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Engineering Tools for Complex Task of Reducing Energy Consumption

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ABSTRACT

Reduction of energy consumption in buildings while ensuring a good indoor environment is a very challenging and difficult engineering task. For this we need tools which are based on an integral approach of the building, control systems, occupants and outdoor environment.

A building energy simulation environment is outlined. By means of case studies, application in practice is demonstrated. Finally some future development areas are indicated.

1. INTRODUCTION

In the former Eastern European countries typically more than 60% of the air pollution is due to the energy sector together with ventilating, heating and cooling of buildings. On national levels, buildings account typically for more than 40% of the overall energy consumption. These two figures clearly indicate the necessity for energy conservation measures. The following will make clear that this is a very challenging and difficult engineering task which needs appropriate tools.

Apart from the general need for energy efficiency and protection of the environment, building designers and environmental engineers encounter a vast range of other problems in everyday practice; for example: in **offices** with phenomena like "Sick Building Syndrome" and always new developments like recently: atria, climate facades; in **houses** where occupants expect higher comfort levels; in **industry** with indoor air quality issues; in **conversions** when an existing building gets a completely new destination like for instance an obsolete industrial building which is converted into apartments; etc.

So which is the system we are actually trying to address? The whole of building form and fabric, control systems, environmental issues and methodical design comprises a very wide area. Many of the above indicated problems are in fact caused by the complexity due to interactions between the various sub-fields. These interactions are indicated in Figure 1. Obviously this diagram is merely a gross simplification of reality, because in the real world this is a n-dimensional problem involving the 3-dimensionality of building and plant, the dimension of time, and the dimension of the various aspects like: thermal environment, air quality, lighting, acoustics, etc.

As illustrated for the thermal aspects only, the 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, occupants (casual heat gains), and the auxiliary system which may perform heating, ventilating and / or air-conditioning (HVAC) duties. These sources act upon the indoor environment via various heat and

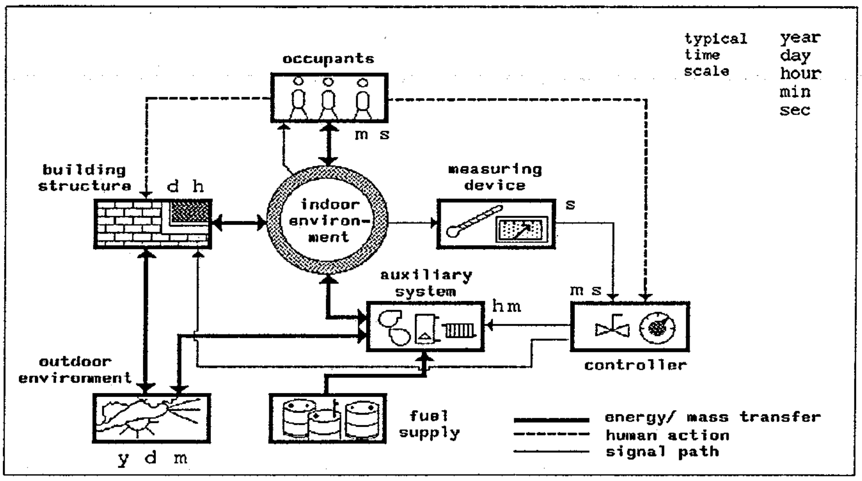

Figure 1 The building as an integrated, dynamic system

mass transfer processes such as conduction, solar transmission, long wave radiation exchange, convection, air flows, and flow of fluids within the plant system. Within the overall configuration as sketched, several energy sub-systems may be identified, each with their own dynamic thermal characteristics: occupants (very complicated dynamic systems themselves), building structure, and auxiliary systems. The cycle periods of the excitations 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.

The above mentioned type of problems and the need for an integral approach of the complete "system" comprising building structure, environmental control systems, and occupants, have become more important during the last decades due to a number of inter-related economical, technical, political and social developments:
- need to preserve our environment by energy conservation and reduction of pollutant emissions;
- internationalization and industrialization of the building sector;
- emergence of performance (as opposed to prescriptive) standards;
- increasing complexity of buildings and the building industry;
- increasing awareness of quality (total quality management);
- liability "chaining" in the building process.

