only used indirectly as a design decision support mechanism; ie its power is not delivered very efficiently to the design profession.
There is however an increased interest in research aimed at providing mechanism to overcome this problem by developing "intelligent front ends" which bridge the gap between sophisticated computer simulation tools and the design profession, and by developing frameworks for coupling building energy simulation tools with other CABD applications; for example within the COMBINE (Computer Models for the Building Industry in Europe) research programme of the EU (DG XII).

4. CONCLUSIONS

A building is a very complicated dynamic energy system. In view of the "risk" of missing out important energy aspects when using simplified models, plus the fact that comprehensive models are much more general applicable, it is most strongly recommended to employ comprehensive building energy simulation models in the context of design support.

As is demonstrated, the argument that simplified models are easier to use and are therefore more suitable for design decision support is clearly bogus!
If deemed necessary, there are several techniques available which - when activated - completely hide for a user whether he/she is using some simplified method or a comprehensive energy simulation model. Obviously the results (in terms of design

decision support) of the latter are far superior.

To make proper use of building energy simulation (instead of the traditional prescription based methods), the user have "energy intuition". This can be acquired through learning (emphasizing fundamentals/ understanding instead of techniques) and training (eg studying best-practice exemplars). It is only in this way possible to cope with the complexity of the problem, and to arrive at the "optimum" problem solution.

So: design decision support (systems) should employ comprehensive building energy simulation models, the designer should be able to "see" energy flows in a design alternative, and the machine should do the work !

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