Having identified the need for an integral approach and the type of system, we are now able to state our objective: evaluation of building performance while treating the building (including its distributed flow paths), environmental control system(s), and occupants as an integrated, dynamic system.

2. BUILDING ENERGY SIMULATION

There may be several alternative ways to achieve the objective identified above. However, one of the most powerful tools currently available for the analysis and design of complex systems, 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.

Currently there is a wide range of energy design decision support tools available. At one end of this range are the computerized manual methods (ofter "correlation based"), which are, by nature, very limited in scope and applicability. On the other end of the range 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 the Introduction. Within the latter type of simulation approaches (now making a different cross-section) there is again a range: from simplified (meaning 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; implying a "risk" of leaving out important aspects) to comprehensive models. The differences and similarities between these models in terms of applicability, resource needs, and usage is the subject of another paper (Hensen 1994).
As opposed to simplified approaches, comprehensive models try to take into account the full complexity as sketched in the Introduction.

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 evaluation, and environmental engineering.
In the current context, modelling and simulation is thus used for predictions of future reality 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.

Outline of the Approach

Early research in this area focussed on the relation between building design and energy consumption with the auxiliary system usually regarded as parameter instead of as a variable. Only later more attention was directed to the plant side of the overall problem domain. In the former approach the influence of the HVAC system is more or less neglected by over-simplification of the plant. In the latter approach the complex building energy flow paths were usually grossly simplified. Here we started from the principle that neither approach is preferable for the majority of problems indicated above: both building and plant have to be approached on equal levels of complexity and detailedness. What follows is merely an outline of the approach; more rigorous descriptions may be found elsewhere (Clarke 1985, Hensen 1991).

The advanced building and plant energy simulation environment ESP-r (Aasem et al. 1993) is a collaborative research effort - since approximately 1975 - involving up to now an estimated 150 person-years. It is the European Reference Model for building energy simulation. The system has been - and still is - subjected to rigorous validation programmes (eg CEC 1989). Originating from the University of Strathclyde in Glasgow, the system is currently used for education and research at universities and research centres in over 18 countries world-wide.

The modelling in ESP-r is based on a numerical approach using finite volume, state-space conservation equations, in which all heat fluxes are handled simultaneously. All building and plant energy flows and their interconnections are fully taken into account. It is clearly a research orientated environment with the objective to simulate the real world as rigorously as possible to a level which is dictated by international research efforts/ results on the topic in question. The system is very graphically oriented, offers climate, construction, profiles database management, and incorporates shading, solar beam tracking, view factors, window power spectrum response, comfort assessment, condensation analysis, air flow modelling, etc. There is a large volume of background and documentation material available (eg Clarke 1985, Hensen 1991, Hensen 1993, Aasem et al. 1993).

3. APPLICATION

Application of this integral simulation environment can best be demonstrated by means of some case studies. In this case these represent typical usage of the system, and incorporate problems ranging from a comfort and energy problem, via a indoor air flow problem, to a typical case of building and plant interaction.

House in Prague

This is a study on possible strategies for comfort improvement and energy conservation in an existing house (build in 1933) in Prague (Dunovska 1993).

Figure 2 The house when viewed from the east

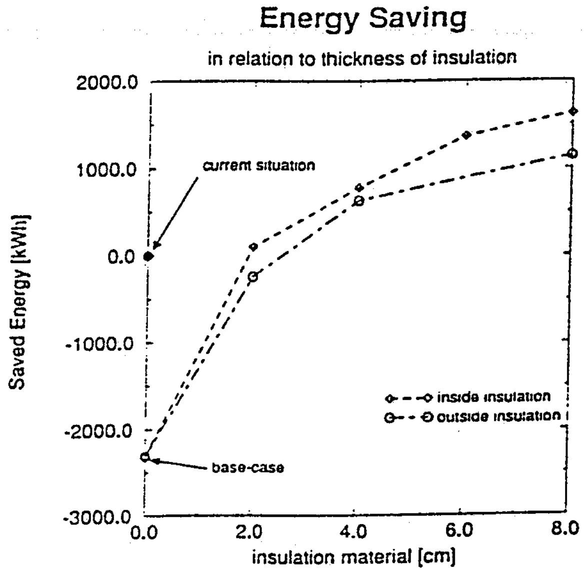

Figure 3 Yearly energy saving relative to the current situation as a function of insulation thickness and placement

Parts of the living area of the house have very poor thermal comfort conditions during the cold periods. The main problem in this study was defined as: how to improve thermal comfort while at the same time decrease the energy consumption for heating.

A base-case situation was defined which would achieve acceptable thermal comfort but would also increase the energy consumption. Next, a number of possible measures to decrease energy consumption were investigated. Simulations were carried out to predict the resulting yearly energy consumption for each option. Figure 3 shows the predicted energy savings when insulation would be applied.

Table 1 Yearly energy consumption and savings for all proposed improvements

Proposed Improvement description	Energy Consumption kWh	Energy Saving %	Energy Saving kWh
current situation	6630	-	-
base-case situation	8940	0	0
2 *cm* of outside insulation	6871	23	2070
2 *cm* of inside insulation	6531	27	2410
draught-proofing	8600	4	340
ventilation heat recovery	7568	15	1372
attached sun-space	7661	13	1280

Table 1 summarizes yearly consumption and savings for all proposed improvements. Since many approximations had to be made in the preparation and definition of the data, and the economical aspects of the proposed improvements were not yet taken into account, it is really to early to make firm conclusions from the results. Having said this, it is felt that good options to improve the environmental quality of the house would be to combine some of the proposed improvements.

Air Flow through Shopping Arcade

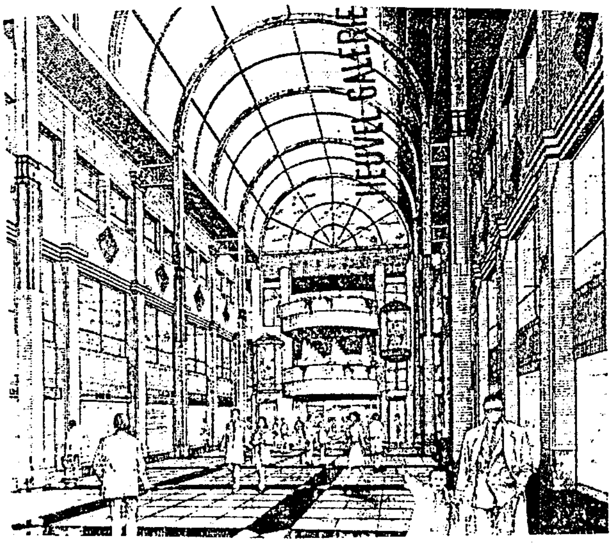

Figure 4 View of the shopping arcade

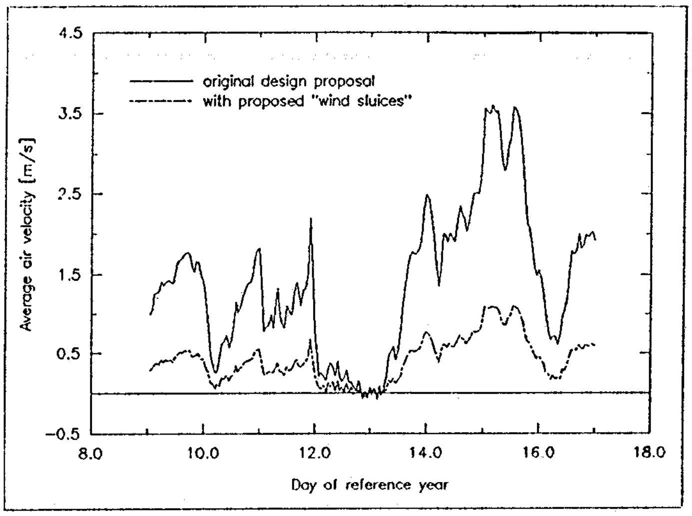

Figure 5 Predicted effect of "wind locks" to decrease air velocities in the pedestrian entrance area

This case study involved predicting the air flows through proposed shopping arcades (see Figure 4), which are part of an extensive shopping mall. This four-level complex incorporates a 220 m long shopping arcade, interspersed with atria and dome-shaped roofs, about 20,000 m^2 of shops, an 8,600 m^2 concert hall, 3,000 m^2 of restaurants, car parks, offices, and apartments. It should be apparent that such a building is a highly complicated system. For instance, the manner in which the air will flow depends on the external (wind) pressures on entrances and domes, on temperature differences inside and relative to outside, and impulses by the ventilation system. ESP-r was used to make various predictions with respect to the indoor environment (Pemot & Hensen 1990). As an example consider Figure 5 which shows the air velocities which may be expected in the pedestrian entrance area. For commercial reasons the architects and the developers want the entrance area to be as open as possible. From the first results it was clear however that the original design proposal (incorporating air curtains) would still lead to unacceptable high air velocities. To avoid this, it was suggested to apply double sets of sliding doors ("air locks"). The predicted results for this (satisfactory) solution can also be seen in Figure 5.

Displacement Ventilation in Offices

This case study concerns the applicability of displacement ventilation for offices (Hensen & Hamelinck 1994). Of particular interest were the design constraints and energy consequences relative to a mixing ventilation system. The modelling of both systems is schematically indicated in Figure 6. For modelling the displacement systems, a number of changes had to be made to ESP-r. Validation with experimental results showed good agreement. Using models of the two types of ventilation system a number of simulations were carried out for a "standard" office module (3.6 x 5.4 x 2.7 m^3, one outside wall, 40% double glazing) and assuming some climatic reference year.

The most important design constraint for application of displacement ventilation turns out to be the casual gains due to people, lighting and office appliances. For application in rooms with heights up to 3 Combined with a cooled ceiling, casual gains up to 80 W/m^2 can be handled.

With respect to energy consumption for cooling, the result from the simulations was that application of displacement ventilation is only advisable in case of relative low casual heat gains (30 W/m^2). When the casual gains are higher, displacement ventilation has no (energy) advantages over a mixing system. When

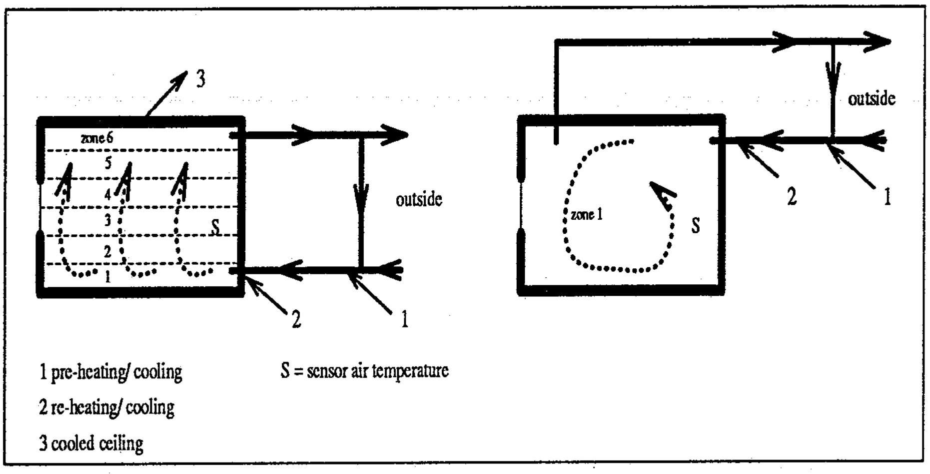

Figure 6 Schematic of displacement and mixing ventilation respectively

the displacement system is combined with a cooled ceiling (casual gains above 35 W/m^2), the overall energy consumption is even higher than for a mixing system.
Based on the possible savings of a displacement system, one could imagine a "reversed" displacement system for heating purposes. However, given the approximations and constraints of the current simulation models, no conclusion could be made in this respect.

4. CONCLUSIONS

A building is a very complicated dynamic energy system which impacts both the indoor and outdoor environment. In view of the "risk" of missing out important energy or other environmental 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 and evaluation. The argument that simplified models are easier to use is not necesarily valid.

To make proper use of building energy simulation (instead of the traditional prescription based methods), the user must 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 reality, and to arrive at the "optimum" problem solution.

Building energy simulation using advanced and state-of-the-art models, is quickly becoming accessible to the engineering community. It is now ready to be applied on a wide scale in education, research, and in practice. Building energy simulation is probably especially applicable in the context of a country which changes its environmental policy, and plans to upgrade its building stock to current expectations in terms of comfort, fuel consumption, and environmental impact.

Acknowledgements

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